Chapter 13
Revolutionizing Early Generation Seed Potato in East Africa

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Abstract Poor access to healthy, high-yielding planting materials hampers potato production in East and Central Africa (ECA). The need to improve the quality and increase the quantity of seed potato available to farmers has been the basis of previous efforts in the subregion. One bottleneck in the seed value chain is the low quantity of early generation seed (EGS) for further multiplication. To break this bottleneck, the International Potato Center (CIP) and local partners introduced two rapid multiplication technologies (aeroponics and rooted apical cuttings) and an improved conventional system (sand hydroponics). These three technologies differ in terms of multiplication rates, investment costs, profitability, required skills, infrastructure, risks, and linkages to the rest of the seed value chain, with its actors, policy environment, plus supply, and demand. The three introduced technologies have helped to increase the supply of certified or high-quality seed in the region over the last decade. However, for successful scaling, the technologies have to be carefully selected based on their situation and their natural and economic environments.

13.1 Introduction

Improved potato production in sub-Saharan Africa can be a pathway out of poverty. The potato grows quickly, is high-yielding, and makes more efficient use of water than do many other food crops. The potato also makes fairly efficient use of capital, making it a smallholder cash crop of the future for the densely populated East and

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Central African highlands, with a high potential of improving livelihoods. The potato is also grown by women in East Africa, although female farmers often face barriers to obtaining land, capital, and seed (Mudege and Demo 2016).

13.1.1 Status of Seed Systems in East Africa

Potato yields are relatively low in the tropical highlands of East and Central Africa, stagnating at around 10 tons per ha for the past decades (FAOSTAT 2020). Increase in production has been achieved by area expansion rather than by productivity. The low yields have largely been attributed to increasing incidences of pests and diseases, particularly late blight, bacterial wilt, nematodes, and viruses, most of which are seed-borne. There is an inadequate supply of clean (healthy) seed, and farmers have poor access to quality seed and to improved varieties, contributing to a huge yield gap (Gildemacher et al. 2009; Harahagazwe et al. 2018b; Schulte-Geldermann et al. 2013; Thomas-Sharma et al. 2017).

Formal seed systems involve specialized activities of the seed value chain governed by an official regulatory environment, which is weak in many countries of East and Central Africa. The lack of high-quality, inexpensive, early generation seed (EGS) remains a major bottleneck in the seed supply chain (Muthoni and Kabira 2014; Negash 2014; Thiele et al. 2011). In the target region, only about 0.1–3% of the seed potatoes used are certified (Ferrari et al. 2017; Kaguongo et al. 2014). In the region, Kenya has the most advanced seed system with an established certification scheme. However, despite a great increase in the supply of certified seed over the last decade (430 tons in 2009 vs. 10,600 tons in 2018) production still only reached a third of the actual demand for certified seed which is estimated at around 10% of the total area planted (National Potato Council of Kenya 2018).

In East and Central Africa semiformal and informal seed systems provide more than 90% of the seed used; they follow various exchange and dissemination patterns. The semiformal seed system in Kenya, referred to as the "clean seed system," uses an onward multiplication of certified seed for one to three seasons by locally recognized informal seed producers, who usually have bigger farms than the average smallholder farmer has and produce an estimated 2–5% of the seed potato supply (Kaguongo et al. 2014). This seed has not been tested, but it is likely to be healthier than farm-saved planting material or other sources from the informal market. However, most smallholders use seed from their own farms, from neighbors, from local markets, or from ware potato traders. These traders drive varietal change as they distribute small ware potatoes of market-demanded varieties as seed to farm communities (Gildemacher et al. 2009; Kaguongo et al. 2014).

Hence the formal seed systems are still not able to meet the estimated demands, and smallholder farmers have poor access to quality seed. Low yields impede profitable farming and confine smallholders to semi-subsistence agriculture (Okello et al. 2017), limiting small farm sector development and entrenching food insecurity and poverty.

Projects intended to improve seed potato systems have been an important component of agricultural development in East Africa for several decades with limited success. Top-down approaches failed because they focused too narrowly on technology, without adequately considering local circumstances and demands (Almekinders et al. 2019a, 2019b; Ferrari et al. 2017). Seed is still a priority for agricultural interventions, with projects of different shapes and scales aiming to increase seed security, food and nutritional security, and agricultural productivity or to reduce poverty. Most interventions strive to make quality seeds and improved varieties more available to farmers. The high cost of quality seed is a bottleneck (Okello et al. 2018). Certified seed is about three times the price of ware potato and would account for up to 60% of the total variable production costs, limiting its use by smallholders.

13.1.2 Enhancing the Supply of Early Generation Seed (EGS)

The supply of affordable, high-quality seed can be increased by improving the efficiency in EGS production, by introducing rapid multiplication technologies (RMTs) and improved conventional technologies. New RMTs must consider the limited resources of the target countries, the local seed sector potential, and the seed customers (ware potato farmers). Multiplying seed in fewer generations reduces the risk of acquiring degenerative diseases, mainly viral and bacterial. Two RMTs, aeroponics and rooted apical cuttings, and an improved conventional system (sand hydroponics) have been introduced to public and private sector seed producers in order to increase early generation seed production. The technologies were selected and designed specifically for these enterprises and validated and improved during development.

Additional reasons for introducing the improved EGS technologies were (i) the faster introduction of new varieties, giving farmers quicker access to genetic gains, (ii) the quicker revitalization of popular varieties and lost seed stocks from a limited number of healthy propagules, and (iii) fast bulking of foreign germplasm and the introduction of varieties into other regions or countries (Struik and Wiersema 1999). Besides improving seed health, removing the bottleneck of poor access to genetic gains has been another major reason for promoting technologies that increase the capacity to produce EGS, to give smallholder farmers faster access to varieties that tolerate abiotic and biotic stresses (Parker et al. 2019; Thiele et al. 2020).

However, a remaining challenge for large-scale uptake is the poor linkages between the formal and the informal seed systems, which would allow for a dynamic increase in supply and demand. Thomas-Sharma et al. (2017) and Forbes et al. (2020) suggest linking the intervention with a more integrative on-farm seed quality improvement strategy. Such a strategy should help farmers manage their own seed stocks, while accessing a regular supply of high-quality seed, which would rely on EGS.

Increased EGS production would reduce the land required for seed multiplication. The region has relatively high pressure of soil- and seed-borne diseases, hence limited land suitable for seed multiplication. More disease-free seed can also be produced by reducing the number of field generations from five to seven to two to four through rapid EGS multiplication. However, producing quality seed requires a set of different skills at various levels, from planning and management of seed production to farm operations, including postharvest handling. Early generation seed production also requires highly skilled technical staff and significant capital investment, which was a constant bottleneck with previous public sector initiatives. Attracting local private investment in RMTs while strengthening the capacity of the public sector and generating efficient public-private partnership (PPP) models has been a way to break the seed bottleneck.

This chapter describes the success and limitations from experiences with three EGS multiplication technologies (aeroponics, sand hydroponics, and rooted apical cuttings), which have been introduced and promoted in East and Central Africa.

13.2 Suitable Technologies for Early Generation Seed Potato Production

The potato seed value chain begins with clean (disease-free) micro-plants that are first reproduced in test tubes by micro-propagation. These micro-plants are then transplanted in a greenhouse or screenhouse to produce the first generation of tubers, called “breeder” or “early generation seed” (EGS). The second and third generations (“foundation” seed) are propagated in carefully selected, disease-free fields. Until recently, certified seed was produced by another two to four field multiplication rounds. This procedure is long, has relatively low multiplication rates of seed potato, and is based on producing EGS with conventional pot-substrate technologies.

Several interventions in sub-Saharan Africa aimed to produce EGS faster with adapted RMTs. Many RMTs exist, but the most common in developing countries are micro-propagation (plantlets and micro-tubers), cuttings (single-node, tuber sprout, axillary, leaf-bud, apical), aeroponics, and hydroponics.

Micro-propagation has been used in developing countries since 1980s (Dodds 1988; Naik and Karihaloo 2007). In vitro techniques allow many micro-tubers to be produced per plantlet, but they have a longer dormancy period than normal tubers. They must also be planted in greenhouses or in net houses. Micro-tubers also suffer from high storage losses, and they may not be suitable for certain climates (Naik and Karihaloo 2007). The vitality of seed tubers from micro-propagated potato plants can be enhanced by producing mini-tubers, which are less delicate and can be directly planted in open fields or in net houses (Wiersema et al. 1987). However, plantlets usually produce fewer than ten mini-tubers (Ritter et al. 2001; Singh et al. 2010). More mini-tubers per plantlet can be produced by repeated tuber harvesting where potato plants are carefully lifted from the soil and replanted after removing tubers above a critical size (Ritter et al. 2001). This technique however is labor-intensive, disrupts plant growth, and may cause early plant senescence, often resulting in few tubers per plantlet.

Potato mini-tuber production from in vitro propagated plantlets permits faster multiplication of seed potato than conventional methods and reduces the number of generations of open field bulking (Farran and Mingo-Castel 2006). However, there is a need to improve the multiplication rates further, especially in the tropical highlands where previous seed potato production technologies have done little to improve the quantity of affordable, quality seed for resource-poor farmers.

