Chapter 7. How could hybrid true potato seed foster development in potato sectors in East Africa?

H. den Braber[1*], M.E. de Vries[2], O.C. Kacheyo[2,3], P.C. Struik[3] and K. Descheemaeker[1]

[1]Plant Production Systems, Wageningen University, Bornsesteeg 48, 6708 PE Wageningen, the Netherlands; [2]Solynta, Dreijenlaan 2, 6703 HA Wageningen, the Netherlands; [3]Centre for Crop Systems Analysis, Wageningen University, Bornsesteeg 48, 6708 PE Wageningen, the Netherlands; harmen.denbraber@wur.nl

Abstract

Hybrid true potato seed (HTPS) holds the promise to foster development in potato sectors in East-Africa. Compared to a conventional production system based on clonal propagation of tetraploid varieties, clear advantages of HTPS are easier transport and storage of starting material, high multiplication rates, increased availability of disease-free planting material and faster and more targeted breeding. Despite these advantages, an informed assessment of how HTPS can be implemented into East African seed and farming systems, and of what the enabling conditions are for such implementation is still necessary. Our aim is to understand if and how HTPS could foster development of potato sectors in East Africa and what are the major opportunities and bottlenecks. We describe the context of potato production in East Africa, and we summarise the key lessons from past experiences with the implementation of (non-hybrid) true potato seed. This informs our analysis of the requirements for an effective and inclusive introduction. Major requirements are a solid understanding of: (1) the criteria farmers use to assess the innovation; (2) local farm realties; and (3) the seed system in which farmers operate. The implementation of HTPS requires adaptations in agronomic management and in seed system configurations, but these adaptations need to fit into the agro-ecological and socio-economic context. This can be achieved through an iterative research cycle linking farmers, researchers, breeders and other stakeholders. To facilitate institutional embedding of the innovation, interactive, multi-stakeholder processes are required to develop shared views on the acceptability, sustainability and societal desirability of HTPS. We conclude by drawing a research agenda with urgent questions that need empirical research prior to and during the introduction of HTPS in East Africa.

Keywords: seed system, SWOT analysis, participatory research, technology characteristics, research agenda

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Impact of hybrid potato
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7.1 Introduction

The potential of hybrid true potato seed (HTPS) to foster development of potato sectors throughout Africa has been recognised by companies, researchers, NGOs and governments. East Africa is commonly mentioned as the first region were HTPS may have an impact (De Vries *et al.*, 2016; NFP, 2021; Stemerding *et al.*, 2020). In this region, potato is a vital source of food and cash for smallholder farmers (Gildemacher *et al.*, 2009b; Devaux *et al.*, 2014). The area under potato cultivation quadrupled in the last few decades and consumer demand increased steadily, but yields stagnated at levels around 8-10 tons/ha, far below potential yields (Gildemacher, 2012).

7.1.1 The promises of hybrid true potato seed

HTPS has the potential to foster development of the potato sector in East Africa, for four major reasons. First, hybrid breeding strongly accelerates the introduction of favourable traits (Jansky *et al.*, 2016; Lindhout *et al.*, 2011). This enables faster development of new varieties attuned to regional needs, for instance in terms of disease resistance (Lindhout *et al.*, 2018).

Second, HTPS has the potential to circumvent seed degeneration through providing clean starting material, since HTPS does not transmit any economically important pathogens (Lindhout *et al.*, 2011). Seed degeneration is caused by the build-up of pests and pathogens in the starting material due to successive cycles of vegetative propagation, and results in reduced potato yield or quality (Thomas-Sharma *et al.*, 2016). Currently, the majority of potato farmers in East Africa rely on farm-saved seed tubers as starting material, hence transmitting seed-borne pests and diseases from one crop cycle to the next (Gildemacher *et al.*, 2009a).

Third, compared to bulky, perishable seed tubers, HTPS can be stored and transported more easily, and in far greater numbers because propagation by means of true (i.e. botanical) seeds from the berries of the potatoes becomes possible. Especially in places with poor infrastructure, in landlocked areas or in remote rural places, HTPS could eliminate logistical challenges of the transport and storage of potato starting material.

Fourth, propagation by means of true seeds results in much higher multiplication rates compared to seed tubers. Conventional clonal propagation by means of seed tubers results in multiplication rates of ten, but with vegetative propagation, multiplication rates of a thousand and higher are possible. Using HTPS, sufficient planting material for a new variety can be obtained within one or two seasons, while it can take up to up to eight seasons in the conventional propagation system. This decreases the potential for disease build-up during multiplication rounds and reduces the costs, time and area requirements of multiplication (Van Dijk *et al.*, 2021a).

These four advantages of HTPS could result in considerable improvements in terms of access to high quality, disease free starting material for farmers.

7.1.2 Aim

Despite these promises, there is an informed assessment needed on how HTPS can be implemented into East African seed and farming systems, and what the enabling conditions are for such implementation. While HTPS is a possibly disruptive technology (Beumer and Edelenbosch, 2019; Stemerding *et al.*, 2020), it is unknown how it performs under farmers' field conditions in East Africa, how it fits in the agro-ecological, economic and institutional context and what the impacts could be in various sustainability domains. In this chapter, our general aim is to understand if and how HTPS could foster development of the potato sector in East Africa and what are the major opportunities and bottlenecks.

7.1.3 Outline

The specific steps to reach the abovementioned aim are discussed in separate sections:
- describe the context of potato production in East Africa;
- summarise the key lessons from past experiences with TPS;
- understand the requirements for an effective and inclusive introduction;
- analyse strengths, weaknesses, opportunities and threats of HTPS;
- develop a research agenda.

