Chapter 6. Potential impact of hybrid true potato seed in Sub-Saharan Africa

P. Gildemacher[1*] and E.M.S. ter Steeg[2,3]

[1]*KIT Royal Tropical Institute, Mauritskade 63, 1092 AD Amsterdam, the Netherlands;*
[2]*Wageningen University & Research, Hollandseweg 1, 6706 KN Wageningen, the Netherlands;*
[3]*SeedNL, Arthur van Schendelstraat 500, 3511 MH Utrecht, the Netherlands; p.gildemacher@kit.nl*

Abstract

Potato farming underpins the livelihoods of millions of smallholder producers in Sub-Saharan Africa, but productivity remains well below its potential. Poor access to and consequent limited use of quality seed is an important factor contributing to low productivity. So far, attempts to develop potato seed systems mirroring the European model have not been successful or only partially. The innovation of hybrid true potato seed (HTPS) has created the opportunity to transform the seed potato sector in Sub-Saharan Africa taking a new, radically different approach. The land requirement for an HTPS-based seed system is lower as fewer generations are needed. Also, it will no longer be necessary to maintain and rapidly multiply plantlets from tissue culture. Availability of early generation seed (EGS) can quickly increase as quality seed can now be produced centrally in large quantities. Subsequently, EGS can be distributed easily to local specialised multipliers circumventing the logistical constrains of transport and storage of the vegetative system. Local multiplication means that seed tubers are grown close to the smallholder's farm; this generates trust between seed supplier and client, which is important in the absence of a functional certification system. It is expected that smallholder potato producers will prefer seed tubers rather than HTPS or seedlings. Of course, HTPS varieties must match the needs of smallholders. Current product portfolios of international breeding companies are not tailored to Sub-Saharan Africa market demands. Short dormancy, late blight resistance and earliness are very important traits in Sub-Saharan Africa, while being (much) less important on the global seed potato market. HTPS (diploid) varieties can be improved faster making breeding for Sub-Saharan African demands feasible. Moreover, seed potato costs are expected to be lower in an HTPS system. Despite these obvious advantages, HTPS will not be an instant success. A last-mile retail system, bringing seed potatoes close to smallholder farms is adamant, and varieties tailored to specific smallholder needs must still be developed and must be affordable. Finally, training of smallholders on good agricultural practices, seed degeneration and the added value of quality seed will take time and resources. This chapter analyses current practices and constraints along the seed value chain and whether HTPS can address these challenges. In this way, it assesses the potential of HTPS to catalyse a transformation of the seed potato sector for the benefit of smallholder producers in Sub-Saharan Africa.

Keywords: hybrid true potato seed, Sub-Saharan Africa, early generation seed, seed potato systems, seed value chain analysis

Paul C. Struik, Peter R. Gildemacher, Dirk Stemerding and Pim Lindhout (eds.)
Impact of hybrid potato

DOI: 10.3920/978-90-8686-946-6_6,

6.1 Introduction

Potato is a food and cash crop that sustains the livelihoods of millions of smallholder producers in Sub-Saharan Africa. In Kenya alone, 800,000 households produce and market surplus potatoes (Kaguongo *et al.*, 2015). Potato can be harvested in 3-4 months and is easily marketable. The market continues to grow because of changing diets and population growth. The crop can only be grown in areas where there are cool night temperatures (Struik, 2007) providing farmers in suitable agro-ecological zones with natural exclusivity. It also prevents markets from being overflown and results in relatively stable remunerative prices.

Potato productivity in Sub-Saharan Africa remains well below its potential. It seems to increase only at a modest pace even though there are strong market incentives resulting from growing home consumption and processing (Figure 6.1). The persistently low productivity can partly be attributed to the use of poor-quality seed potatoes, and associated degeneration due to seed-borne diseases, such as virus diseases and bacterial wilt, in combination with sub-optimal crop husbandry including poor late blight management (Thomas-Sharma *et al.*, 2016). Additionally, potato is mainly a rainfed crop making drought an important factor depressing yields, in comparison to situations where water supply can be managed.

Seed potato systems in Sub-Saharan Africa function differently in comparison to European systems, which is often used as a benchmark. In Europe, most seed tubers used by farmers are grown by formal, reliable and independently controlled specialised producers. Farm-saved seed is only used sporadically. Seed potato trade companies have extensive product portfolios with

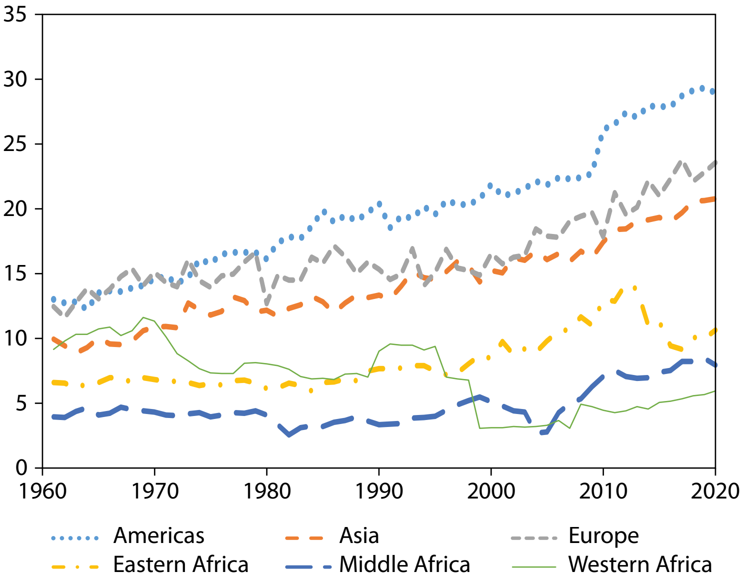

Figure 6.1. Average potato yield (t/ha) in Eastern, Middle and Western Africa, compared to those in the Americas, Asia and Europe (1960-2020) (FAOSTAT, May 2022).

varieties for seed potato users to choose from. There is a private seed potato sector, characterised by competition and the role of public bodies is limited to quality assurance and regulation. In Sub-Saharan Africa, potato producers typically use home-saved seed potatoes selected from their last crop as default option and only occasionally replace their seed stock. The choice of varieties is limited to a few varieties maintained by the public sector, and few varieties from the international private sector. The private seed potato sector is under-developed, and in many countries for parts of the seed potato production chain the public sector is acting as producer.