In recent decades, soil-less technologies have been developed to produce mini-tubers in controlled environments to increase the multiplication rate through repeated mini-tuber harvesting. Such technologies include hydroponics (Muro et al. 1997; Tibbitts and Cao 1994) and aeroponics (Chang et al. 2008; Farran and Mingo-Castel 2006). Other technologies such as rooted cuttings from apical shoots (Van Minh et al. 1990) and improved conventional systems such as sand hydroponics have been developed and validated in particular for low-middle-income countries.

In cooperation with local partners, the International Potato Center (CIP) introduced and validated the EGS potato technologies in the target region: aeroponics in 2008, sand hydroponics in 2012 and rooted apical cuttings in 2016.

13.2.1 Aeroponic Technology

Aeroponics is a method of growing crops, particularly vegetables, in an air-nutrient mixture without soil or any other porous medium. Aeroponics has been adapted to produce large quantities of potato mini-tubers (Otazú 2010) in South Korea, China, Africa, Spain, and Latin America. The technology started with sophisticated equipment and relatively low yields Farran and Mingo-Castel 2006; Ritter et al. 2001; Soffer and Burger 1988), but after 2006, CIP had improved the yields and adapted aeroponics for developing countries (Otazú and Chuquillanqui 2008).

In aeroponics, plant roots are grown suspended in a dark box that is closed or semi-closed. Roots are sprayed with a nutrient-rich solution (Otazú 2010; Singh et al. 2010). The nutrients and improved aeration improve the growth of the root system (Farran and Mingo-Castel 2006; Otazú 2010) (Fig. 13.1).

The investment in the aeroponic units in African countries became possible by 2008, thanks to the support of the US Agency for International Development (USAID), German Agency for International Cooperation (GiZ), Irish Aid, and others. The technology was crucial for the successful Three Generation (3G) project in three sub-Saharan countries and for the release and dissemination of new late blight-resistant varieties in Kenya (Landeo et al. 2009). However, the technology requires training, electricity, an adequate greenhouse, a safe source of water, and robust in vitro plants.

Fig. 13.1 Aeroponic boxes with potato plants (left) and tuber production in boxes (right) at Kevian Farm ltd. in Kenya. (Photo credits M.L. Parker)

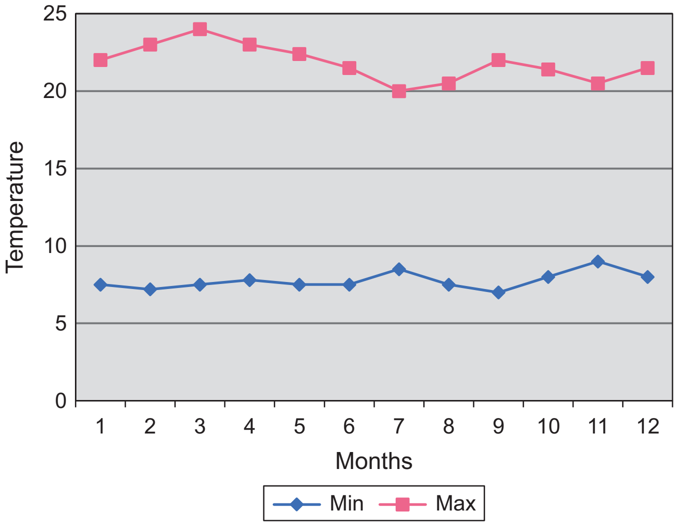

Fig. 13.2 Stable temperatures in Nyahururu, Kenya (2300 masl), permit year-round potato seed production by aeroponics

When the weather is too warm, plants grow foliage but few tubers. In cold weather, plants are low yielding. Temperature can be artificially controlled, but this increases production costs. In a few places, aeroponics can perform well all year, as in Nyahururu, Kenya (Fig. 13.2), where stable temperatures allow year-round production.

In some places, even though adequate greenhouses were built, frequent interior temperatures of over 30 °C for more than 4 hours caused setbacks, including pathogen proliferation. Greenhouses at higher elevations, above 2200 masl, produced more tubers (Schulte-Geldermann 2013; Demo et al. 2015; Atieno and Schulte-Geldermann 2016; Kakuhenzire et al. 2017,Sharma and Atieno 2020). Temperatures can also be regulated with low-cost methods such as shade, ventilation, and production during the cooler months.

In aeroponics, harvesting can last up to 5 months, creating uneven sprouting. At the end of the season, the mini-tubers are not of uniform dormancy or physiological age. Planting mini-tubers with large differences in physiological age results in crops with large variations in important yield parameters such as date of emergence, stem numbers, canopy growth pattern, maturity date, total yield, and tuber size distribution. This can cut yields in half (Lung'aho et al. 2013) and make mini-tuber production unprofitable. This can be managed with plant growth regulators (PGR) (Tsegaw 2006; Van Ittersum and Scholte 1993). Aeroponics requires judicious management to ensure that mini-tubers are in the correct physiological stage at the time of planting.

Aeroponics requires proper training over at least one season. The best learning experience involves the trainees in building the modules, followed by lectures. This worked well, except in places with a rapid staff turnover. In many cases, new personnel were not trained appropriately, which put several units at risk. The in vitro plantlet to mini-tuber multiplication rates of the aeroponic units differed largely by environmental, management, and genotypes (varieties) between 1:20 and 1:70 (Kakuhenzire et al. 2015; Atieno and Schulte-Geldermann 2016; Kakuhenzire et al. 2017, Muthoni et al. 2017; Harahagazwe et al. 2018a, b

Profitability of aeroponics Labarta (2013) compared the profitability of three mini-tuber production systems: (1) conventional pot system, (2) aeroponics with a regular power supply and a backup generator, and (3) aeroponics using a solar power supply and a backup generator. All of them produced mini-tubers of the same quality, but they had different levels of investment, variable costs, and multiplication rates of mini-tubers. Aeroponics reduced the unit cost of each mini-tuber from 0.60 USD to 0.10 or 0.12 USD. All three techniques require a high initial investment (Table 13.1).

The calculation in Table 13.1 presents the level of investment required and assumed that each technology last for ten seasons (5 years). The variable cost include the cost of plantlets, substrates, nutrients, water, electricity, labor, and soil sterilization where needed.

Table 13.1 Profitability of mini-tuber production under three different production schemes (in USD)

	Conventional pot	Aeroponics with backup generator	Aeroponics with solar power and backup generator
Initial investment	31,053	27,310	32,841
Variable cost (season)	3146	1220	1315
Discounted total cost	57,288	37,482	43,809
Mini-tuber per plantlet	7	26.4	26.4
Unit cost per mini-tuber	0.60	0.10	0.12

Source: Labarta (2013)

All of them produced mini-tubers of the same quality but using different levels of investment and variable cost and showing different multiplication rates of mini-tubers. For the profitability analysis, we use the average multiplication rate found for the base conventional pot system (seven mini-tubers per plantlet) and for both aeroponic systems (26.4 mini-tubers per plantlet).

In the public sector, where conventional pot mini-tuber production is dominant, the initial investment is often not accounted in the production cost, and they can barely cover the variable cost that is highly driven by the cost of sterilizing the soil (Labarta 2013).

13.2.2 Rooted Apical Cuttings Technology

Rapidly growing young vegetative tissue of potato can be cut and rooted in a number of ways (Bryan et al. 1981). Rooted apical cuttings have long been used in SE Asia (Vander Zaag and Escobar 1990), particularly in Vietnam (Van Minh et al. 1990). This technique is being introduced into sub-Saharan Africa to provide a simple, effective technique for multiplying early generation seed as alternative to mini-tubers (Parker 2019).With rooted apical cutting (RAC) technology; seedlings are produced vegetatively, with cuttings taken from plantlets in the screenhouse every two to three weeks (Fig. 13.3). The cuttings are planted into plugs for rooting with a substrate of coconut sawdust, clean subsoil, and sterilized decomposed manure. After 6 weeks, the cuttings are fully rooted, and they are transplanted to the field. Rooted apical cuttings are transplanted right away in the field, thereby saving one generation, as mini-tubers are no longer needed (Parker 2019). The cuttings can also be placed in flower boxes, but they must be planted within 24 hours or kept in a protected location until planting. However, mini-tubers are more versatile; they can be stored until ready to plant and are easy to transport.

Fig. 13.3 Rooted apical cutting production in a screenhouse at Stokman Rozen Ltd., Naivasha, Kenya (left), and harvested tubers derived from RAC field multiplication (right). (Photo credits: Benson Kisinga and Monica L. Parker)

Rooted apical cuttings have high multiplication rates after only 5 months in the screenhouse. Investment costs are lower than for aeroponics. Electricity is needed only for the tissue culture lab. There is no need to break tuber dormancy, and no storage facility is required. This makes seed potato available to farmers one season sooner.

A manual by Nyawade and Parker (2020) describes this technique in detail for any size of farm. Integrating cuttings in seed systems greatly expands opportunities in seed businesses of any scale (e.g., small and medium enterprises, youth groups, farmer groups, entrepreneurial farmers) at different points along the seed production chain. Cuttings are penetrating the seed system, and the opportunities they present are in validation in Kenya and Uganda to scale out the technology through diversified partnership models and uses.