7.2 Potato production in East Africa

This section characterises the context of potato production in East Africa in terms of current seed systems, cropping systems and common diseases, with special attention to relevant issues for the introduction of HTPS.

7.2.1 Seed systems

Potato seed systems in East Africa are mostly informal, which implies that selection, production and diffusion of seed tubers occurs mostly through informal networks (Gildemacher *et al.*, 2009a). Diffusion of new potato varieties in informal seed systems happens via friends, relatives and neighbours and through purchasing at local markets. By contrast, formal seed systems are characterised by the involvement of public or private actors who have controlled procedures for seed production, multiplication and release (Louwaars and De Boef, 2012). In East Africa, only a small proportion of the seed tubers used comes from the formal sector, as seed tubers are often not available or simply too expensive for smallholder farmers. In some countries in the region, commercial certified seed schemes are in development, e.g. in Kenya (Kwambai *et al.*, 2022), where small and large seed growers produce and sell certified seed to ware growers who are commercially oriented. This is especially possible in countries with a market for high quality table or processing potatoes. But it also requires a cost-effective production system of early generation seed.

A recent study on informal seed potato systems in Ethiopia found that farmers who received a new potato variety dispersed seed potatoes to more than six other farmers on average. The informal networks in which the seed potatoes were shared were differentiated by gender, wealth and religion: new variety seed potatoes tended to flow from rich to poor farmers, men were more likely to disperse to other men, and dispersion happened more often between people of the same religion (Tadesse *et al.*, 2017a). A main advantage of the informal seed system for potato farmers is that planting material can often be obtained without spending cash. In addition, the above example shows that diffusion of new varieties via informal networks can be an effective strategy, if new varieties are distributed strategically to a diverse group of source farmers. A major disadvantage of the informal seed system is that the planting material circulating in it is almost never free of pest and pathogens. Since potato crop growth, development and yields are highly determined by the quality and health status of the seed tuber, seed degeneration is a major problem (Haverkort and Struik, 2015). For instance, in Kenya and Uganda, respectively 59% and 75% of the potato growers rely entirely on farm-saved seed tubers as starting material, hence transmitting seed-borne diseases from one crop cycle to the next. Buying seed tubers is often not economically viable and the supply of good quality seed tubers is highly insufficient. In addition, 97% of seed tubers sold on Kenyan local markets were found to contain at least one important potato virus (Gildemacher *et al.*, 2009a). Hence, the lack of clean planting material and high disease pressure are two major, interlinked causes of poor yields in East Africa (Gildemacher *et al.*, 2009b; Schulte-Gelderman, 2013). A survey among potato scientists in developing countries reported that: 'the need for improved seed production methods was expressed as an important or very important need by all of our survey respondents' (Fuglie, 2007, p. 359). In this regard, the advantages of HTPS in terms of disease-free seeds, easy transport and storage and high multiplication rates are clear, but what type of seed system configuration is needed to accommodate HTPS remains a major knowledge gap.

7.2.2 Cropping systems

Potato cropping systems in East Africa are dominated by smallholder farmers, who grow potatoes as a major food and cash crop. Due to a bimodal rainfall distribution, potatoes can be grown twice per year throughout most of the East African highlands. In general, land pressure in potato growing areas in East Africa is high and farm sizes are usually between 1 and 2 hectares (Gildemacher *et al.*, 2009b). As a result, rotations are often very short. In Kenya and Uganda, the majority of farmers allocate more than 25% of their farm area to potato (Gildemacher *et al.*, 2009b; Muthoni *et al.*, 2013). In Rwanda, and in some Kenyan districts farmers dedicate on average almost half of their farm area to potato (Muhinyuza *et al.*, 2012; Muthoni *et al.*, 2013). Short crop rotations, in combination with the use of contaminated seed tubers, result in high disease pressure and low yields. In turn, the poor yields result in relatively low profitability of potato farming, and farmers using risk-averse strategies (Figure 7.1) (Gildemacher *et al.*, 2009b; Janssens *et al.*, 2013). In general, potato is grown as a monocrop. Other main crops grown by potato farmers are maize and beans in Kenya, Uganda and Rwanda, whereas grain crops such as barley, wheat and teff are important in Ethiopia (Gildemacher *et al.*, 2009b). Cabbage is widely grown in Kenyan potato areas: depending on the district, 30-60% of potato growers grow cabbage (Muthoni *et al.*, 2013). In Rwanda, vegetables were ranked as fourth important cash crop by potato farmers (Muhinyuza *et al.*, 2012). In East Africa, the production of cabbage and vegetables such as tomato and onion often relies on seedling raising in nurseries, followed by transplanting into the field (De Putter *et al.*, 2007; Gogo *et al.,* 2012; KALRO, 2016). The importance of cabbage and other vegetables in potato growing areas suggests that many potato farmers are used to produce seedlings from seeds, and that transplanting is a commonly known practice. This could provide an entry point for the introduction of HTPS, since the use of HTPS may also require farmers to raise seedlings and transplant these seedlings to the field. However, what shapes farmers preferences for a certain starting material – which could be seeds, seedlings or seed tubers – remains an open question.