For decades, efforts have been made to improve seed potato systems to assure better access to seed and to increase the quality of seed potatoes for Sub-Saharan African smallholder producers. Most efforts have been made by development organisations. However, it appears that these efforts have not (yet) resulted in a substantial rise in potato productivity contributing to increasing land-use efficiency, rural household incomes, and food security. Ter Steeg *et al.* (2022a) distinguish two existing models for the development of formal potato seed systems in low-tech markets. The first system is based on imported elite material of private commercial varieties, multiplied locally or directly marketed. The second system is based on rapid multiplication of private varieties, or multiplication by local seed potato producers of varieties largely originating from public breeding efforts. The authors indicate that hybrid true potato seed (HTPS) could become the basis of a third, alternative system.

The innovation of HTPS has created the opportunity to transform the seed potato sector in Sub-Saharan Africa taking a new, radically different approach. This chapter explores whether the HTPS technology could transform the seed potato sector in Sub-Saharan Africa improving availability and use of quality potato starting material and breaking the deadlock of stagnant productivity levels. The chapter first dissects the seed potato value chain in Sub-Saharan Africa analysing its current underperformance. Subsequently, it explores if HTPS technology could remove these challenges limiting development of seed potato systems. Finally, it outlines recommendations when seeking to transform the seed potato systems in Sub-Saharan Africa through the deployment of HTPS technology.

6.2 Production systems in Sub-Saharan Africa

Discussing 'potato production systems in Sub-Saharan Africa' is a gross simplification considering enormous existing diversity. Each country is home to unique production systems shaped by the agroecological and socioeconomic context, regulatory environment and level of seed sector development, with different seed potato value chains operating in parallel as well as being intertwined. Describing the specificities of individual countries goes far beyond the purpose of this chapter but it may be helpful to distinguish between three potato production areas to inform readers (Table 6.1). The first production area encompasses the East and Central African highlands (above 1,500 m a.s.l.) including Ethiopia, Kenya, Uganda, Rwanda, Burundi, DR Congo and Tanzania. In these countries, potato production is characterised by the bi-modal rainfall pattern, resulting in two main growing seasons. At the highest altitudes, where evapotranspiration is low, the period between the two seasons is less dry allowing for year-round production. There is also production in valley bottoms drained during the dry season, complemented by limited production

Table 6.1. Potato production zones in Sub-Saharan Africa.

	East and Central Africa	Southern African and West-Africa	Sahelian zone
Altitude in m a.s.l.	Highlands above 1,500	Mid-altitude 1,200-1,500	Sea level
No. of seasons	2-3	1-2	1
Water source	Rainfed	Rainfed / irrigation	Irrigated
Dominant seed source	Self-supply	Self-supply	Import
	National formal seed system	National formal system	
		Import	
Type of potato producers	Smallholders	Smallholders and medium scale producers	Medium scale producers with some capital

using basic sprinklers or furrow irrigation. It is relatively easy for potato producers to recycle small tubers from their last harvest as seed for the next season. The year-round potato production means that pest and disease pressures are high. Potato production is done by smallholder producers and medium-scale farmers, while large-scale (mechanised) potato production is very rare.

Southern and Western Africa represents the second production zone, where the potato areas are located at mid-altitude (1,200-1,500 m a.sl.) where cool night temperatures occur, making potato production possible. Depending on the country, there are two rainfed seasons (Malawi, Northern Mozambique, Cameroon), or a single rainfed and an irrigated season (Nigeria, Southern Mozambique, Zimbabwe, Zambia, Angola). Potato farmers largely rely on self-supply of seed. Producers that only grow potatoes for a single season per year are more likely to buy seed from specialised multipliers or imported seed potatoes. Storing home saved seed for 7-8 months to bridge between the seasons, is (very) challenging under ambient temperatures occurring at mid-altitude. Some Southern African production areas are routinely served with South African seed potatoes. Potato production is mostly done by smallholders in Malawi, Nigeria, and Northern Mozambique. Medium-scale farms are more prominent in Southern Mozambique, Zimbabwe, Zambia and Angola.

The third production zone is the Sahelian region. During the dry season in countries like Guinea, Mali, Burkina Faso, Niger, but also Sudan, night temperatures drop and reach levels which allow for potato production. Production is irrigated, and seed potatoes are imported, as the high ambient temperatures and the long storage period between seasons make seed recycling virtually impossible; it would require cold storage. As production is based on imported seed potatoes and a water source is required, potato production in the Sahelian zone is done by better-off medium scale farmers with access to required capital.

6.3 Seed potato value chain analysis

The African potato seed system will be analysed in more detail using the Seed Value Sector Analysis model (Audet-Bélanger *et al.*, 2013). For each seed value chain component, Sub-Saharan

African characteristics are described and constraints for potato seed sector functioning are identified. Examples of past interventions and their results are discussed. Finally, the ability of HTPS technology to remove these constraints is evaluated. Table 6.2 summarises the text below and provides an overview of this step-by-step analysis of the Sub-Saharan African potato seed sector value chain and opportunities offered by HTPS.

Table 6.2. Potato seed value chain analysis (based on studies conducted by KIT Royal Tropical Institute for the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) in Cameroon, Mali, Nigeria, Kenya and Uganda and authors' personal observations).

	Characteristics	Constraints	Opportunities HTPS
Breeding	• Public mandate mainly • Mostly done by CIP • Desired traits not prioritised: – Short dormancy – Short growing season – Drought tolerance – Heat tolerance – Late-blight resistance – Bacterial wilt resistance – Virus resistance – Multi-purpose, little market segregation	• Under-funded • No private sector breeding focusing on SSA needs • Breeding for short dormancy reduces storability • Late-blight resistance associated with longer growing season (Collins *et al.*, 1999) • No reliable bacterial wilt resistance for potato • Virus resistance not prioritised by private sector	• Focused breeding for African desired traits • Specific traits can be bred into existing varieties using conventional breeding techniques.
Variety selection and registration	• Variety selection by NARS • Variety selection by Dutch private sector	• Long registration procedures in each individual country • Hesitance to register many varieties to cater for the diversity of demands of farmers and consumers	• Rapid multiplication, allowing for faster registration process and immediate release after registration
Early generation seed production	• Breeder seed, pre-basic seed often public • Basic seed private multipliers • EGS poorly available • Poor link between supply and demand for EGS	• Disease pressure, resulting in low quality • Lack of multiplication capacity • Fixed prices • Poor availability and timing of public EGS production	• Use of true seed as EGS – Reducing production to 1 season – Under fully controlled conditions – On very limited space • Bulk production in a single or few locations possible • EGS timing and distribution simple

Table 6.2. Continued.