13.2.3 Sand Hydroponic Technology

Unlike aeroponics and rooted apical cuttings, which are new technologies, sand hydroponics is an improved conventional technique that lowers the cost of quality EGS. Sand hydroponics is relatively easy to handle, and it costs less than conventional multiplication technologies. Sand hydroponics uses a greenhouse with wooden boxes, plastic pots, polythene bags filled with sterilized river sand, and growing plants (Naik and Karihaloo 2007). This new hydroponic system is independent from electricity. The system uses gravity to distribute the nutrients dissolved in water, and sand replaces the conventional substrate. It combines the principles of hydroponics and fertigation (chemical fertilizer dissolved in irrigation water) (Fig. 13.4).

Fig. 13.4 Potato seed multiplication using sand hydroponics in pots, Holeta, Ethiopia

Sand hydroponics is an open (run-to-waste) system in which the nutrient solution is not recycled, greatly reducing the likelihood of diseases (unlike aeroponics where a disease can spread quickly in recycled nutrient media). Besides wooden beds, sand hydroponics can work with any available container. Sand hydroponics is a versatile technology, and existing resources can be adapted for seed potato multiplication.

Substrate must be sterilized to kill the pathogens that can cause plant disease. This requires an expensive boiler and fuel. If the substrate does not get hot enough, diseases may occur. If the substrate is overcooked, toxic manganese may be released and damage the plants. In the conventional system, the substrate is made of mixtures of peat moss, compost, dark soil, and sand. Some of these are hard to obtain and expensive. However, with sand hydroponics, the sand is sterilized with ordinary sodium hypochlorite bleach, so sterilization is easier, and cheaper without the risk of toxic releases. Before planting, sand is treated with boiling water to eliminate pathogens. Bleach is affordable and efficient as disinfectant, and it can also be used to treat sand (Otazú 2008). Sand can be reused several times, but after each harvest, it must be cleaned of any plant debris, root pieces, and mini-tubers to avoid pathogen buildup.

Unlike some soils, sand allows the free expansion of tubers for good tuber formation. Other than the aeroponic units, the system does not require electricity and can be managed by relatively unskilled workers, because water and nutrients flow by gravity.

Aeroponics can produce some mini-tubers that are too small (under 5 g) to plant in the field, and seed multipliers are reluctant to use them. Sand hydroponics produces bigger mini-tubers and slightly more than in conventional pots (11 vs. 8.9), which also helps to reduce seed costs (Mbiri et al. 2015). Sand hydroponics is a good technology for places where electricity, trained staff, and investment capital are limited.

13.3 Strengths and Weaknesses of Introduced EGS Production Technologies

The introduction of EGS multiplication technologies into sub-Saharan Africa has been successful, but no technology is suitable for all conditions. Nevertheless, all three technologies when operated properly, in the right environment, have helped to increase early generation seed production (Sect. 13.5). The rooted apical cutting technology produces certified seed in less time. Up to generation four, its multiplication rate up is about 20 times faster than with conventional seed production and about three times faster than with aeroponics (Table 13.2).

Each technology has its strengths and weaknesses, so some may be more suitable for certain natural or social environments (Table 13.3). It is important to choose the right technologies for each business type and to develop a business plan which

Table 13.2 Certified seed production cycle by various potato EGS technologies

	Screenhouse production (G1)		Breeder seed (G2)	Foundation seed (G3)		Certified 1 seed (G4)	
	per in vitro plant	Months	# seed tubers	# seed tubers[a]	Months	# seed tubers[a]	Months
Rooted apical cuttings	120 rooted cuttings	5	1080[b]	10,800	17	108,000 [3]	23
Aeroponics	35 mini-tubers	8	280[c]	2800	20	28,000	26
Sand hydroponics	10 mini-tubers	8	80[c]	800	20	8000	26
Conventional	8 mini-tubers	8	64[c]	640	20	6400	26

[a]Assumed multiplication rate of 10
[b]Assumed multiplication rate of 12 at 75% of survival
[c]Assumed multiplication rate of 8

Table 13.3 Strengths and weaknesses of EGS potato production technologies

Technology	Strengths	Weaknesses
Aeroponics	Effective RMT with high multiplication rates of 1:20–80 Needs fewer generations of seed potato multiplication in the field, lowering costs Seed can be harvested at seed size (from 5 to 30 grams) since the fertilizing sprays that are applied to the roots allow the plant to grow without interrupting its vegetative cycle of up to 180 days Costs are about one-quarter those of a conventionally grown tuber Requires much less water and fertilizer than conventional systems, minimizing fertilizer residues seeping into ground water Excellent circulation of air, which strengthens the roots Uses less greenhouse space Attracts private sector engagement	High investment Requires uninterrupted power supply Consumables and equipment are often unavailable on the local market Lack of synchronization of aeroponic production with downstream activities due to sequential harvests (normally every 2 weeks) Small and fragile mini-tubers require cold storage facility Requires well-trained staff Risks of contamination within the boxes, causing plant health problems Sensitive to high temperatures Difficult to clean properly inside the boxes Leakages of nutrients in system raise production costs Metal equipment causes rust within the boxes Long growth cycles, which normally end with less productive periods

(continued)

Table 13.3 (continued)

Technology	Strengths	Weaknesses
Sand hydroponics	Mini-tubers of high quality and larger than with conventional and aeroponic technologies No need for expensive substrate steaming or boiling Easy to establish and run Substrate can be recycled Suitable for resource-poor settings	Difficulty to determine the optimal nutrient use efficiency Sand disinfestation requires a lot of clean water to wash out the sterilization agent Labor-intensive when pots are used Yield lower than with RMTs Nutrients and equipment are often unavailable on the local market
Rooted apical cuttings	High multiplication rates (cuttings) High field multiplication rates (1:12–18) Not dependent on electricity First field-grown seed produced in one season less than with other technologies Stable production across varieties Doesn't require cold storage Fast dissemination of new varieties Attracts private sector investment Excellent opportunity for diversifying business operations of existing tissue culture labs	Cuttings cannot be stored Sensitive to cold temperatures Output market is difficult to create and manage due to cutting harvests carried out over time Labor-intensive Bulky for transport from greenhouses to farmers' fields Needs irrigation when transplanted in the field
Conventional pot system	Easy to manage with stable yield in mini-tubers (backup technique when conditions for RMTs are not optimal) Acceptable tuber size and high survival rates when planted	Low mini-tuber per plantlet ratio High requirement of greenhouse space Risk of contaminations with soil-borne diseases Substrate expensive and not recycled High cost of substrate sterilization Labor-intensive

Source: adapted from Harahagazwe et al. (2018a)

includes further multiplication steps and the point of sale. Decision support tools such as the risk assessment framework for investments in aeroponics (Andrade-Piedra et al. 2019) are useful for choosing the right technology. The potato varieties, staff, funding, and the possibility of using existing buildings and resources should be considered on an individual basis before investing. The seed producer should anticipate seed multiplication efficiency in order to assess the cost of goods sold (COGS) as well as the demand from seed customers (farmers) for specific varieties.

13.4 Scaling Up Improved Early Generation Multiplication Technologies

Producing quality seed requires different skills at various levels, from planning and management of seed production, through to farm operations, including postharvest handling. This is particularly true when introducing these early generation seed innovations. Aeroponics and rooted apical cuttings require skilled technical staff and high capital investment, which are usually limited in national programs. Improving infrastructure and capacity for high-grade seed production is resource- and knowledge-intensive. It requires investments in facilities, equipment, and inputs, which is risky because of the uncertainty about market size. Technical support is essential at the start of seed enterprises. But the private sector is increasingly realizing the market potential for seed potato and has begun to invest in seed production.

13.4.1 Partnerships for the Innovation: Engaging Local, Private Enterprises in the Seed Potato Business

A major thrust of the interventions was to attract private sector engagement in early generation seed, as in most countries EGS potato was solely produced by the public sector. These partnerships were established for the first time during the project "Tackling the Food Price Crisis in Eastern and Central Africa with the Humble Potato: Enhanced Productivity and Uptake through the '3G' Revolution." The USAID-funded project (generally referred to as "3G") was implemented in Kenya, Rwanda, and Uganda from 1 October 2008 to 30 June 2011. The strategy involved delivering low-cost, quality seed to growers in three generations of field multiplication, rather than the conventional five to seven generations (hence "3G" for three generations). The 3G seed strategy envisaged producing many mini-tubers through one generation of a rapid multiplication technology, thus allowing bulking of sufficient seed in fewer field generations. This reduced both the cost of production and prevented the buildup of diseases in the field (Atieno and Schulte-Geldermann 2016).

CIP worked with several private companies and public organizations to deliver seed of improved varieties to smallholder farmers. Large-scale private farms were attracted to produce quality seed through a 50:50 cost sharing for constructing aeroponic facilities and by linking them to markets. CIP advertised through the local media for private sector companies interested in producing breeder seed. CIP supplied in vitro plantlets to the companies and offered technical support to produce mini-tubers. The private companies produced the mini-tubers using both the traditional soil-based method and aeroponics. Kenya Plant Health Inspectorate Service (KEPHIS), the authority responsible for seed certification, ensured the inspection of the seed for pests and diseases.

While supporting the private sector's production of early generation seed, the interventions continued to increase the capacity of national agricultural research institutes, which still played a vital role in producing EGS. In the early stages of establishing a seed potato system, the national programs provided a base to private enterprises and assured them of business opportunities in seed production.