7.2.3 Common diseases

Late blight and bacterial wilt are commonly mentioned as the most important potato diseases in the region (Schulte-Gelderman, 2013). Bacterial wilt, caused by *Ralstonia solanacearum*, is a soil- and seed-borne disease, which can cause yield losses of up to 30-75% (Lemaga *et al.*, 2005). A nation-wide survey in Uganda reported an overall bacterial wilt prevalence of 80%, while disease incidence was on average around 2% (Abdurahman *et al.*, 2019). Similar prevalence, but slightly lower incidence were reported for the major potato growing areas in Kenya (Gildemacher *et al.*, 2009a). The disease has a wide host range, can survive in the soil for several seasons and spreads via latently infected planting material (Abdurahman *et al.*, 2019). Hence, short rotations and lack of clean planting material are major causes of the high bacterial wilt incidence. Late blight, caused by the oomycete *Phytophthora infestans*, causes major yield losses throughout Sub-Saharan Africa. Similar to bacterial wilt, the disease can be soil borne and can also spread via latently infected planting material. A main difference between the two diseases is that late blight is also air-borne, enabling the disease to disperse over long distances and to infect whenever the conditions are conducive (Nowicki *et al.*, 2012). Contrary to wilt, chemical control of late blight is common in the region, and late blight is the main reason for the use of fungicides on potato in Kenya, Uganda and Ethiopia, which has important ecological and economic consequences (Gildemacher *et al.*, 2009b). A case-study in Ethiopia showed that seed and ware potato farmers had limited knowledge about causal agents, spreading mechanisms and effective disease management options of bacterial wilt

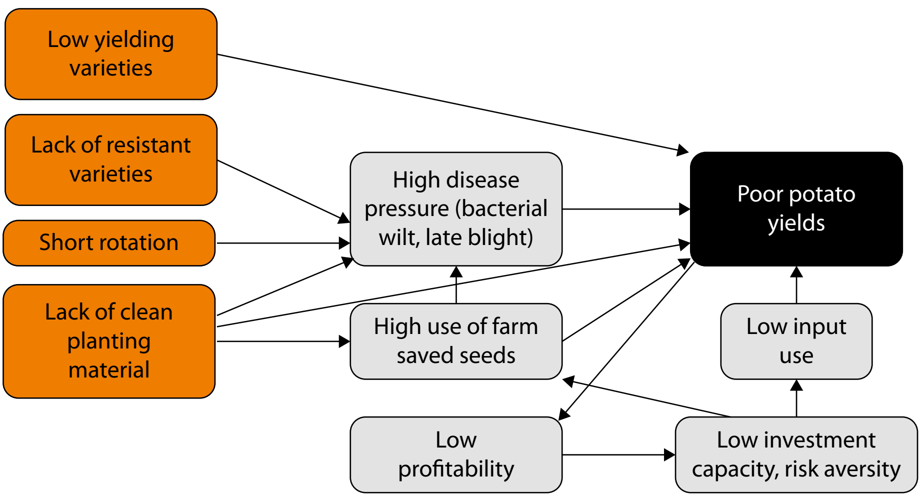

Figure 7.1. Diagram showing some of the main causes of low potato yields in East Africa.

and late blight. Effective disease control requires integrated management options and collective action at community-level (Damtew *et al.*, 2020; Tafesse *et al.*, 2018). The increased availability and use of clean planting material is an important aspect of such an integrated approach, alongside various other phytosanitary and cultural practices, such as rogueing diseased plants, implementing crop rotations and decontamination of farm tools (Tafesse *et al.*, 2018, 2020). As HTPS could increase the availability of clean planting material, it could provide an essential building-block of such integrated approaches to alleviate disease pressure. With regards to breeding for late blight resistance, hybrid potato breeding provides an unprecedented opportunity. Recently, hybrid potato breeding has been applied to stack multiple late blight resistance genes into an existing variety in just 3 years (Su *et al.* 2019).

7.3 Key lessons from experiences with true potato seed

Past experiences with true potato seeds (TPS) provide valuable insights to understand if and how HTPS could foster development in potato sectors. The International Potato Center (known under its Spanish acronym CIP) conducted extensive research on TPS technologies from 1977 to 2000. The advantages of TPS in terms of logistics and pathogen-free starting material made TPS a promising pro-poor technology (Almekinders *et al.*, 2010). In contrast to HTPS, the varieties used in CIP's TPS programme were not diploid, inbred hybrids, but non-inbred tetraploid varieties which produced a relatively heterogenous crop. However, in terms of the implementation in potato production systems, TPS and HTPS are not hugely different. Similar to TPS, HTPS requires new agronomic practices, it requires new seed system configurations, it may change the role of existing stakeholders and it may draw in new stakeholders.

7.3.1 Experiences with true potato seed: where and how

As a result of CIP's research, TPS was adopted by farmers in a wide variety of regions and agro-ecologies, such as China, Vietnam, Nicaragua and Egypt (Almekinders *et al.*, 1996). Converting potato from a vegetatively propagated crop to a sexually propagated crop added new options for propagation and for obtaining planting material (Table 7.1). For instance, ware potato farmers in Sri Lanka sowed TPS in seedbeds and propagated their own planting material. In most cases, seedling tuber production from TPS was done by specialised actors. In Bangladesh, cooperatives and large-scale farmers specialised in the production of seedling tubers from TPS, whereas in China, government seed farmers and specialised nurseries were involved in the propagation from TPS. In Egypt and India, TPS provided cheaper or better planting material than the national seed tuber systems (Almekinders *et al.*, 1996). In Vietnam, on-farm research on the agronomic practices for TPS was conducted in close collaboration between farmers, extension agents and researchers. In this case, farmers grew and transplanted TPS seedlings using methods very similar to rice cultivation (Hoang *et al.*, 1988). In the Vietnamese cropping system, potatoes are grown in a relative short winter period between two rice crops. At first, TPS varieties were too late-maturing to fit in this short growing season, but later varieties fitted better. In addition, yields from TPS seedling tubers were higher than yields from locally available seed tubers. This led to a relatively high use of TPS in Vietnam: in the late nineties, TPS-derived seedling tubers were used on 10% of the total potato area. After a flooding disaster in Peru, the fast multiplication opportunities