	Characteristics	Constraints	Opportunities HTPS
Seed potato multiplication	• Seed potato multiplication by a limited number of medium-scale multipliers	• International private companies not able to find large-scale local partners • Large scale multipliers often lacking because of poor access to highland • Seed potato multiplication less economic than ware potato production • Cash flow constraints and risks for medium scale multipliers • Storage is a major cost and risk. • Non-sale is also a major risk.	• Seedling production possible on much smaller areas, saving land compared to conventional multiplication • Decentralised multipliers easily supplied with TPS • Possibly self-nursery (rather than seed plot, like rice)
Seed potato marketing and dissemination	• Limited marketing necessary. Demand is higher than the supply. Marketing largely done on reputation. • Often no adapted retail packaging • Few varieties on offer • Lack of pre-ordering systems	• Country-wide retailing difficult, but this is more theoretical as demand is higher than supply. • International trade is complex because of transport, sprouting and dormancy.	• For HTPS: Risk of non-sales lower, as less perishable • Wider marketing HTPS possible because light • In case of seedlings more staggered production is possible.
Seed potato use	• Farmers recycle seed from their own farm. • Farmers only occasionally buy certified seed.	• Farmer agricultural practices are sub-optimal, thus not making the best use of high-quality seed. • Farmer own seed quality management is sub-optimal.	• In case of TPS use, additional farmer training is a pre-requisite. • In case of tuber use, no difference with current system. Promotion of good quality seed use required.

Table 6.2. Continued.

	Characteristics	Constraints	Opportunities HTPS
Seed policy and regulation	• Regulation based on vegetative multiplication. • Phytosanitary rules for imports focus on quarantine disease risk management.		• Seedlings require a form of quality assurance. • Quality assurance for tubers exists, but may require some adaptation. • HTPS requires to be accepted under same conditions as hybrid vegetable seed for import and certification (truthful labelling).

6.4 Breeding and variety selection

6.4.1 Current practices, constraints, and opportunities

Specific potato breeding efforts for Sub-Saharan Africa are highly limited. The most important actor is the International Potato Center (CIP), which collaborates with the national agricultural research organisations (NARS) in African countries. The main breeding programme of CIP is located in Latin America and does not focus exclusively on African demands; it does have an eye for these demands. NARS receive at request candidate varieties for local variety selection. The international private potato breeding enterprises are not breeding specifically for Sub-Saharan African demand, which is understandable as the market for seed potatoes remains very small. They offer best-bet varieties from their portfolios in selected African countries.

The lack of focus on specific Sub-Saharan African traits has contributed to current narrow variety portfolios, which do not respond very well to producer and market demands. Producers and traders alike appreciate multi-purpose varieties, which are suitable for home consumption and production of French fries through single frying. Contrary to the global potato market, the bulk of French fries' production in the region is still done through hand-cutting and single frying in smaller restaurants and hotels. The market for frozen or vacuum packed pre-fried French fries is in its infancy. Furthermore, popular traits in Sub-Saharan Africa are a very short dormancy period, late-blight resistance, virus resistance, bacterial wilt resistance, earliness and heat and drought tolerance. Kaguongo *et al.* (2008) found these traits to be sought after by producers in Kenya and Uganda.

Short dormancy compromises storability making breeders reluctant to focus on it. However, in all bi-modal production areas in Sub-Saharan Africa, short dormancy enables producers to almost immediately replant their farm-saved seed. Losses during the storage period can reach up to 50%. Thanks to the short or non-existent dormancy period, farmers do not have to store their seed tubers and can avoid the risk of high losses. In Kenya, during the early 2000s the landrace Nyayo was more popular than other formally released varieties because of a dormancy period of

3 weeks. Similarly, the most popular Kenyan variety of today, Shangi, is also appreciated for its very short dormancy period, and has been registered formally only after having emerged as a landrace.

Late blight and virus resistance have been the focus of the CIP but have not been prioritised by international commercial breeders. The European market has focused on full chemical control and zero disease tolerance rather than integrated disease management, which better matches the needs of African farmers. Virus resistance slows down seed degeneration and hence, reduces the need to renew seed, which is not aligned with interest of commercial breeding companies. Varieties with stable bacterial wilt resistance have not been developed until today. The first late-blight resistant varieties developed by international potato breeding companies are entering the market now.

In the East African highlands as well as the West and Southern African mid-altitude production zones, a medium level of late-blight resistance is the minimum requirement for smallholder potato producers. Most potato production in these areas is rainfed, while late-blight control by farmers is mediocre. Consequently, there is high late-blight pressure in the potato production areas during the rainy season. Smallholder farmers rely on hand-operated knapsack sprayers, which result in sub-optimal crop cover. Moreover, they tend to have access to a limited selection of fungicides of variable quality. In summary, management of the disease is difficult when growing susceptible varieties. Problems are exacerbated by the lack of regular dry spells during the main rainy season allowing the fungicide to dry on the crop. A high level of varietal resistance significantly reduces the risk of high crop losses, and farmers can get away with fewer and imperfect crop protection measures.

In most countries, smallholder potato producers seek for super early maturing varieties for a variety of reasons. Generally, potato production is practised on prime land, in prime agro-ecologies, where land pressure is high. Rapid returns on investments are crucial for cash-short smallholders farming small plots. In bi-modal rainfall areas, or irrigated areas, farmers want to clear their land quickly to move to the next crop in their rotation scheme. In other areas, such as Nigeria, farmers need early varieties to escape the peak of late-blight disease pressure.

Considering the rainfed nature of smallholder potato production in Sub-Saharan Africa, drought tolerance is of major importance. Rainfall patterns are becoming less reliable due to climate change. Also, increased tolerance of potato plants to higher soil temperatures would expand the area where potatoes can be grown commercially to more tropical conditions and lower elevations. Currently, potato growing area is constrained by the requirement of moderate average daily temperatures (below 18 °C), but better still 15 °C) to trigger tuberisation, enhance tuber bulking and increase dry matter content (Struik, 2007).

6.4.2 Opportunities hybrid true potato seed

The major benefit of HTPS varieties is that they are diploid hybrids, making targeted breeding for the specific traits appreciated by Sub-Saharan African producers and consumers possible and more affordable (Ter Steeg *et al.*, 2022a). Breeding of tetraploid potato varieties is based on making best-bet crossings from pre-breeding lines and requires assessment of field performance of the entire progeny. Breeders 'hope' to 'discover' individual plants that outperform established cultivars: effectively, it remains a game of chance and can take decades to find varieties. In contrast, the diploid genome of HTPS varieties allows for targeted inclusion of desired traits ('trait-stacking') from wild potato species or existing cultivars through conventional breeding techniques. This can be done as rapidly as within 2 years (Lindhout *et al.*, 2011; Su *et al.*, 2019), once a broad collection of parent lines is available allowing for gradual improvement of (diploid) varieties. With diploid varieties, a potato breeding programme could be launched, which takes into consideration the demands of African farmers and consumers, which currently receive little attention in commercial breeding (Beumer and Stemerding, 2021). Still, hybrid breeding is still a highly expensive undertaking, and companies tend to prefer markets with more secure returns on investments. A dedicated potato breeding programme for the low-tech Sub-Saharan African market will require public-private collaboration (Ter Steeg and Lindhout, 2022; Ter Steeg *et al.*, 2022a).