Crucially, the project helped private and public enterprises develop business plans to select the most appropriate and cost-effective RMTs (aeroponics, rooted stem cuttings, sand hydroponics, or other improved conventional systems) for producing mini-tubers (G1). The project funded a cost-share scheme to support capital investments in screenhouses and equipment for producing mini-tubers. Backstopping of seed producers focused on creating awareness of emerging pathogens, adherence to the plant health standards, and improving working relations with the regulatory body. The project trained entrepreneurs and farmers in seed quality management, seed use and storage, and accessing new varieties in order to contribute to the uptake of new varieties and improved practices.

13.4.2 Quality Control: Enable Seed Quality Control and Disease-Monitoring Schemes

One bottleneck was quality assurance and the certification system, which are vital to develop a seed system based on guaranteed quality standards, and of equal importance for seed producers and users. A formal seed quality control system generally involves seed certification by national regulatory agencies; however, many African countries either do not have such systems, or they are not implemented. Of the target countries, only Kenya has an established and functional certification scheme, mandated to KEPHIS. But recent massive increases in seed production are taxing KEPHIS's ability to implement timely, customer-friendly services, because its human capacity is limited, and its inspection technologies and schemes are outdated. Despite its problems, Kenya's quality control is still far ahead of the other countries in the region, where the National Agricultural Research Systems (NARS) are basically testing the seed they produce and only to a certain level. This discourages specialized private investment in quality seed production, as buyers doubt the product's quality.

To strengthen formal seed certification schemes, it is vital to develop and introduce easy-to-use and affordable technologies for rapid, low-cost quality control or better seed health assessments. Examples include pocket diagnostics such as lateral flow devices, heel-end coring devices for rapid disease detection, and molecular methods based on polymerase chain reaction for confirmation tests (i.e., LAMP assay). In Rwanda, Malawi, Tanzania, and Uganda, where formal seed certification schemes for seed are in the planning stages, technical support and training in new methods will be critical. Standards for seed quality such as defined thresholds for degenerative seed-borne diseases need to be aligned to local conditions. Though time-consuming, a strategy that involves constant stakeholder reviews has been the most useful way to improve the quality and quantity of certified seed. An alternative semiformal quality control system named Quality Declared Planting Material (FAO 2010), based on visual inspections, has been introduced to countries like Ethiopia, Malawi, Rwanda, Tanzania, and Uganda where formal certification systems are not operational.

In both Kenya and Uganda, rooted apical cuttings have been included into the national seed certification protocol for potato. In both countries RACs are classified as breeders' seed (stock seed) in the same category as mini-tubers.

13.4.3 Stimulating Demand for Potato Seed and Making It More Accessible to Smallholders

The demand for high-quality seed is key for attracting investment in early generation seed and for developing a vital seed sector. Most potato farmers are smallholders with limited cash. As seed is a large investment, most farmers save their own seed or access it from other local sources. The accessibility of certified seed is also limited because it is often produced in regions with poor roads and because a 1-hectare potato field requires about 2 tons of seed tubers, which are perishable and may be lost. For these reasons, certified seed has little penetration into the local seed system (Gildemacher et al. 2009). Recycling farm-saved seed potato leads to a decline in productivity due to seed degeneration (Gildemacher et al. 2009; Schulte-Geldermann et al. 2013). In order to provide smallholder farmers with better seed sources, CIP and partners investigated the efficacy of establishing a network of decentralized seed multipliers to increase the supply and reduce the price of seed. However, there was not enough clean land suitable for producing healthy seed tubers. These difficulties have been reported in Ethiopia and Kenya, where bacterial wilt and potato cyst nematodes (the latter only in Kenya) have been widely distributed by local seed multipliers (Abdurahman et al. 2017; Mburu et al. 2020). Even though seed from local multipliers outperformed the farm-saved seed significantly, the risk of spreading pests and diseases throughout the seed system has to be considered (Andersen et al. 2019).

Another option is to advise farmers to invest in certified seed for a smaller area of their farm, in combination with improved management (Thomas-Sharma et al. 2016). To curb seed degeneration and lower the cost of certified seed, farmers can buy small amounts of certified seed and bulk it themselves using on-farm seed selection and management. One study showed that with little investment in high-quality certified seed, farmers were able to more than double their yields in only 1 year. After the first year, participating farmers continued to source small amounts of certified seed. However, in some cases local availability remained an issue (Ochieng 2021).

Local extension services increased awareness with on-farm demonstration trials. CIP's USAID-funded 3G and Better Potato for a Better Life projects distributed massive amounts of certified seed to smallholders, including new, farmer- and market-preferred varieties in affordable, low-risk units (5 to 25 kg bags). Other strategies to improve accessibility included seed banks (based on commodity loan systems), seed fairs, input loans (e.g., in Kenya, Equity Bank and Kenyan Women Finance Trust), input insurance systems (e.g., Kilimo Salama by the Syngenta Foundation for Sustainable Agriculture), and strengthening seed value chain linkages with contract farming. In Kenya an information and communication technology (ICT)-based information portal, Viazi Soko ("potato market"), was set up and is maintained by the National Potato Council of Kenya, which includes detailed information on the traits and availability of seed varieties. Other activities generated knowledge about and linkages to seed distribution channels.

13.4.4 Scaling Strategy and Key Partnerships for Scaling

Successful scaling requires assessing institutional arrangements, the business environment and capacities of the public and private sectors, the natural environment, supply and demand, and the general enabling environment for the comparative advantage of the innovation. Scaling-improved EGS technologies depend on tissue culture labs and tissue culture material of the varieties to be produced. Nurseries or seed multipliers must be identified who are willing to invest in producing cuttings or mini-tubers. Markets must be developed by raising awareness among seed customers. Regulatory authorities must be engaged to ensure that seed produced from cuttings and mini-tubers from aeroponics is eligible for certification.

Critical Bottleneck for Further Scaling of Rooted Apical Cuttings
Nurseries must be close to potato producing areas. Technical backstopping is a further bottleneck because few of nursery operators know how to produce apical cuttings.

Critical Bottleneck for Further Scaling of Aeroponics
Aeroponics also faces a high risk for failure if conditions are not favorable and the capacities are inadequate (Atieno and Schulte-Geldermann 2016; Kakuhenzire et al. 2017). CIP developed a risk analysis tool based on the lessons learned from previous interventions. This tool provides a total score by weighing different factors according to their impact on performance of aeroponics and applying scores from 1 (very good) to 4 (poor). With total scores ranging between 21 and 30, aeroponics should operate with no major problems. From 31 to 40, aeroponics can be implemented with caution, and with scores of over 40, aeroponics is likely to fail. Table 13.4 summarizes an assessment conducted in 2013 by Otazu and Schulte-Geldermann (unpublished; method described in Andrade-Piedra et al. 2019).

Table 13.4 Risk analysis performance in selected sites where aeroponics is operating (green = no major problems, yellow = implement with caution, red = likely to fail)

Location*	Electricity	Water	Climate	Facility	Plants	Training	Total score
Tigoni, KE	5 × 3 = 15	3 × 1 = 3	4 × 2 = 8	3 × 1 = 3	3 × 1 = 3	3 × 2 = 6	38
Kisima, KE	5 × 1 = 5	3 × 1 = 3	4 × 1 = 4	3 × 1 = 3	3 × 2 = 6	3 × 2 = 6	27
Molo, KE	5 × 1 = 5	3 × 1 = 3	4 × 1 = 4	3 × 1 = 3	3 × 2 = 6	3 × 3 = 9	30
Nairobi, KE	5 × 1 = 5	3 × 1 = 3	4 × 3 = 12	3 × 2 = 6	3 × 1 = 3	3 × 1 = 3	32
Holeta, ET	5 × 5 = 25	3 × 1 = 3	4 × 2 = 8	3 × 1 = 3	3 × 1 = 3	3 × 1 = 3	43
Mbeya, TZ	5 × 3 = 15	3 × 3 = 9	4 × 2 = 8	3 × 3 = 9	3 × 2 = 6	3 × 2 = 6	53
Gisozi, BU	5 × 3 = 10	3 × 1 = 3	4 × 1 = 4	3 × 1 = 3	3 × 2 = 6	3 × 4 = 12	38
Lichinga, MZ	5 × 3 = 15	3 × 2 = 6	4 × 2 = 8	3 × 1 = 3	3 × 1 = 3	3 × 2 = 6	41

[a]KE Kenya, ET Ethiopia, TZ Tanzania, BU Burundi, MZ Mozambique

This assessment indicated that locations with poor electricity service are most likely to fail or get low numbers of mini-tubers. Frequent power cuts of more than 2 hours are a major limiting factor for scaling the technology. The cost for running a backup generator would greatly increase the cost of mini-tuber production.

Climate is difficult to change. Other factors are more within immediate human control. For instance, in Tanzania, a new dependable backup generator with an automatic starting up system was installed after the assessment. Improved management and facilities might change a risky operation to one that could operate with caution.

13.4.5 Example for a Scaling Approach of Rooted Apical Cuttings and Robust Varieties of Potato in Uganda

As mentioned above, rooted apical cuttings have been successfully implemented in Kenya staring from a small pilot intervention with a private sector partner. CIP aimed to scale this technology to other countries in the region such as Uganda. Within a project funded through the RTB scaling funds, a systematic scaling approach was developed for the intervention in Uganda, described below.