TPS offered were used to rapidly restore potato production. In Nicaragua, TPS thrived for a while, mainly because the TPS varieties had a higher resistance to late blight than other locally available varieties, even though the TPS variety was not uniform in terms of tuber colour (Almekinders *et al.*, 2010). However, in this particular case, the lack of institutional embedding prevented the widespread use and scaling of TPS (Swart and Stemerding, 2019). In 2009, TPS, or TPS-derived planting material, was used by farmers in China, India, Nepal, Bangladesh, Vietnam, Peru, Nicaragua and Venezuela (Almekinders *et al.*, 2010).

7.3.2 Key lessons

Contrary to the high rising expectations, TPS did not revolutionise potato production in smallholder farming systems. However, it remained a technology that was used in a wide variety of 'niches'. On-farm research in Indonesia, India, Egypt and Peru showed that although TPS-derived starting material was cheaper compared to the use of seed tubers, the crop value produced was also lower, due to lower yields and a larger proportion of small tubers (Almekinders *et al.*, 2010). Furthermore, farmers using TPS-derived planting material were facing problems with late maturity, lack of uniformity of the produce and unreliable germination (Almekinders *et al.*, 1996). Manrique (1994) concluded that for TPS to be successfully used by farmers, the main prerequisites were the availability of high yielding, uniform, stress tolerant varieties, adequate water supply and growing medium, good plant protection options and experience with vegetable production, as most vegetables need transplanting as well. Despite the abovementioned challenges, farmers successfully used TPS in a wide variety of agro-ecological and socio-economic conditions. The common characteristic of those 'niches' where TPS was adopted by farmers were a limited seed

Table 7.1. Examples of countries where farmers experimented with true potato seed, and different modes of utilisation.

Country	Mode of utilisation	Source
China	Government seed farms and nursery farmers used TPS to grow seedlings. Seedlings were transplanted in field at high density to produce seedling tubers, which were sold to ware farmers.	Bofu *et al.*, 1987
Vietnam	CIP provided farmers with TPS. Farmers sowed TPS in raised beds. Seedlings were transplanted in the field bare-rooted (e.g. rice) to produce seedling tubers. Seedling tubers used by farmers to grow a ware crop.	Hoang *et al.*, 1988; Malagamba and Monares, 1988
Bangladesh	TPS was used by cooperatives and large-scale farmers to produce seedling tubers for commercialisation.	Almekinders *et al.*, 2010
Peru	CIP provided ware potato farmers with mini-tubers derived from TPS. Vegetable farmers were provided with seedlings derived from TPS.	
Nicaragua	TPS were distributed to specialised farmers, who had the expertise and conditions to grow seedling tubers.	
Sri Lanka and Rwanda	TPS were provided to farmers. Farmers produced seedling tubers from TPS, either through transplanting, or by direct sowing in nursery beds.	Almekinders *et al.*, 1996; Malagamba and Monares, 1988

tuber supply from formal seed systems and high disease pressure (Almekinders *et al.*, 1996). The Vietnamese case showed that familiarity with seedling nursing and transplanting, a good fit in the cropping system, high yields and participatory research on new agronomic practices were important factors contributing to the relative success of TPS in the country.

How do these experiences with TPS around the world relate to HTPS in the context of East Africa? First, the key characteristics of the 'niches' where TPS was adopted are clearly present in East Africa: as explained in Section 7.2, the current seed systems in East Africa fail to provide a steady supply of affordable, clean planting material and disease pressure is high. Second, in terms of the breeding opportunities, HTPS is better placed to remove some of the main disadvantages of TPS, such as low yields, issues with uniformity and unreliable germination. In this regard, progress has been remarkably fast. The proof of principle of hybrid potato breeding was reported in 2011 by Lindhout *et al.*, 2011. Already in 2016, experimental hybrids based on the inbred lines developed by Lindhout *et al.* yielded up to 29 tons/ha in field trials in the Democratic Republic Congo (De Vries *et al.*, 2016). The high yield potential was further confirmed in field trials with a seedling-based crop in 2018, under well-managed conditions in the Netherlands. The best performing experimental hybrids yielded over 100 ton/ha in a flat-bed system in sandy soils, and 45 tons/ha in a ridge-system on clayey soils (Van Dijk *et al.*, 2022). Third, in terms of agronomy and seed systems, the experiences with TPS in developing countries show that potato production systems based on sexually propagated potatoes are feasible in a wide variety of agro-ecologies and under diverse socio-economic circumstances. In addition, various seed system configurations have worked in different places.

7.4 Requirements for an effective and inclusive introduction

This section first addresses crucial technology characteristics that HTPS should fulfil. Some important factors and stakeholders for an enabling environment for the introduction of HTPS are described. Clearly, seed systems providing reliable access to high quality hybrid potato planting material are another requirement for the introduction of HTPS. Participatory testing of new hybrid varieties and agronomic practices is crucial to investigate how the innovation can best be adapted to fit into the agro-ecological and socio-economic context. The need for sustainable business models, both for breeding companies and for farmers is discussed. Finally, we argue that a framework for Responsible Innovation, building on the dimensions of reflexivity, inclusion, responsiveness and anticipation, could provide guidance for the introduction of HTPS.