6.5 Early generation seed production

6.5.1 Current practices, constraints and opportunities

The potato early generation seed (EGS) production chain is, without exception, underperforming in Sub-Saharan African countries. The few existing commercial seed potato multipliers are almost without exception struggling to obtain a reliable supply of quality starting material. The ordering and distribution system of potato EGS is functioning poorly across countries; provided there even is a 'system'. In East Africa, the public research institutes play a pivotal role in EGS production. They maintain breeder seed as *in vitro* plantlets and run limited rapid multiplication operations to produce mini-tubers. Public institutes are not profit-driven and do not respond directly to market incentives. Consequently, production volumes of mini-tubers are often too low, and production timing tends to be suboptimal.

In Kenya, Ethiopia, Rwanda, Burundi, Malawi, Tanzania and Uganda, public and private mini-tuber producers have emerged with assistance of development actors assuring a broader base of mini-tuber sources (Schulte-Geldermann *et al.*, 2022). The private mini-tuber producers tend to remain dependent on the NARS for their supply of rooted plantlets. Still, it is difficult for private actors to enter the market and compete with inefficient public actors as mini-tubers are often sold at artificially cheap prices using subsidies. Involvement of private producers at different stages of EGS production could assure that multipliers further down the chain do not rely fully on the public ability to produce and distribute EGS. In Kenya and Rwanda, the seed potato system has advanced, and there are private operators maintaining and rapidly multiplying *in vitro* plantlets and producing mini-tubers for (semi-)private multipliers. Such examples of privately run for-profit *in vitro* laboratories producing potatoes plantlets remain scarce (Harahagazwe *et al.*, 2018).

Importation of mini-tubers or other EGS materials from Europe for multiplication is the 'go-to alternative' of private enterprises. It reduces the required investment and hence, risk for breeding companies. However, phytosanitary regulations in most East African countries have made this cumbersome. There has been a strong push over the last decade to simplify import regulations for both advanced breeding materials and potato EGS. In West-Africa, countries like Cameroon, Mali and Burkina Faso rely entirely on imported European seed potatoes. Nigeria has the largest area under potato cultivation of the African continent with more than 300,000 hectares in production annually (Gildemacher and Belt, 2019; Ugonna *et al.*, 2013) but a rapid multiplication system is non-existent, and the few seed potato multipliers rely fully on haphazard import of certified seed from Europe as starter material (Gildemacher and Belt, 2019). In some countries, for example Burundi, prices of the first generations of seed potatoes are fixed by the public seed regulatory body, which has a distorting effect. Fixed, low prices of pre-basic seed make it attractive for seed multipliers to buy pre-basic seed in larger quantities and reduce the number of multiplication cycles they do themselves. As a result, the limited amount of high-quality seed available flushes out early and loses its value. Advocacy by the seed multipliers to abandon the fixed prices have proven idle until today, as the governments resort to price fixing to keep seed potatoes affordable for smallholders.

Seed-borne diseases such as bacterial wilt and viruses pose a significant challenge for EGS production. In many Sub-Saharan African countries, bacterial wilt is endemic and multiplying EGS without attracting any infection is an uphill battle and risky business. It has proven very difficult to keep viruses at acceptable levels during the first field generations. EGS is usually grown in the middle of potato production zones, and isolation of EGS fields is difficult. Isolation of EGS fields is required by law in Nyanza, Zimbabwe since 1956, but these rules are hard to enforce (Svubure *et al.*, 2016).

Alternative rapid multiplication techniques to make the EGS production more efficient are currently being tested. Sand hydroponics, aeroponics and apical cuttings have been applied with varying levels of success. These technologies definitely hold potential to improve the EGS value chain (Schulte-Geldermann *et al.*, 2022). However, required investment for an aeroponic facilities is high and returns cannot be obtained in the absence of a functioning multiplication system.

6.5.2 Opportunities hybrid true potato seed

With HTPS, EGS can be produced from true potato seed rather than potato seed tubers. This changes, and significantly simplifies the EGS production system. EGS can be produced and processed, as is done for tomato hybrids, at few locations in the world and is easily shipped to clients by air mail or courier. Seed of parent lines can be produced under fully controlled and secure conditions, and the F1 seed for global distribution in a single field generation. For HTPS, local maintenance and rapid multiplication of *in vitro* materials are not required, nor is a system in which mini-tubers are produced from *in vitro* plantlets. Effectively, the effort of setting up a new or improving the dysfunctional EGS chain can be avoided completely. Additional advantages are the virtual absence of seed-borne diseases in HTPS, absence of seed dormancy, low perishability, and last but surely not least, the ease of logistics. Considering that it is invariably difficult to produce potato EGS for profit in Sub-Sahara Africa, HTPS offers a strong potential alternative. A country like Nigeria, with no *in vitro* laboratory producing potatoes, can invest in developing a multiplication system based on HTPS, rather than building a full potato EGS system based on *in vitro* multiplication.

6.6 Seed potato multiplication

6.6.1 Current practices, constraints and opportunities

It remains a major challenge for seed multipliers to obtain a sufficient supply of EGS in terms of quantity and quality. In most cases, their enterprise depends on the performance of a single source of mini-tubers, or if there are multiple sources of mini-tubers, these depend on a single source of *in vitro* plantlets. High disease pressure makes it impossible for seed producers to multiply many generations, especially due to viruses and bacterial wilt.

A challenge blocking the development of a commercial seed multiplication system is that in most areas where potatoes are grown, large landholdings are relatively scarce. Larger areas facilitate crop rotation and a minimum of four seasons is recommended for seed potato production. This recommendation is a requirement for most certification schemes and makes it less attractive for farmers to grow seed. Potato is the main cash crop in highland areas. In the absence of high price premiums, farmers will prefer to grow ware potatoes (almost) every season instead of seed potatoes every four seasons. In addition, the time gap between seed potato production and seed potato marketing is hard for smallholders, as they are cash-strapped, and run into cash-flow problems if they cannot immediately sell their produce after harvest.

As a result, commercial seed potato multiplication is practised mostly on medium-scale farms of 5 ha and larger. Large-scale seed potato producing farms are uncommon, as large farms in general are hard to find in the high-altitude and mid-altitude areas. International seed potato companies struggle to enter the market because there are no large local farms to partner with. The companies seek large and reliable local partners to multiply seed tubers and bring their varieties to the local market in an affordable way. In Kenya, there are a few larger farms in the highlands, which are collaborating with Dutch potato trade companies HZPC and Agrico to do multiplication at a larger scale. Similarly, HZPC has co-invested in the development of the seed potato multiplication value chain in Ethiopia. In Burundi, the number of medium-scale seed potato producers has grown exponentially in the past years supported by a ready market and development projects.