The scaling project team used the concept of "scaling readiness to assess the innovation packages". "Innovation readiness" refers to the demonstrated capacity of an innovation to fulfill its contribution to development outcomes in specific locations. This is presented in nine stages showing progress from an untested idea to a fully mature proven innovation. "Innovation use" indicates the level of use of the innovation by the project, partners, and society. This shows progressively broader levels of use beginning with the intervention team who develop the innovation to its widespread use by users who are completely unconnected with the team or their partners. "Scaling readiness" of an innovation is a function of innovation readiness and innovation use. Table 13.5 provides summary definitions for each level of readiness and use adapted from Sartas et al. (2020).

Description of Innovation Package Starter material is crucial for seed multiplication. Mini-tubers normally serve as starter material, producing five to ten tubers per unit. Apical cuttings are a faster alternative, producing 10 to 20 or more tubers per unit. There are two stages in apical cutting systems: producing apical cuttings in a screenhouse and then changing hands to a seed producer or farmer to plant the apical cuttings in the field to produce seed tubers. Seed produced from apical cuttings can be saved on-farm for a few seasons with little risk of quality loss. Apical cuttings offer opportunities for seed production in areas without enough land for traditional seed bulking and crop rotation. Apical cuttings accelerate new varieties quickly. Farmers can also plant apical cuttings directly to produce seed on-farm. In this context a scaling pathway at different levels of the seed potato value chain has been developed and is described in Fig. 13.5.

Present Level of Innovation Readiness and Innovation Use For a systematic monitoring and evaluation of the scaling process and success of the technology in Uganda, the project team used a scaling tool (Sartas et al. 2020) that defines each stage of innovation readiness and use scale. Figure 13.6 represents the starting point

Table 13.5 Summary definition of levels of innovation readiness and use (Sartas et al. 2020)

Stage	Innovation readiness	Innovation use
1	Idea	Intervention team
2	Basic model (testing)	Direct partners (rare)
3	Basic model (proven)	Direct partners (common)
4	Application model (testing)	Secondary partners (rare)
5	Application model (proven)	Secondary partners (common)
6	Application (testing)	Unconnected developers (rare)
7	Application (proven)	Unconnected developers (common)
8	Innovation (testing)	Unconnected users (rare)
9	Innovation (proven)	Unconnected users (common)

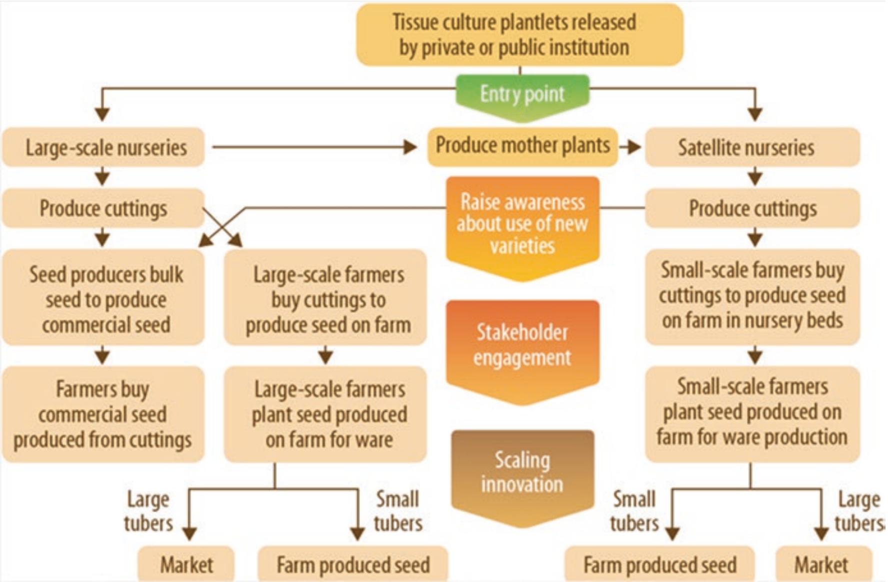

Fig. 13.5 Scaling pathway for rooted apical cutting technology

of the innovation package components (technologies, products, services, and institutional arrangements) when interventions began in Uganda in December 2018 based on feedback from private, public, and NGO stakeholders.

Most components started at a low level of readiness and use and progressed rapidly in both readiness of innovation and use scale within 2 years (Fig. 13.6) due to demand from users and stakeholders.

13.5 Outcomes from Scaling the Innovation in East and Central Africa

13.5.1 Impact of New Technologies and Partnership Models on the Production of EGS

The dissemination of technologies and the impact on early generation seed production have been studied by Harahagazwe et al. (2018a). Of the 18 institutions studied, 9 belong to governments, 1 is a parastatal, and 8 are private. The production of EGS potato in sub-Saharan Africa is still dominated by the conventional technique. Over 500,000 in vitro plantlets can be accommodated at one time under protective structures for mini-tuber production in the 7 study countries, and more than 7.5 million

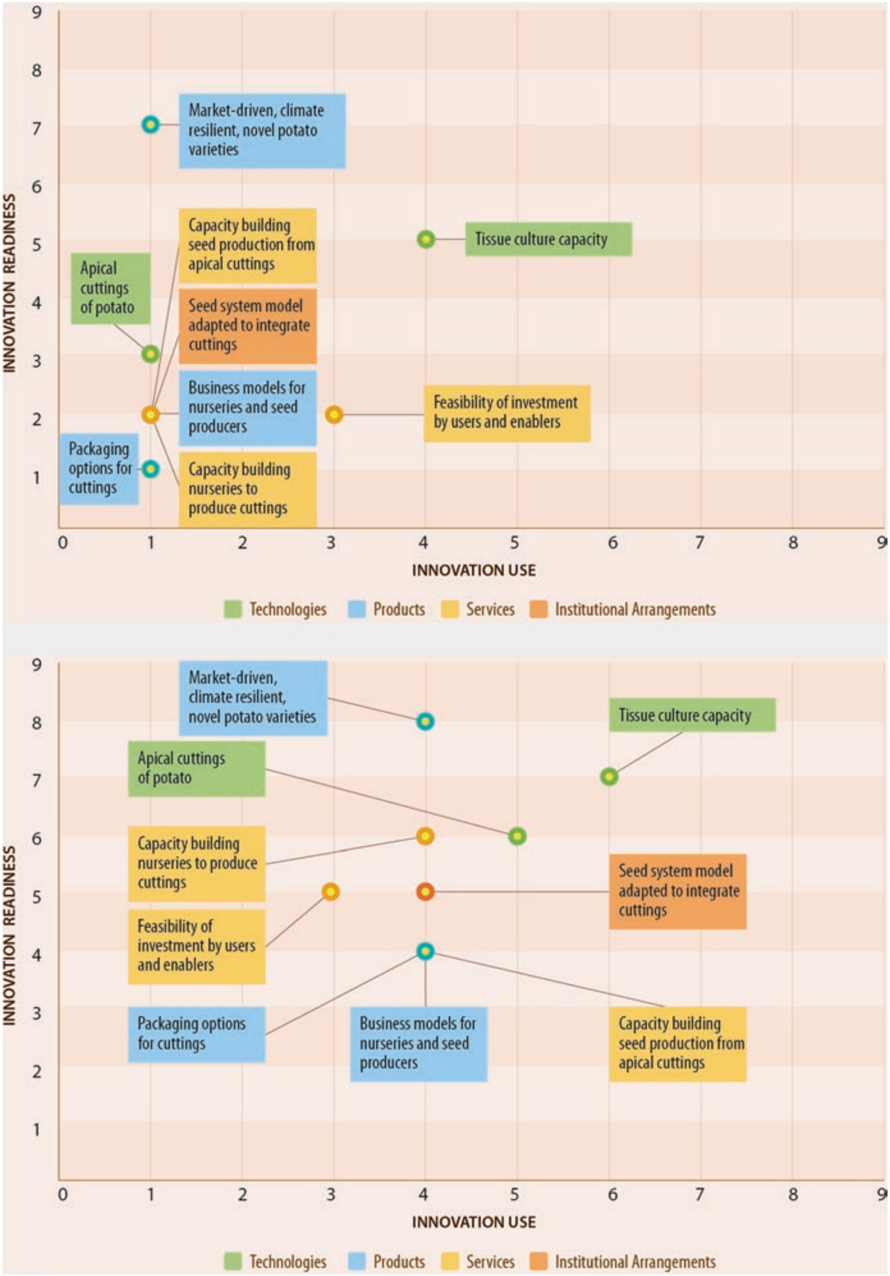

Fig. 13.6 *Readiness* versus use at introduction (top) and 2 years after (below) introduction of apical cuttings and robust potato varieties in Uganda

mini-tubers can be produced in a single season. This is enough seed to plant over 150 ha per season for the first field generation, compared with only 10 ha per season in 2008—using mini-tubers locally produced, i.e., 93,500 mini-tubers in Uganda, Rwanda, Malawi, Kenya, and Ethiopia (Demo et al. 2015) and 148,034 mini-tubers in Burundi. There was, however, no mini-tuber production in Tanzania in 2008 (Kakuhenzire et al. 2015) as shown in Fig. 13.7. In the region, 49% of mini-tubers derive from conventional technique, 30% from sand hydroponics, and 21% from aeroponics (Harahagazwe et al. 2018a). Additionally, more than 650,000 rooted apical cuttings are produced in Kenya and about 300,000 in Uganda enough to plant 13 and 6 ha for further multiplication, respectively.