7.4.1 Hybrid true potato seed: technology characteristics

Many 'innovations' aiming to deliver benefits to smallholder farmers have limited success, and interventions aiming to improve farmers' access to improved varieties of vegetatively propagated crops are no exception (Almekinders *et al.*, 2019). Case-studies show that a main reason for the meagre successes of interventions is that farmers' demand for improved seeds was often based on simplistic assumptions, leading to an overestimation of demand. In addition, limited efforts were made to understand the seed and farming systems in which farmers operate, and hence the motivations for farmers to use or not use improved seeds were often not well understood

(Almekinders *et al.*, 2019). Currently, the majority of farmers in East Africa are not used to paying for their potato starting material (Gildemacher *et al.*, 2009a) and the adoption of any new variety or technology involves risks, investments and experimentation (Verkaart *et al.*, 2019). In this regard, Sumberg (2005) highlights four technology characteristics of a successful innovation in the context of agriculture in Sub-Saharan Africa. Firstly, hybrid potato varieties should address an important demand or constraint, or they should deliver a clear benefit to potential users. Clearly, these benefits could be improved yields, disease resistance or financial gains (Verkaart *et al.*, 2019). However, case-studies show that motivations to use or not use new varieties are more diverse and can also include low risks, taste and colour preferences or maintaining diversity as a risk spreading strategy (Almekinders *et al.*, 2019). Second, the degree to which a variety can tolerate less than optimal management and/or growing conditions while still yielding positive results, should be acceptable. For instance, Ethiopian potato farmers perceived that improved varieties required more management, and this was a main reason for choosing local varieties. In addition, farmers regarded crop management intensity as a more important variety characteristic than yield and disease resistance (Abebe *et al.*, 2013). Thirdly, the innovation should be socially and culturally acceptable. As an example, Peruvian smallholder potato farmers preferred native potato varieties over varieties provided by the formal seed system, because the improved variety seed lots were grown at low altitudes, using synthetic fertiliser and chemical pest and disease control. These management practices were not in line with farmer's personal values and with the culturally determined 'quality cues' that farmers were looking for when selecting seed lots and varieties (Urrea-Hernandez *et al.*, 2016). Fourth, the innovation should be compatible with other farm and non-farm activities that are common among potential users. The importance of crop management intensity as a variety selection criterion, as shown by Abebe *et al.* (2013), points in this direction. The abovementioned technology characteristics show that simplistic assumptions about farmer demand for improved potato seed should be avoided, and that a solid understanding is required of local farm realities and the seed systems in which farmers operate (Almekinders *et al.*, 2019).

7.4.2 An enabling environment

Enabling environments are shaped by knowledge and evidence, politics and governance and by capacity and resources (Gillespie *et al.*, 2013). In terms of knowledge and evidence main actors are (local) knowledge institutes, extension services and NGOs (Figure 7.2). For instance, access to knowledge and participation in demonstration and training activities was an important factor explaining the adoption of improved practices and varieties among potato farmers in Ethiopia (Tadesse *et al.*, 2017b). It is therefore important that farmers, extension services and local knowledge institutes are equal partners in the generation of the knowledge and evidence (see below). With regards to capacity and resources, access to credit and the availability of land and labour were other important factors explaining adoption of improved potato varieties (Abebe *et al.*, 2013; Tadesse *et al.*, 2017b). Connecting farmers with micro-credit services has been suggested as a way to enable cash-constrained farmers to obtain seeds of improved varieties (Tadesse *et al.*, 2017b), but the benefits of HTPS must be very clear before farmers will venture into that. Another important contextual factor that is currently unknown, is the marketability of the hybrid varieties. In terms of politics and governance, an important hurdle for the introduction of HTPS is variety registration (Section 7.4.3).

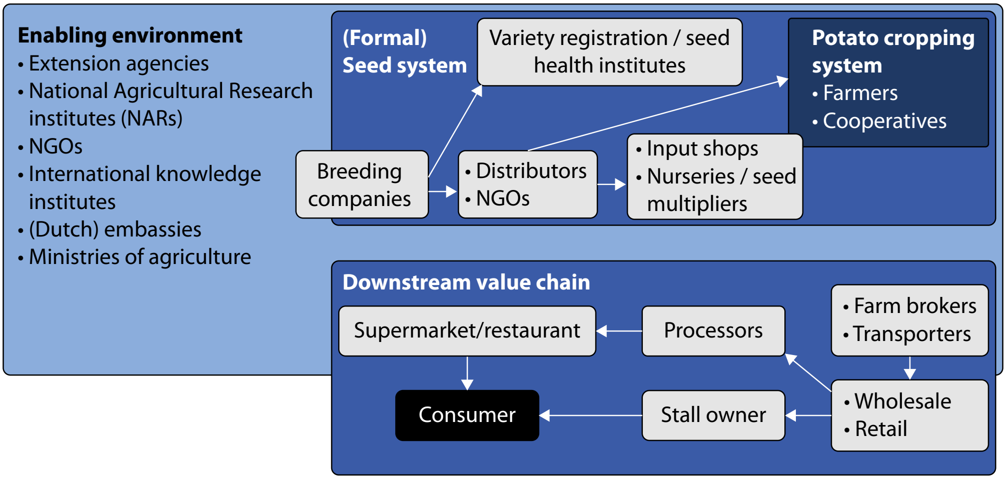

Figure 7.2. Stakeholders in the potato sector in East Africa and actors who may play a role in shaping an enabling environment for the introduction of HTPS in East Africa (Danial *et al.*, 2016; Janssens *et al.*, 2013; NFP, 2021).