Table 6.3. Classic rapid multiplication generations compared to HTPS multiplication system.

Classic rapid multiplication		HTPS	
Method	**Generation**	**Method**	**Generation**
In vitro germplasm maintenance	0	Simple dry storage true seed of parental lines	0
In vitro rapid multiplication	1	F1 hybrid seed production	1
Mini-tuber production	1	Seedling production	2
Field multiplication	2, 3, 4, 5, 6, 7, 8	Field production seed tubers	2

6.6.2 Opportunities for hybrid true potato seed

HTPS will change the *modus operandi* of seed multipliers. Currently, they buy mini-tubers, pre-basic or basic seed, which they multiply one or more seasons. When adopting HTPS, it will no longer be necessary to multiply seed tubers for several seasons, as multiplication is done during the true seed phase. The role of seed multipliers would likely be to transform HTPS into familiar starting material. Effectively, the seed potato chain can be reduced to a true seed-based multiplication phase, and a true seed to planting material conversion step (Table 6.3). The future role of seed multipliers in this chain will depend on the choice of seed users: will they continue to use seed tubers, convert to seedlings, raise their own seedlings or adopt direct seeding of HTPS? It should be noted that this choice will not only depend on the farmer, but also on the innovation itself and whether direct sowing becomes feasible, for example, through the use of coating.

For the Sahel production system, HTPS will offer business opportunities for local multipliers. Currently, local multiplication is complex with cold storage being a necessity during the hot season. With HTPS, the opportunity emerges to produce seedlings locally offering an alternative for seed tubers imports from Europe. In countries with year-round temperate conditions in the potato producing areas, seed multiplication based on HTPS has major transformative potential. Multipliers are no longer dependent on a supply of sprouted seed tubers and can germinate true seed according to demand. Moreover, multipliers with access to irrigation can plant seedlings for the production of seed tubers year-round. In Nigeria, in the absence of an existing seed potato multiplication system, HTPS could be a breakthrough technology.

The success of the HTPS technology will depend to a large extent on the development of a cost-effective and efficient multiplication system, offering quality seed potatoes at an attractive price. HTPS must be marketed at an affordable price: competitive with existing sources of EGS and compatible with the purchasing power of potato growers buying seed tubers from the multiplier. Local seed multipliers need to learn to use and economically optimise the production of seedlings and seed tubers from HTPS.

6.7 Seed potato marketing

6.7.1 Current practices, constraints, and opportunities

In West-Africa, seed potato marketing is based on import of seed potatoes, both for the mid-altitude as well as for the Sahel production systems. Farmer organisations play an important role in accumulating orders of farmers into block-orders to potato trade companies from France and the Netherlands. In East and Central Africa, seed potatoes are mostly sold directly by seed potato multipliers at the farm gate. Demand is so high that certified seed producers do not need to put in much effort to sell their produce: clients come to them. Considering the fragile nature of seed tubers and need for good storage conditions, this system serves both the producer and client. However, it does make certified seed potatoes difficult to access for those producers with no ability to travel. Last-mile access to quality seed potatoes is better when seed producers are spread throughout potato production areas. In the absence of effective certification systems, the reputation of a seed supplier shapes purchasing decisions of ware producers. Proximity of seed multipliers to ware potato producers is important because farmers may prefer to buy from their neighbours as they can visit their potato fields and storage facilities themselves. A relation of trust between client and supplier offers a local substitute for a certification system.

6.7.2 Opportunities for hybrid true potato seed

The low volume and limited perishability of HTPS allow for a simple distribution system facilitating decentralisation of seed multiplication. HTPS can be marketed to multipliers through existing marketing channels such as seed shops selling staple crop and vegetable seed. It should be noted that potato farmers, multipliers but especially ware producers, may not be connected to these channels at the moment. Last-mile distribution reaching ware potato growers will likely still be arranged via direct marketing from seed multiplier to seed user because of the importance of a trusting relationship. Alternatively, a mail or courier system can be used. Marketing of potato seedlings, raised from HTPS, is a possible new way to commercialise potato planting material. Seedling producers for vegetable crops are emerging in Kenya and Ethiopia. It remains to be seen whether ware potato producers deem seedlings an attractive alternative for seed tubers. In Sahel countries, seedlings may well become popular with the only alternative being expensive imported seed tubers. In other countries where seed multipliers can opt for production and marketing of seed tubers, the competitiveness of marketing seedlings as planting material to ware potato producers is doubtful. Ware producers may be reluctant to change as production from seedlings is much more cumbersome than planting sprouted seed tubers.

6.8 Seed potato use

6.8.1 Current practices, constraints, and opportunities

Currently, only a small proportion of potato seed tubers planted are sourced from specialised multipliers, who produce seed potatoes for a profit. For the greatest part, seed and ware potato production systems overlap: most seed tubers planted in Sub-Saharan Africa are smaller tubers harvested from ware potato fields which are graded, stored, and then re-planted. Farmers usually select and save their own seed. If they (have to) sell most of their harvest or suffer losses during storage, they source seed tubers from neighbours or on the local market, where in potato areas small tubers are sold as planting material. In Eastern Uganda, traders who collect potatoes, sort potatoes based on size and sell the 'less marketable' small tubers as seed on local markets at the start of the next season. In Nigeria, these small potatoes represent the only source of seed available on the market.

The rate at which potato producers renew their seed differs. In countries, where bacterial wilt is highly endemic, such as Rwanda and Burundi, farmers are more inclined to renew their seed regularly. A study by Gildemacher *et al.* (2009) showed that in Kenya 41% and in Uganda 26% of farmers indicated to renew their seed regularly, on average farmers did so once every 6-7 seasons, which is very low. Ever since, the supply of quality seed potatoes, either certified or quality-declared, is growing, thanks to public-private efforts to build for-profit seed potato systems. More recent research by Mumia *et al.* (2018) showed that in Kenya nowadays over 80% of farmers regularly replace their seed stock, with an average frequency of once per four seasons. In the experience of the authors, increased volumes of quality seed potatoes find a willing market. The major issues are quality guarantees, timely distribution, and affordability. There is sufficient demand from ware producers, but the seed system fails to deliver at the right time, at the right place and at the right price.