This means that, as in Latin America (Mateus-Rodríguez et al. 2013), the conventional technique remains the most commonly used technology to produce minitubers. As one seed expert told Harahagazwe et al. (2018a), "the conventional technology remains the easiest and best known way of producing clean seed potato when working conditions and funding are suboptimal."

Nonetheless, the introduction of new technologies seems to have triggered interest in EGS production and contributed to the significant increase in it since 2008 (Fig. 13.7).

Despite this huge capacity of EGS infrastructure in the seven countries, the actual production remains below expectations. The total number of mini-tubers produced in 2017 is only 65% of the mini-tubers that could be produced in a single

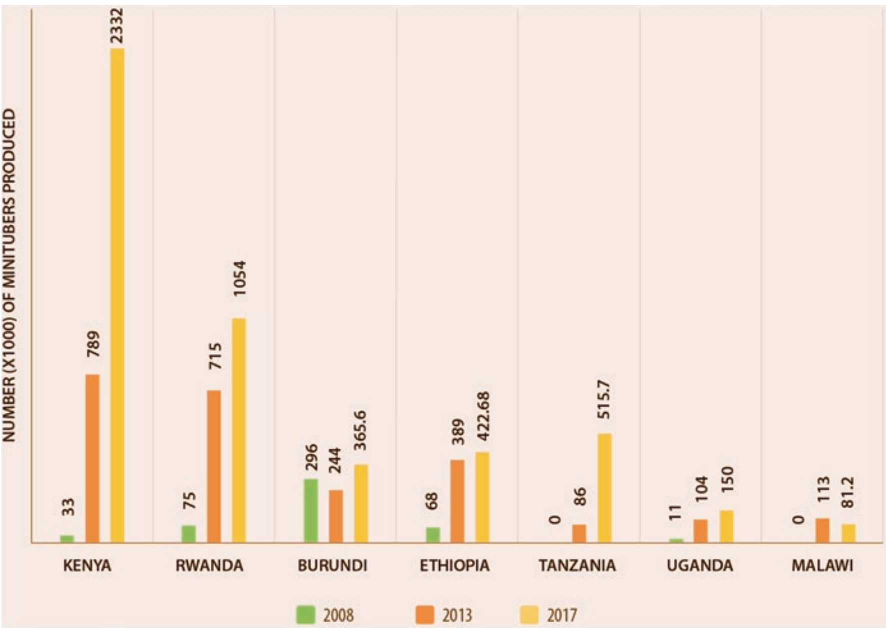

Fig. 13.7 Mini-tuber production over time in seven SSA countries. (Adapted from Demo et al. (2015). 2017 data were provided from Harahagazwe et al. (2018a))

season of 3 to 6 months, indicating inefficiencies in the management of the units, in particular by some public sector institutes. Public sector aeroponic units in Kenya, Ethiopia, and Uganda only produce at about 30% of their capacity, while some are not operational at all. However, results from Tessema and Dagne (2018) report that one-third of the 600,000 mini-tubers produced in Ethiopia were coming from aeroponic units in the period from 2011 to 2014 suggesting a better performance prior to the study conducted by Harahagazwe et al., in 2018. In contrast, private sector aeroponic units in Kenya produce at about 90% of their capacity. Aeroponics is challenging to operate but offers a high potential when conditions and capacities are adequate. This should be considered when deciding to scale this technology, which is best suited to enterprises with the capacity to invest in infrastructure and which already have experience with similar operations (e.g., greenhouses) in the flower and horticultural sectors.

Nonetheless, data collected in seven African countries show that the capacity for mini-tuber production is significantly increasing (Fig. 13.8), in part as a result of the investments in RMTs, including the implementation of the CIP project funded by USAID, Irish Aid, GiZ, and the Government of Finland in Ethiopia, Kenya, Malawi, Rwanda, Tanzania, and Uganda (Demo et al. 2015).

Rooted apical cuttings are starting to be used in the potato sector; the number of rooted apical cuttings sold in Kenya is rapidly increasing from about 70,000 in 2017 to 265,615 in 2018 and 337,418 in 2019 (unpublished data provided by Stokman Rozen Ltd.). In 2019 about 46% of the cuttings were ordered by 44 private

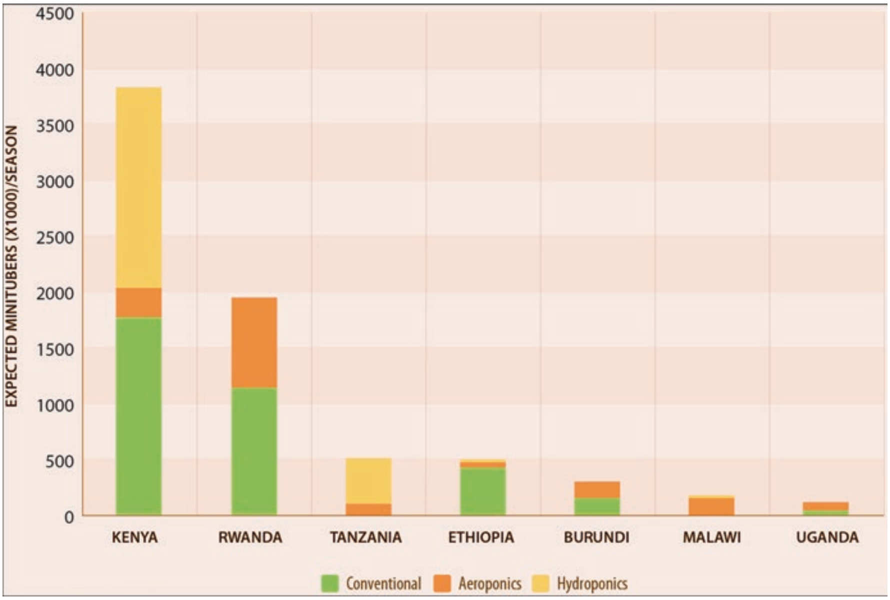

Fig. 13.8 Capacity of facilities used for potato mini-tuber production in seven African countries using three techniques

enterprises (farmers and commercial seed multipliers) and 54% by two projects (CIP and an NGO), which increased to 71% of sales to private enterprises in 2020 out of 586,000 cuttings. Cuttings are penetrating the seed system, and their opportunities for being scaled out are being validated in Kenya.

13.5.2 Impact on Availability of Certified Seed: Results from Kenya

The impact of the new techniques on the availability of certified seed is difficult to support with data as only Kenya has a reliable certification system and documentation of amounts produced. In many countries such as Ethiopia, Rwanda, and Uganda, foundation seed produced by programs is distributed to trained farmers, farmer groups, or seed cooperatives, which are not engaging in certification systems, so production is not officially documented. In Ethiopia, for instance, the semi-formal Quality Declared Seed standards have been introduced for the crop in 2016 as an intermediate quality control system based on local visual inspection; however, the amounts produced are not systematically documented. Therefore, the focus in this section will be on Kenya.

Since 2010 Kenya showed a clear trend of increasing amounts of certified seed. From only 1000 tons in 2005 and a drop to 300 tons in 2008 (due to political unrest) provision of certified seed rose to 2500 tons in 2010. This increase can be solely attributed to the introduction of RMTs in 2000–2009, as well as the further increase to 5600 tons annually in 2015 and 2016 (compare Fig. 13.9). Increases in the following years have been achieved in part due to the local multiplication of imported foundation seed from Europe. However, about 70% of the certified seed has been

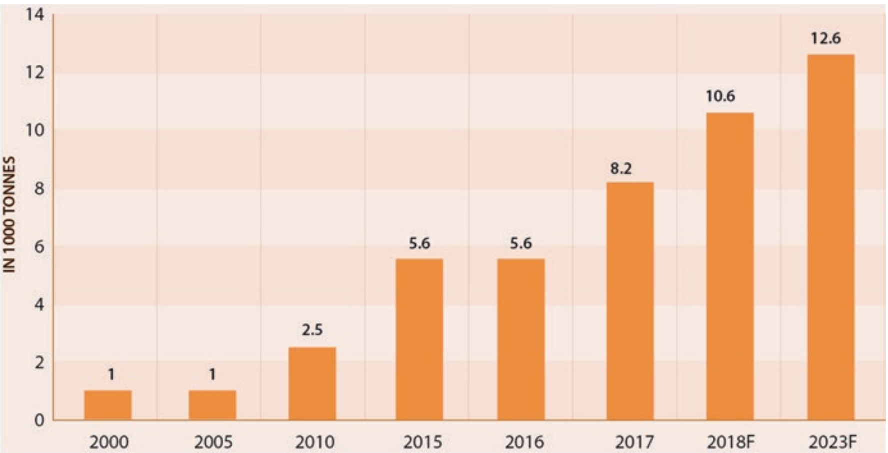

Fig. 13.9 Certified seed (in 1000 tons) produced in Kenya since 2000 (F = forecast)

produced using locally produced EGS (data from KEPHIS, amounts of certified seed in 2019 by producer). The most important local producers of certified seed, Kisima Farms Ltd. and the parastatal Agricultural Development Cooperation (ADC) produce 3400 tons and 2500 tons annually, respectively. Both produce EGS locally. Kisima Farms is producing its EGS through aeroponics and sand hydroponics and purchases rooted apical cuttings (RAC) from Stokman Rozen Ltd. Hence, all of the certified seed at Kisima Farms has been produced from EGS produced with the recently introduced technologies. The EGS production at ADC, however, is still dominated by conventional pot systems, accounting for about 80% of their minituber production. In sum, currently about 4000 tons, or 40% of certified seed, is produced using EGS derived from the introduced technologies.