7.4.3 Variety registration

Currently, several breeding companies are working on the development of hybrid potato varieties, such as Solynta, HZPC, Bejo Zaden and Aardevo (NFP, 2021). To commercialise and distribute hybrid varieties, breeding companies need to register their varieties at official variety registration institutes, which are usually hosted by the ministries of agriculture. For instance, in Kenya, candidate varieties need to be tested in 'value of commercial use' trials, which are sometimes referred to as 'national performance trials'. These trials take place over at least two growing seasons in multiple locations. They are meant to assess the agronomic potential of the candidate varieties and to test against locally available varieties. Commonly, registering new vegetable varieties, grown from seeds, requires different procedures than registering seed potatoes. Since hybrid potato has characteristics of both, it is often not clear what procedures have to be followed, or existing procedures have to be adapted, which complicates and delays the registration (NFP, 2021). In this regard, HTPS varieties need to comply with regulations set-up for seed-tuber propagated varieties, often requiring an extra step of seed-tuber production from HTPS transplants.

7.4.4 Functional seed systems supporting hybrid true potato seed

For the introduction of HTPS, an accessible and reliable seed system is pivotal to provide farmers with the desired starting material, which could be clean seeds, seedlings or seedling tubers (Lindhout *et al.*, 2018). Any intervention involving seeds or starting material should build on a solid understanding of existing seed systems (Almekinders *et al.*, 2019). Relevant stakeholders in formal and informal seed systems should be identified through stakeholder mapping, interviews and focus group discussions. This also informs understanding regarding how seed systems and their actors will be affected by the introduction of HTPS.

To find functional seed system configurations that can support HTPS, it is crucial to understand which type of planting material is required by farmers, which type of logistics is most effective to get planting material to farmers and which actors are needed for that (Table 7.2). Farmers may use the seeds to grow seedlings in a raised seedbed or small nursery, after which the seedlings can be transplanted at high densities in the nursery or in the field to obtain seedling tubers, or the seedlings can be transplanted at lower densities in the open field to obtain a ware crop. Alternatively, specialised nurseries may use the seeds to raise seedlings or seedling tubers, which can be distributed to farmers. Nurseries could be managed by local entrepreneurs or cooperatives – also called decentralised multipliers (Almekinders *et al.*, 2019) –, or the multiplication could be done more centrally by larger public or private organisations (Table 7.2). Most seed system interventions in vegetative crops assumed a system with decentralised multipliers, but the empirical evidence for this assumption is scant (Almekinders *et al.*, 2019). A major bottleneck for the introduction of HTPS is the intermediate infrastructure needed to get planting material to farmers (NFP, 2021). Nurseries and seed tuber multipliers are not yet familiar with HTPS, and capacity building needs to happen to solve this.

Table 7.2. The top part summarises the main advantages of using seeds, seedlings and seedling tubers. Possible seed system configurations are shown in the bottom part.

	HTPS (Botanical seed)	Seedling	Seedling tubers
Advantages	• Free of diseases	• Versatile, can be used for ware crop or for obtaining seed tubers	• Short crop cycle to obtain a ware crop
	• Easy to transport and store		• Farmers are used to seed potatoes
Disadvantages	• Sowing tiny seeds requires skill and patience	• Cannot be stored for long	• Can transmit diseases
		• Requires regular water and intensive care	• Bulky
		• Transplant shocks	• Require specific storage conditions
Possible seed system configurations			
Farmers only	Farmers use HTPS to grow their own starting material, and produce a ware crop from that starting material; ware potato farmers are involved in all stages.		
Decentralised multipliers	Local entrepreneurs or cooperatives use HTPS to produce starting material, either seedlings or seedling tubers. Specialised nurseries may be employed. Starting material is then sold to farmers who use it to grow a ware crop.		
Centralised multipliers	Larger public or private organisations use HTPS to produce seedlings or seedling tubers, using specialised nurseries and dedicated seedling tuber producers. Seedling tubers are then distributed to ware crop farmers.		

7.4.5 Adapted agronomic management

HTPS provides multiple cultivation pathways for potato production through direct field sowing, field transplanting of nursery raised seedlings and the use of seedling tubers (Van Dijk *et al.*, 2021a). In contrast to tuber-based cultivation systems, where various aspects of the system, including agronomy, have been rigorously studied, limited information is available for most of the aspects of the above-mentioned cultivation pathways. The implementation of HTPS requires major changes in agronomic management practices, most notably in terms of growing the starting material, and the starting material itself. Growing the desired starting material, which could be seedlings or seedling tubers, starts with the sowing of true seeds, followed by seedling nursing, and in most cases, seedling transplanting into the field. Currently, most studies on the agronomy of hybrid potato have been conducted on nursery-raised seedlings which were transplanted to the field, mostly in the Netherlands, and to a limited extent in East Africa. The effect of transplanting date, plant density and some aspects of transplant crop management through additional hilling on yields and tuber size distribution have been explored (Van Dijk *et al.*, 2021a,b, 2022). When using seedlings as starting material, adaptations in plant density are most likely needed, because under Dutch conditions, increased plant densities result in higher yields, but they also affect the tuber size distribution. Optimal plant density for total yield is between 50 and 100 plant/m^2 but this depends on the soil type and cultivation system (Van Dijk *et al.*, 2022). Furthermore, seedlings have a slower initial growth than seed tubers, and therefore, a seedling-based usually crop has a longer crop cycle. However, the length of the crop cycle also depends on the genotype (Van Dijk *et al.*, 2021b). It is paramount to align these findings to current cropping systems in East Africa and bridge various knowledge gaps in the agronomy of HTPS based cropping systems. For instance, it is important to assess whether a seedling crop with a longer growing cycle could fit in East African cropping calendars. Finetuning agronomic management practices and adapting them to fit a local context will require participatory testing and evaluation.