Seed potato recycling ('using farm-saved seed') by ware potato producers is not necessarily a bad practice. In many situations, ware potato farmers have little choice, as quality seed potatoes are simply not available in the reasonable vicinity of their farms. Furthermore, it may be the least risky decision considering the low availability of quality seed, high price of certified seed and unknown quality of purchased seed. Depending on the level of seed degeneration and associated yield loss, recycling seed potatoes for a number of seasons can be an economically sound farming practice. The lack of a reliable seed quality assurance system also poses a serious risk. There may be no or little guarantees regarding quality of certified seed tubers sourced from an anonymous formal system. Two technologies are being promoted to improve the quality of recycled seed: small seed plots to assure one season of multiplication by the ware potato farmer under controlled conditions (Demo *et al.*, 2015) and positive selection (Gildemacher *et al.*, 2012).

Not all ware potato producers are aware of the major impact of seed quality on the production potential. A large component of the loss of yield potential results from accumulating virus infections. Virus infections are only visible to the trained eye. In Kenya, ware potato producers and public extension officers alike deemed heterogeneity of potato plant appearances as a normal feature of the potato crop. They were unaware that differences in appearance were caused by virus infection. Similarly, in Nigeria, farmers explained how they selected seed potatoes from light-coloured plants in the belief that it was a special variety. However, the authors expect the light-coloured plants were virus infected. Demonstration projects can raise awareness, while simultaneously increasing demand for quality seed. The authors witnessed the positive impact of demonstrations with quality seed potatoes on the seed potato market in Burundi.

6.8.2 Opportunities for hybrid true potato seed

It is highly likely that most ware potato producers will prefer seed tubers over tedious true seed or fragile seedlings. Contrary to vegetable farmers, potato producers are not used to working with seeds and raising seedlings. Tubers are robust and have a short growing season. Transplants, either produced by specialised young plant raisers or farmers themselves, could provide an alternative. However, transplants are fragile and initially require more care including irrigation, as they are susceptible to drought. Hence, most smallholders in the East and Central African highlands as well as the West- and Southern African mid-altitude areas may continue to use tubers as starting material. Adoption of seedlings is more likely in the Sahelian zone, where seed tubers are hard to store during the hot period between the potato growing season, and the single source of quality seed is importation. Potatoes are grown during the dry Harmattan season using some form of irrigation. Hence, it makes the transition to seedlings easy and practically possible for all potato producers.

Potential benefits of HTPS for smallholders are threefold: improved access, improved quality, and reduced cost of quality potato seed. The cost reduction is expected as a result of the simplification of the seed potato chain from up to eight generations of multiplication to only two generations, the F1 hybrid true seed and the production of seed tubers from this true seed (Table 6.3). This will improve the seed health, as there is no seed-borne disease build-up possible over generations. It will reduce costs, as multipliers require fewer generations, which reduces storage losses, it reduces the required effort per kg of seed tubers, and the risk and working capital required. Transport costs will also be significantly reduced. Finally, it will be possible to decentralise the seed tuber production much easier, which can bring the seed tubers closer to the ware potato producers, making access to quality seed potatoes easier.

6.9 Seed policy and regulation

6.9.1 Current practices, constraints, and opportunities

When considering the enabling environment of the seed potato sector, there are four main topics: import regulation, variety registration and release, plant variety protection (PVP) and quality assurance (Ter Steeg *et al.*, 2022b). Import regulations are focused on the management of phytosanitary risks. Usually, a distinction is made between importation of research versus commercial material. Research material can be imported more easily, commercial material only when a variety is registered in the national variety catalogue. A certificate of disease testing from the exporting country is required, and additional post-entry quarantine or testing measures are sometimes required. These measures make seed potato export from Europe cumbersome and expensive.

Variety registration in many Sub-Saharan African countries is a (relatively) long process as NARS and national regulatory bodies require the assessment of variety performance for several seasons. Candidate varieties must pass a distinctness uniformity stability (DUS) test to get registered as a new variety. Some countries accept European DUS test reports, but most require local DUS testing. Next value for cultivation and use (VCU) tests are demanded for registration in national variety catalogues. Traditionally, much emphasis has been placed on genotype by environment interaction and yield, while less emphasis has been placed on meeting diverse market demands of producers, processors, and consumers. In the last decade, engagement of the international private sector has contributed to a gradual shift and appreciation of a diverse variety portfolio, allowing producers to choose and catering for different market demands.

Shorter variety registration process or complete abandonment of national variety trials are widely voiced desires in the international private sector. Burundi shows that speeding up procedures is feasible, as its variety testing and registration process have successfully been shortened to one year (or two seasons), through a collaborative effort of seed sector actors. Implementation of harmonised variety release protocols and variety catalogues of the Common Market for Eastern and Southern Africa (COMESA), the Economic Community of West African States (ECOWAS) and the Southern African Development Community (SADC), could further reduce regulatory barriers making more varieties available to farmers.

Variety registration is linked to PVP. In many countries in the region, PVP is either not regulated or implementation of regulations remains a challenge. PVP is of particular importance to international potato breeding companies because they want to protect their varieties. Contrary to single-use products like hybrid maize or vegetable seed, potato varieties can be multiplied vegetatively by farmers. Therefore, companies are careful when exporting tubers or other planting material to countries with a weak enabling environment.

Potato seed certification schemes offer quality assurance of seed potatoes. Certification procedures usually entail field inspections, tuber sampling and laboratory testing to ensure the quality of seed. Subsequently, seed potatoes are labelled as being of 'certified' quality. Seed potato certification is logistically cumbersome. Functional and trustworthy certification systems are still rare in the region. Only in a few countries, such as Zimbabwe and Burundi, the certification system is operational, and certificates offer a reasonable quality guarantee. Seed potatoes are inspected, tested in a laboratory, and labelled within a reasonable time. Kenya, Uganda, Rwanda and Ethiopia continue their efforts to improve the performance of the certification system. Considering the impact of the seed-borne disease bacterial wilt, a seed inspection system has to involve field inspections during the growing season, in combination with tuber sampling and laboratory testing, which requires decentralised inspectors and facilities (Gildemacher *et al.*, 2017) to assure timely delivery of the certificate. In some cases, testing labs are not operational making certification impossible. In other cases, the staffing might be insufficient to do field inspections.

6.9.2 Opportunities for hybrid true potato seed

Importation of HTPS poses a much lower phytosanitary risk as the seeds are not produced in soil. There are only six seed-borne viruses, which can be avoided when producing hybrid seeds under sterile conditions (Lindhout *et al.*, 2018). Hence, HTPS can likely be legally categorised and treated as vegetable seed rather than potato seed tubers. Vegetable seed is simply tested in the country of origin with additional checks via random sampling and quality testing, rather than requiring a full post-entry quarantine system. Initially, countries may require similar tests and procedures for HTPS and seed tubers because they apply the same policies to all potato starting material. However, it should be feasible to push for a more liberalised import procedure similar to the one applicable for vegetable seed.