The impact of the recently introduced RAC technology on certified seed production is difficult to estimate, as most cuttings are directly purchased by farmers and further multiplied on-farm without certification. Nonetheless, the impact of the technology could be even bigger than with previous techniques. Based on the production data from 2019 (see previous paragraph) and assuming a field survival rate of 70% with two further field multiplications before using the seed to produce ware potatoes, the production would be enough to plant about 640 ha. This would be equivalent to 1280 tons of seed which is about 11% of the current provision of certified seed in the country, hence adding a significant amount of high-quality seed to the sector.

Initial results with pilot farms and farmer groups indicate huge yield gains after two rounds of on-farm multiplication. These yield increases are similar to those when using certified seed but with reduced costs. This technology could contribute significantly to improve seed quality at the farm level and nationally. The technology would also be a perfect fit for multiplying true potato seed from hybrid potatoes, a technology that promises to revolutionize potato breeding and seed systems.

13.5.3 Impact on Yields and Demand for Seed at Smallholder Level

Total yield impacts are difficult to determine. FAOSTAT inaccurately reported yields in Kenya from 2008 to 2012 at around 20 tons per ha, which is double of those reported in several peer-reviewed publications (Gildemacher et al. 2009; Harahagazwe et al. 2018b; Haverkort and Struik 2015). In following years, the reported yields dropped significantly to around 14 tons per ha in 2014 and 2015 and to 9 or 10 tons since 2016. Data from other countries in the region show less fluctuation but still seem to be unreliable. Therefore, it is basically impossible to estimate impacts at larger scales.

The only reliable data on the impact of high-quality seed at the farm level come from surveys and on-farm trials. Okello et al. (2017) found that adopters of certified seed (N = 167) had a yield about 2.5 tons per ha higher (11.5 vs. 8.7) than non-adopters (N = 241). The survey however was conducted during a season with low rainfall which might have dampened yields. The adopters did not plant 100% of their fields with certified seed every season but reused the seed for two to three seasons before purchasing new certified seed. This might be a good tactic for balancing investment risk and yield improvements and probably portrays a realistic scenario for potential demand.

Participatory research on 18 farms in Kenya between 2010 and 2011 evaluated the effects of different seed qualities on yield and crop heath. When using recommended management practices, certified seed can double the yield from farm-saved seed (Schulte-Geldermann et al. 2013). However, this yield gain can only be achieved by properly managing plant nutrition and pests and diseases. With suboptimal management, e.g., lower rates of fertilizer and reduced chemical control of late blight, the yield gain was usually 30–75% higher than farm-saved seed. That means that the investment in high-quality seed, which amounts to 1200 to 1500 USD per ha, needs to be protected by additional investments in farm inputs, often difficult for cash-constrained farmers.

Ochieng (2021) indicate that with current farm-gate ware potato prices, if farmers planted only certified seed, yields would have to be about 18 tons per ha to achieve the same profit as with farm-saved seed, which yields on average 8 tons per ha. That suggests that investing in certified seed is risky, which explains the reluctance of many farmers to invest in it.

However, alternative strategies such as purchasing 5% of certified seed, bulking it on land where potatoes haven't been planted for a long time, at close spacing and conducting positive selection allow for replacing the old seed stock with better seed within three seasons. With this strategy, yields were just 10–15% below those obtained with certified seed but at much lower costs. Compared to the use of farm-saved seed, this strategy required a yield increase of only 2.5 tons per ha to cover the additional investment. This was achieved easily at all eight farms involved in the study. The integrated strategies have a profit margin about 10–25% higher than when using certified seed alone (Ochieng 2021).

Farmers need to be capacitated on the best management options, in order to break the vicious cycle of declining yields brought about by using farm-saved seed, while also reducing the high cost and risk of planting only certified seed. A bottleneck is dissemination, as seed producers are usually reluctant or unable to deal with the logistics of distributing small quantities to many individual customers. Organizing farmers into groups or cooperatives to buy larger quantities would be a viable option. This has been documented in a study (110 farmers) in Rwanda comparing access to high-quality seed by individual farmers and by members of cooperatives. The cooperatives were able to purchase certified seed from the Rwanda Agricultural Board and multiplied it one further season before it was distributed to all members. Only about 10% of the individual farmers accessed high-quality seed. This resulted in huge differences in yields between the two groups. About 40% of the cooperative members achieved yields higher than 20 tons per ha, and 90% harvested more than 15 tons per ha. About 80% of individual farmers achieved yields of below 15 tons per ha, and 60% had yields below 10 tons (Uwimana 2020).

Demand for high-quality seed could also be bolstered by distributing it in smaller packages, e.g., in bags of 5 to 25 kg, even though this is below the standard size of 50 kg defined in local seed laws. Smaller seed bags would improve smallholders' access to quality seed (and to validate its quality on their own farms), allowing for the growth of the seed sector and creating business opportunities based on RMTs.

13.5.4 Contribution to Gender and Social Inclusiveness

The technologies indirectly contributed to gender and social inclusiveness by reducing the price for certified seed. Mudege and Demo (2016) and Mudege et al. (2020) concluded that improved technologies that are affordable and available in local markets are generally friendly for vulnerable groups, including women. In Kenya, for instance, the price for a 50 kg bag of generation four seed prior to the introduction of the EGS technologies in 2008 has been 3300 or 3500 KSH (33 or 35 USD) and dropped to between 2500 and 3000 KSH (25 and 30 USD) in 2020, hence making it more available to resource-poor farmers.

In particular, rooted apical cuttings are becoming more accessible as they can easily be traded in small quantities of 100–200 cuttings at an affordable price of 10–15 KSH (0.09 to 0.14 USD) per cutting, which can be multiplied on the small parcels typically farmed by women and youths (Fig. 13.10). Investing in rooted cuttings for seed production could be interesting for women and youth as little land is required, and profit margins are high.

Fig. 13.10 Women farmers in Kenya multiplying seed from rooted apical cuttings. (Photo credits Benson Kisinga CIP)

13.6 Conclusion

Rapid multiplication technologies such as aeroponics, rooted apical cuttings, and sand hydroponics save costs and have a place in the seed business in Eastern Africa. RMTs have contributed significantly to the increased supply of certified or high-quality seed in the region over the last decade. However, technologies have to be carefully selected for their situation and for underlying conditions including climate. Highly productive technologies such as aeroponics and rooted apical cuttings place high demands on management and infrastructure while requiring suitable business models that go beyond producing EGS. Both technologies are well suited for businesses that already manage tissue culture or screenhouses, e.g., in the horticultural and floricultural sectors. For these enterprises, both technologies offer viable opportunities to diversify their business and earn an additional stream of income. The less productive sand hydroponic technology reduces costs while slightly improving production over the conventional pot system, contributing to lowering seed production costs. Its relatively ease of management is an opportunity for less skilled and resource-constrained enterprises and public sector institutes to produce EGS. A careful assessment (e.g., a business plan) is required before choosing the best technologies for each situation.

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References

Abdurahman A, Griffin D, Elphinstone J, Struik PC, Schulz S, Schulte-Geldermann E, Sharma K (2017) Molecular characterization of Ralstonia solanacearum strains from Ethiopia and tracing potential source of bacterial wilt disease outbreak in seed potatoes. Plant Pathol 66(5):826–834. https://doi.org/10.1111/ppa.12661

Almekinders CJ, Walsh S, Jacobsen KS, Andrade-Piedra JL, McEwan M, De Haan S, Kumar L, Staver C (eds) (2019a) Why interventions in the seed systems of roots, tubers and bananas crops do not reach their full potential. Food Secur. First Online 23 Jan 2019, 20 p. ISSN 1876-4525

Almekinders CJ, Beumer K, Hauser M, Misiko M, Gatto M, Nkurumwa AO, Erenstein O (2019b) Understanding the relations between farmers' seed demand and research methods: the challenge to do better. Outlook Agric 48(1):16–21

Andersen KF, Buddenhagen CE, Rachkara P, Gibson R, Kalule S, Phillips D, Garrett KA (2019) Modeling epidemics in seed systems and landscapes to guide management strategies: the case of sweet potato in Northern Uganda. Phytopathology 109(9):1519–1532. https://doi.org/10.1094/PHYTO-03-18-0072-R

Andrade-Piedra JL, Kromann P, Otazu V (2019) Manual for seed potato production using aeroponics. In: Ten years of experience in Colombia, Ecuador and Peru. International Potato Center (CIP), National Institute of Agricultural and Livestock Research (INIAP), Colombian Agricultural Research Corporation (CORPOICA), Quito, Ecuador. ISBN 978–92–9060-504-1, 267 p