7.4.6 Participatory trials and evaluation

Involving farmers and other stakeholders in innovation design and evaluation enhances the likelihood that an innovation yields options that fit in farmers' realities (Descheemaeker *et al.*, 2019). Research on the feasibility of HTPS at farm level is urgently needed and requires agronomic insights and information on household-level constraints and opportunities. Farm-level management decisions concerning rotations, soil fertility management and the allocation of land, labour and capital influence the performance of a new technology. Moreover, between farming households, there is a large diversity in terms of resource endowment, farm management and farmers' aspirations and attitudes, which implies that the feasibility of hybrid potato will differ among different types of households (Descheemaeker *et al.*, 2019; Ronner *et al.*, 2019). It is more useful to tailor the innovation and the adaptation of the system towards the needs and capabilities of different household types, rather than offering a fixed technology package (Giller *et al.*, 2011). A recent workshop with several European and African research institutes, governments, companies and NGOs called for a forward-looking view, concluding that:

> Given the many uncertainties associated with HTPS-technology, innovation can only take place in a responsible manner if it is accompanied by sufficient pre-implementation research in collaboration with African stakeholders to better understand the potential merits and robustness of the technology, its socio-economic consequences and the way in which the technology should be introduced (Swart and Stemerding, 2019).

Hence, for an inclusive, effective and responsible introduction of HTPS in East Africa, an iterative research cycle linking farmers, researchers, breeders and other stakeholders is needed. On-farm trials should involve nurseries and potato growers to test, evaluate and adapt agronomic practices, to find out what type of logistics are most suitable, and to select the best performing varieties (Figure 7.3). This participatory testing of different varieties, planting materials (seed, seedlings, seed tubers) and agronomic practices will yield information on desired crop traits and will inform the design of sustainable seed systems and farming systems that could accommodate hybrid potato varieties. Breeders can use this information to improve the variety selection criteria and to develop varieties attuned to regional needs. Vice versa, new varieties can be tested immediately in the on-farm evaluations. Furthermore, ex-ante analyses are needed to gain insight in the potential consequences of HTPS for a diversity of potato farmers, and for various actors in the potato sector.

7.4.7 Business models

Profitability for all actors involved in the potato chain (Figure 7.2), from breeding companies to distributors, multipliers and the downstream value chain is regarded as a key requirement for

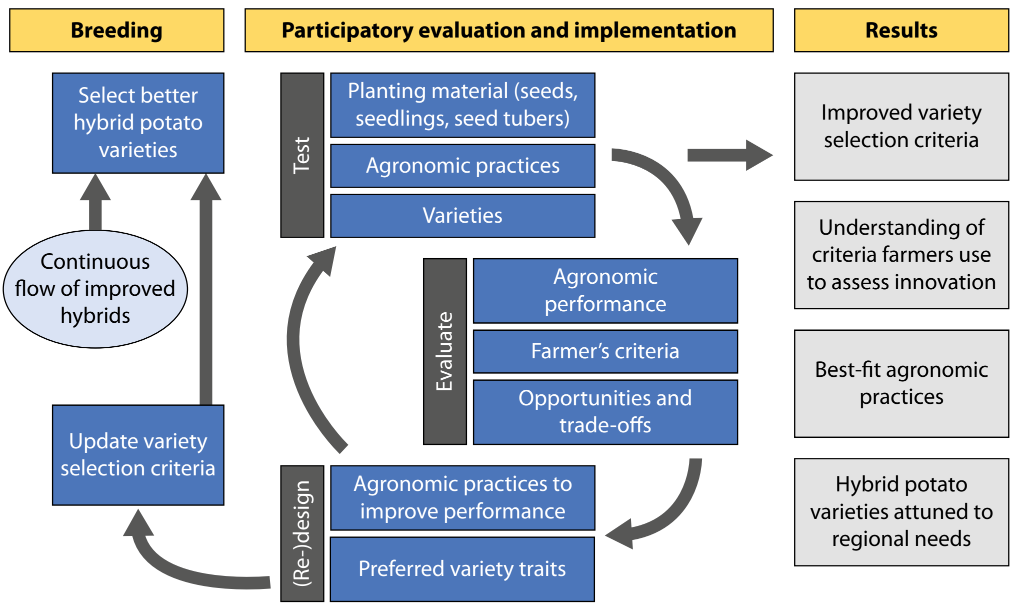

Figure 7.3. Iterative research cycle linking farmers, researchers, breeders and other stakeholders for a participatory implementation of HTPS.

sustainable introduction and continued use of HTPS (Lindhout *et al.*, 2018). This poses major challenges because currently, commercialisation of HTPS is in its infancy. HTPS may have added value in developing countries, but investments to further develop the technology are considerable, and the initial market, consisting of resource poor smallholders may not be profitable enough (Beumer and Stemerding, 2021; NFP, 2021). How much the hybrid seeds or planting material will cost is yet unclear. Future research should investigate the financial feasibility of using HTPS, for ware growers, seed multipliers and other actors in the chain. Financial feasibility for farmers and seed multipliers will to a large extent depend on how much added value hybrid potatoes have in comparison with farm-saved seeds and on how fast the clean hybrid material will degenerate. Business models along the value chain remain an important area for further research.