HTPS variety registration is a matter of national and regional policy. On the one hand, it can be argued that 'diploid' HTPS varieties are somewhat comparable to conventional 'tetraploid' potato varieties. Hence, they can be subjected to the same variety registration requirements and tetraploid local checks can be used during VCU testing. On the other hand, diploid HTPS varieties can be grown from true seed and seedlings instead of seed tubers, and the type of starting material will impact the growth cycle and yield. It might be necessary to define distinct testing protocols and requirements for true seed, seedlings, and seed tubers. An important element is that variety registration takes into consideration the diversity of demands of the potato industry and also considers desired traits such as earliness, pest and disease resistances and processing qualities.

The quality assurance system for HTPS may be simplified and again, comparable to the system used for vegetable seed. In most countries, hybrid vegetable seed is commercialised using 'truthful labelling', rather than deployment of a full seed certification system. Truthful labelling requires the seed supplier to state the seed quality on the packaging and makes the supplier liable if seed does not meet the indicated quality standards. Hence, there is no need for independent field inspections and laboratory testing. Whenever seed tubers are grown from HTPS by specialised multipliers, seed certification would still be necessary. The quality assurance system process would then be comparable to vegetatively propagated seed potatoes. However, HTPS might be a good match for new decentralised systems like quality declared seed, which offer localised and cheaper alternatives for full certification.

6.10 Discussion

Seed potato systems in Sub-Saharan Africa differ from those in Europe. Farmers tend to save their own seed rather than sourcing seed potatoes from specialised multipliers on a regular basis. This decision to recycle seed makes sense considering the high price, low availability and uncertain quality of seed potatoes sold on the market. So far, the impact of attempts to develop formal seed potato systems and increase farmer adoption of quality seed have been limited. Nonetheless, improving the performance of potato seed systems remains and should remain a key priority as low-quality seed remains the single most important depressant of potato yields. Enhanced use of high-quality potato seed has tremendous potential to improve farm productivity and raise smallholder incomes.

There are several reasons for the limited success of previous potato seed sector interventions, which focus on imported seed tubers or rapid multiplication. The import model is difficult to launch in the absence of larger local farms, which can serve as partners of international potato seed companies. These companies seek to partner with one or few larger local multipliers to make their seed available on the local market. These partners are hard to find in areas suitable for potatoes, as these areas have a high population density, and sub-divided landholdings. Also, current variety portfolios of international commercial potato traders are not tailored to specific sub-Saharan African market demand, which makes that it is difficult to reach the mainstream market. Especially, short dormancy and late blight resistance are desired but underrepresented in private portfolios. Finally, several regulatory challenges exist blocking the importation of seed tubers because of phytosanitary risks and/or political reasons.

Launching the second model based on rapid multiplication also turns out to be difficult. It has been a struggle to establish functioning tissue-culture labs. It has proven even harder to establish for-profit labs making these operations commercially viable. The market for potato EGS is relatively limited, which does not make it an easily rendering investment. Kenya and Rwanda are exceptions having a more advanced system with private operators maintaining and rapidly multiplying *in vitro* plantlets and producing mini-tubers. In Kenya, a small but fully commercial EGS production chain exists, which operates in parallel to the public system. In other Sub-Saharan African countries, potato EGS production relies on inefficient production by public services.

HTPS technology could be the driver of potato sector development in Sub-Saharan Africa as it addresses some fundamental challenges of the conventional vegetative multiplication system. The land requirement for an HTPS based seed potato system is reduced, as fewer generations are needed. The constraint of EGS availability can be solved, as EGS can be produced centrally, in large quantities, with very high quality. HTPS can be distributed and stored easily, making a single highly localised multiplication into seed tubers possible. The quality of these locally produced seed tubers will be higher, and the costs are expected to be lower compared to the convention vegetative multiplication. Finally, breeding for specific demands is possible with diploid HTPS, offering a long-term perspective of varieties adapted to African smallholder potato farmer needs.

Despite these obvious advantages, HTPS will not be an instant success. The impact of HTPS in Sub-Saharan Africa will depend on a match with smallholder farmer needs and economics, which are based on principle of prudence and risk minimisation. It is likely that smallholder potato producers will prefer seed tubers over HTPS or seedlings. Seed tubers are much more robust in comparison to HTPS or seedlings. In the Sahelian zone, where irrigation of potato fields is already common, ware producers may be more likely to accept buying seedlings or producing seedlings themselves. Therefore, the main potato transformation would have to take place upstream in the value chain where specialised multipliers will play a crucial role converting HTPS and seedlings into familiar seed tubers. Furthermore, adoption will require HTPS varieties to match local preferences such as short dormancy, late-blight resistance and earliness. These varieties still need to be developed and made available at an affordable price.

HTPS has the potential to radically transform seed potato systems in sub-Saharan Africa and contribute to smallholder income and food security. Past interventions in the seed potato sector in Sub-Saharan Africa demonstrate that one cannot expect a new technology to be a self-multiplying success. In order to realise the potential impact of HTPS in sub-Saharan Africa, specific efforts are needed. Firstly, public-private partnerships are needed to breed varieties tailored to local demand and focusing in particular on smallholder farmers in the tropical lowlands. The current market is too small and risky to make tailored breeding commercially interesting for the private sector. Secondly, ware potato producers need training on the seed degeneration and the added value of quality seed, combined with good agricultural practices. Finally, a last-mile retailing system with quality assurance will present another challenge. Seed potatoes should be produced close to farms to reduce logistical challenges minimising effort and costs to purchase and transport the seed.

References

Audet-Bélanger, G., Thijssen, M.H., Gildemacher, P., Subedi, A., De Boef W.S. and Heemskerk, W., 2013. Seed value chain analysis. ISSD Technical Notes Issue no 3. Centre for Development Innovation, Wageningen UR, Wageningen & KIT Royal Tropical Institute, Amsterdam, the Netherlands.

Beumer, K. and Stemerding, D., 2021. A breeding consortium to realize the potential of hybrid diploid potato for food security. Nature Plants 7(12): 1530-1532.

Collins, A., Milbourne, D., Ramsay, L., Meyer, R., Chatot-Balandras, C., Oberhagemann, P., De Jong, W., Gebhardt, C., Bonnel, E. and Waugh, R., 1999. QTL for field resistance to late blight in potato are strongly correlated with maturity and vigour. Molecular Breeding 5: 387-398. https://doi.org/10.1023/A:1009601427062

Demo, P., Lemaga, B, Kakuhenzire, R., Schulz, S, Borus, D., Barker, I., Woldegiorgis, G., Parker, M. and Schulte-Geldermann, E., 2015. Strategies to improve seed potato quality and supply in Sub-Saharan Africa: experience from interventions in five countries. In: Low, J., Nyongesa, M., Quinn, S. and Parker, M. (eds) Potato and sweetpotato in Africa: transforming the value chains for food and nutrition security. CAB International, Wallingford, United Kingdom, pp. 155-167.

Gildemacher, P., Kleijn, W., Ndung'u, D., Kapran, I., Yogo, J., Laizer, R., Nimpagritse, D., Kadeoua, A., Karanja, D., Simbashizubwoba, C, Ntamavukiro, A., Niangado, O., Oyee, P., Chebet, A., Marandu, D., Minneboo, E., Gitu, G., Walsh, S. and Kugbei, S., 2017. Effective seed quality assurance; ISSD Africa synthesis paper. KIT Working Paper series 2017-2, KIT Royal Tropical Institute, Amsterdam, the Netherlands, 20 pp.

Gildemacher, P. and Belt, J., 2019. Potato sector development in Nigeria. Recommendations for policy and action. KIT Royal Tropical Institute, Amsterdam, the Netherlands, 34 pp.

Gildemacher, P., Kaguongo, W. Ortiz, O. Tesfaye, A., Woldegiorgis, G., Wagoire, W., Kakuhenzire, R., Kinyae, P., Nyongesa, M., Struik, P.C. and Leeuwis, C., 2009. Improving potato production in Kenya, Uganda and Ethiopia: a system diagnosis. Potato Research 52: 173-205. https://doi.org/10.1007/s11540-009-9127-4

Gildemacher, P.R., Leeuwis, C., Demo, P., Borus, D., Schulte-Geldermann, E., Kinyae, P., Mundia, P., Nyongesa, M. and Struik, P.C., 2012. Positive selection in seed potato production in Kenya as a case of successful research-led innovation. International Journal of Technology Management and Sustainable Development 11(1): 67-92.

Harahagazwe, D., Andrade-Piedra, J.L., Parker, M. and Schulte-Geldermann, E., 2018. Current situation of rapid multiplication techniques for early generation seed potato production in Sub-Saharan Africa. RTB Working Paper, CIP, Lima, Peru, 46 pp.

Kaguongo, W., Maingi, G., Rono, M. and Ochere, E., 2015. Potato market survey report. USAID-KAVES, Nairobi, Kenya, 56 pp.

Kaguongo, W., Gildemacher, P., Demo, P., Wagoire, W., Kinyae, P., Andrade, J., Forbes, G., Fuglie, K. and Thiele, G., 2008. Farmer practices and adoption of improved potato varieties in Kenya and Uganda. Social Sciences Working Paper 2008-5. International Potato Center (CIP), Lima, Peru, 85 pp.

Lindhout, P., De Vries, M., Ter Maat, M., Su, Y., Viquez-Zamora, M. and Van Heusden, S., 2018. Hybrid potato breeding for improved varieties. In: Wang-Pruski, G. (ed.) Achieving sustainable cultivation of potatoes. Volume 1, Breeding, nutritional and sensory quality. Burleigh Dodds Science Publishing, Cambridge, United Kingdom.

Lindhout, P., Meijer, D., Schotte, Hutten, R., Visser, R. and Van Eck, H., 2011. Towards F1 hybrid seed potato breeding. Potato Research 54: 301-312. https://doi.org/10.1007/s11540-011-9196-z

Mumia, B.I., Muthomi, J.W., Narla, R. D., Nyongesa, M.W. and Olubayo, F.M., 2018. Seed potato production practices and quality of farm saved seed potato in Kiambu and Nyandarua counties in Kenya. World Journal of Agricultural Research 6(1): 20-30. https://doi.org/10.12691/wjar-6-1-5

Schulte-Geldermann, E., Kakuhenzire, R., Sharma, K. and Parker, M., 2022. Revolutionizing early generation seed potato in East Africa. In: Thiele, G., Friedmann, M., Campos, H., Polar, V. and Bentley, J.W. (eds) Root, tuber and banana food system innovations. Springer, Cham, Switzerland, pp. 389-419.

Struik, P.C., 2007. Responses of the potato plant to temperature. In: Vreugdenhil, D., Bradshaw, J., Gebhardt, C., Govers, F., MacKerron, D.K.L., Taylor, M.A. and Ross, H. (eds) Potato biology and biotechnology: advances and perspectives. Elsevier, Amsterdam, the Netherlands, pp. 366-396. https://doi.org/10.1016/B978-044451018-1/50060-9

Su, Y., Viquez-Zamora, M., Den Uil, D., Sinnige, J., Kruyt, H., Vossen, J., Lindhout, P. and Van Heusden, S., 2019. Introgression of genes for resistance against *Phytophthora infestans* in diploid potato. American Journal of Potato Research 97: 33-42. https://doi.org/10.1007/s12230-019-09741-8

Svubure, O., Struik, P.C., Haverkort, A.J. and Steyn, J.M., 2016. A quantitative framework for evaluating the sustainability of Irish potato cropping systems after the Landmark Agrarian Reform in Zimbabwe. Outlook on Agriculture 45(1): 55-65. https://doi.org/10.5367/oa.2016.0228

Ter Steeg, E.M.S. and Lindhout, P., 2022. Maximizing impact of hybrid breeding. Prophyta Europe 10-13. Available at: https://www.prophyta.org/focus/ProphytaEurope2022.pdf.

Ter Steeg, E.M.S., Struik, P.C., Visser, R.G.F. and Lindhout, P., 2022b. Crucial factors for the feasibility of commercial hybrid breeding in food crops. Nature Plants 8: 463-473. https://doi.org/10.1038/s41477-022-01142-w

Ter Steeg, E.M.S., Weening, K. and Jacobs, J. 2022a. Potato seed sector development: 10 key lessons learned. SeedNL, Utrecht, the Netherlands.

Thomas-Sharma, S., Abdurahman, A., Ali, S., Andrade-Piedra, J.L., Bao, S., Charkowski, A.O., Crook, D., Kadian, M., Kromann, P., Struik, P.C., Torrance, L., Garrett, K.A. and Forbes, G.A., 2016. Seed degeneration in potato: the need for an integrated seed health strategy to mitigate the problem in developing countries. Plant Pathology 65: 3-16. https://doi.org/10.1111/ppa.12439

Ugonna, C.U., Jolaoso, M.O. and Onwualu, A.P., 2013. A technical appraisal of potato value chain in Nigeria. International Research Journal of Agricultural Science and Soil Science 3: 291-301. https://doi.org/10.14303/irjas.2013.084