7.4.8 Responsible innovation

The introduction of HTPS comes with many uncertainties in multiple dimensions and at various levels (Swart and Stemerding, 2019), and it could have major consequences for the seed and farming systems where it will be introduced (Stemerding *et al.*, 2020). Who will benefit from the innovation, and who may not be interested or able to adopt it? What are the suitability criteria that guide such decision making by various stakeholders? Potato sometimes serves as a 'hunger breaking crop' due to its short growing cycle (Haverkort and Struik, 2015), but this function may be impaired by the longer growth period of HTPS grown from seeds or seedlings compared to starting from seed tubers. Ideas about desired future cultivation systems and preferred pathways of getting there may differ among stakeholders, from breeders to seed growers, farmers and policy makers. A framework for Responsible Innovation, building on the dimensions of reflexivity, inclusion, responsiveness and anticipation (Stilgoe *et al.*, 2013) may guide further research and implementation of HTPS in East Africa. This involves interactive, multi-stakeholder processes to develop shared views on the acceptability, sustainability and societal desirability of HTPS. Inherent in this 'responsible innovation approach' is that the potential impact of an innovation should be assessed prior to introducing the technology. In that way, potential negative impacts can be mitigated in time, and the positive impacts can be fostered. Inclusivity should be safeguarded by engaging with a diversity of rural households in the co-design process (Figure 7.3). Participatory processes can encourage all stakeholders involved to be reflexive on their activities, beliefs and assumptions regarding how HTPS should be deployed. Finally, responsiveness can be fostered through the feedback loops in the iterative research cycle (Figure 7.3).

7.5 Strengths, weaknesses, opportunities and threats analysis

Building on the above sections, we summarise the main strengths, weaknesses, opportunities and threats with respect to the introduction of hybrid true potato seed in East Africa (Figure 7.4). As strengths and weaknesses, we regard the attributes of the HTPS itself, which are internal to the innovation. Opportunities and threats are context-dependent and shaped by the external environment of the potato sector in East Africa.

HTPS attributes

Strengths

- Faster and more targeted breeding for disease resistance and for locally adapted varieties
- Seeds are free from economically important diseases, preventing disease transmission
- Seeds are easy to transport and store
- Multiplication of varieties can be done fast, on limited area, and locally
- Improved access to clean planting material

Weaknesses

- Adapted agronomic management required, e.g. weed management, seedling nursing and transplanting
- Seedlings are vulnerable and require irrigation
- When ware crop is grown from seeds or seedlings: longer crop cycle
- Seeds are small and sowing requires skills and precision

System attributes

Opportunities

- High disease pressure and limited seed tuber supply: improved access to clean planting material is a top priority
- Low baseline yields: HTPS varieties are competitive in terms of yield
- Many potato farmers are familiar with seedling nursing and transplanting for vegetable production
- High demand for potato

Threats

- Farmers are not used to seeds and seedlings for potato production
- Majority of farmers don't pay for starting material
- Intermediate infrastructure needed to get planting material to farmers not in place yet
- Seed governance for variety registration not in place yet

Figure 7.4. SWOT analysis of hybrid true potato seed (HTPS) in East Africa.

7.6 Research agenda

We conclude with urgent research questions that need empirical research prior and during the introduction of HTPS in East Africa. Building on the overview presented in this chapter, we identified four main 'research themes'. First, it is critical to understand which criteria and motivations are important to farmers when they judge the new options that HTPS brings along. This implies that understanding of local farm realities in terms of constrains, priorities and opportunities is required. The wide diversity of farmers and farming systems in terms of resource endowments, cultures, agro-ecology, socio-economy in East Africa makes this a challenging task. A second major area of research is if and how HTPS can be embedded into seed systems, and what the consequences of HTPS introduction will be for various actors in the seed systems. Third, insights from the abovementioned research areas should drive on-station and on-farm research to assess the performance of HTPS. Finally, some pertinent questions remain in the broader context of the introduction of HTPS in East Africa.

Farmers' criteria to judge performance of hybrid true potato seed:

- What are the criteria farmers apply when making decisions regarding HTPS? Do these criteria change under different socio-economic, cultural and agro-ecological conditions, and if so, how?
- Important criteria could be: investments and management intensity needed, length of growing season, marketability of produce, labour, risk, yield, susceptibility to major diseases (late blight, several viruses, bacterial wilt), prone-ness to weed infestation.
- What type of planting material is preferred by farmers, and what are motivations for these preferences? Planting material could be seeds, seedlings or seedling tubers.

Embedding in seed systems:

- What type of seed system configuration and intermediate infrastructure is best suited to deliver the preferred type(s) of hybrid planting material to farmers, and which actors are needed for that?
- Possible options are a 'farmers only system', decentralised multipliers or centralised multipliers (Table 7.2).
- Will hybrid potato varieties percolate into informal seed systems, and how?
- What are the consequences of HTPS introduction for actors in the seed systems?

Performance at field level:

- What are the best-fit agronomic practices to grow ware potatoes from HTPS derived planting material?
- What are the yields from HTPS derived planting material, under farmers' management and farmers' fields conditions?
- How does HTPS-derived planting material compare with the status quo (farm-saved seeds) in terms of farmers' criteria?
- How fast will seed tubers derived from HTPS degenerate?

Broader context:

- Are HTPS varieties acceptable to consumers and to actors in the downstream value chain, in terms of taste, colour, cooking quality or other culturally defined preferences? Who will benefit from HTPS? Will HTPS be mainly interesting for the relatively rich farmers who can invest, or will it also be interesting for farmers with less resources? Which other actors in the value chain and seed systems may benefit? For instance, nurseries, seed multipliers, or downstream value chain actors.
- What are business models for companies delivering seeds to a market of resource-poor smallholders?

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