Atieno E, Schulte-Geldermann E (2016) Public-private partnerships to multiply seed potato in Kenya. Case studies of roots, tubers and bananas seed systems, 2016-3

Bryan JE, Jackson MT, Malendez NG (1981) Rapid multiplication techniques for potatoes. International Potato Center, Lima, Peru, p 20

Chang DC, Park CS, Kim SY, Kim SJ, Lee YB (2008) Physiological growth responses by nutrient interruption in aeroponically grown potatoes. Am J Potato Res 85(5):315

Demo P, Lemaga B, Kakuhenzire R, Schulz S, Borus D, Barker I, Woldegiorgis G, Parter ML, Schulte-Geldermann E (2015) Strategies to improve seed potato quality and supply in sub-Saharan Africa: experience from interventions in five countries. In: Potato and sweetpotato in Africa: transforming the value chains for food and nutrition security. CABI, Wallingford, pp 155–167

Dodds JH (1988) Tissue culture technology: practical application of sophisticated methods. Am Potato J 65:167–180. https://doi.org/10.1007/BF02854450

FAO (2010) Quality declared planning material. Protocols and standards for vegetatively propagated crops. In: FAO plant production and protection paper 195, Rome, p 126

FAOSTAT (2020) Food and Agriculture Organization of the United Nations. FAOSTAT Statistical Database. FAO, Rome: http://www.fao.org/faostat/en/#data/QC. Accessed December 2020

Farran I, Mingo-Castel AM (2006) Potato mini-tuber production using aeroponics: effect of plant density and harvesting intervals. Am J Potato Res 83(1):47–53

Ferrari L, Fromm I, Jenny K, Muhire A, Scheidegger U (2017) Formal and informal seed potato supply systems analysis in Rwanda. In: Tropentag 2017: future agriculture: social-ecological transitions and bio-cultural shifts, Bonn. September 20–22, 2017

Forbes GA, Charkowski A, Andrade-Piedra J, Parker ML, Schulte-Geldermann E (2020) Potato seed systems. In: Campos H, Ortiz O (eds) The potato crop. Springer, Cham, pp 431–447

Gildemacher PR, Kaguongo W, Ortiz O, Tesfaye A, Woldegiorgis G, Wagoire WW, KakuhenzireR KPM, Nyongesa M, Struik PC, Leeuwis C (2009) Improving potato production in Kenya, Uganda and Ethiopia: a system diagnosis. Potato Res 52(2):173–205

Harahagazwe D, Andrade-Piedra J, Parker M, Schulte-Geldermann E (2018a). Current situation of rapid multiplication techniques for early generation seed potato production in Sub-Saharan Africa International Potato Center, CGIAR Research Program on Roots, Tubers and Bananas (RTB) RTB Working paper no. 2018-1

Harahagazwe D, Condori B, Barreda C, Bararyenya A, Byarugaba AA, Kude DA, Lung'aho C, Martinho C, Mbiri D, Nasona B, Ochieng B, Onditi J, Randrianaivoarivony JM, Tankou CM, Worku A, Schulte-Geldermann E, Mares V, de Mendiburu F, Quiroz RQ (2018b) How big is the potato (*Solanum tuberosum L.*) yield gap in Sub-Saharan Africa and why? A participatory approach. Open. Agriculture 3(1):180–189

Haverkort AJ, Struik PC (2015) Yield levels of potato crops: recent achievements and future prospects. Field Crop Res 182:76–85

Kaguongo W, Maingi G, Barker I, Nganga N, Guenthner J (2014) The value of seed potatoes from four systems in Kenya. Am J Potato Res 91:109–118. https://doi.org/10.1007/s12230-013-9342-z

Kakuhenzire R, Temu N, Kwigizile O, Valkonen J, Shayo T, Msemwa J (2015) Seed potato development project in Tanzania (2012–2015). Final Project Report. International Potato Center, Uyole, Tanzania, p 44

Kakuhenzire R, Tibanyendera D, Kashaija IN, Lemaga B, Kimoone G, Kesiime VE, Otazu V, Barker I (2017) Improving minituber production from tissue-cultured potato plantlets with aeroponic technology in Uganda. Int J Agric Environ Res 3:3948–3964

Labarta RA (2013) Possibilities and opportunities for enhancing the availability of high-quality seed potato in Ethiopia: lessons from the successful 3G project in Kenya. Proceedings of the National Workshop on Seed Potato Tuber Production and Dissemination, 12-14 March 2012, Bahir Dar, Ethiopia. ISBN: 978-99944-53-87-x. pp. 21–34

Landeo J, Barker I, Otazú V (2009) Novel approaches to promote and diffuse new Potato varieties in Kenya. 15th Triennial of the Symposium of the International Society for Tropical Root Crops. Proceedings

Lung'aho C, Mbiyu M, Nyongesa M, Otieno S, Onditi J, Schulte-Geldermann E (2013) Are dormancy management and physiological age the Achilles' heel of aeroponic minituber production in seed potato value chains in SSA? In: Transforming potato and sweetpotato value chains for food and nutrition security. 9. Triennial Congress of the African Potato Association, Naivasha. 30 Jun-9 Jul 2013

Mateus-Rodríguez JR, de Haan S, Andrade-Piedra JL, Maldonado L, Hareau G, Barker I, Chuquillanqui C, Otazú V, Frisancho R, Bastos C, Pereira AS, Medeiros CA, Montesdeoca F, Benítez J (2013) Technical and economic analysis of aeroponics and other systems for potato mini-tuber production in Latin America. Am J Potato Res 90(4):357–368

Mbiri D, Schulte-Geldermann E, Otazu V, Kakuhenzire R, Demo P, Schulz S (2015) An alternative technology for pre-basic seed potato production–sand hydroponics. Potato and Sweetpotato in Africa: Transforming the Value Chains for Food and Nutrition Security. p. 249

Mburu H, Cortada L, Haukeland S, Ronno W, Nyongesa M, Kinyua Z, Bargul J, Coyne D (2020) Potato cyst nematodes: a new threat to potato production in East Africa. Front Plant Sci 11:670. https://doi.org/10.3389/fpls.2020.00670

Mudege N, Demo P (2016) Seed potato in Malawi: Not enough to go around. In: Andrade-Piedra J, Bentley JW, Almekinders C, Jacobsen K, Walsh S, Thiele G (eds) Case studies of roots, tubers and bananas seed systems. CGIAR Research Program on Roots, Tubers and Bananas (RTB), Lima, RTB Working Paper No. 2016-3. ISSN 2309-6586., pp 151–167

Mudege NN, Escobar SS, Polar V (2020) Gender topics on potato research and development. Potato Crop 475

Muro JV, Goñi JL, Lamsfus C (1997) Comparison of hydroponic culture and culture in a peat/sand mixture and the influence of nutrient solution and plant density on seed potato yields. Potato Res 40:431–438

Muthoni J, Kabira J (2014) Multiplication of seed potatoes in a conventional potato breeding programme: a case of Kenya's national potato programme. Aust J Crop Sci 8(8):1195

Muthoni J, Mbiyu M, Lung'aho C, Otieno S, Pwaipwai P (2017) Performance of two potato cultivars derived from *in vitro* plantlets, mini-tubers and stem cuttings using aeroponics technique. Int J Horticult 7(27):246–249

Naik PS, Karihaloo JL (2007) Micropropagation for production of quality potato seed in Asia-Pacific. Asia-Pacific Consortium on Agricultural Biotechnology, New Delhi, p 54

National Potato Council of Kenya (2018) Background and seed potato challenges. In: Kaguongo W (ed) Seed potato stakeholders' meeting. PanAfric Hotel, Nairobi

Negash K (2014) Rapid multiplication techniques (RMTs): a tool for the production of quality seed potato (*Solanum tuberosum L.*) in Ethiopia. Asian. J Crop Sci 6(3):176–185

Nyawade S, Parker M (2020) Planting and management of potato rooted apical cuttings: a field guide. Extension brief

Ochieng BO (2021) Bacterial wilt and virus disease management in potato production systems in Kenya Dissertation for the acquisition of the degree Doktor der Agrarwissenschaften (Dr. agr. sc.). Submitted to Faculty of Organic Agricultural Sciences at University of Kassel, January 2021

Okello JJ, Zhou Y, Kwikiriza N, Ogutu S, Barker I, Schulte-Geldermann E, Atieno E, Ahmed JT (2017) Productivity and food security effects of using of certified seed potato: the case of Kenya's potato farmers. Agricult Food Secur 6(1):1–9

Okello JJ, Lagerkvist CJ, Kakuhenzire R, Parker M, Schulte-Geldermann E (2018) Combining means-end chain analysis and goal-priming to analyze Tanzanian farmers' motivations to invest in quality seed of new potato varieties. Br Food J

Otazú V (2008) Steam sterilization of greenhouse substrates (in Spanish). In: Alternativas al uso del bromuro de metilo en la producción de semilla de papa de calidad. International Potato Center (CIP). Documento de trabajo 2007–2, Lima, pp 15–25

Otazú V (2010) Manual on quality seed potato production using aeroponics. International Potato Center, p 44
Otazú V, Chuquillanqui C (2008) Quality seed potato production by aeroponics. (in Spanish). In: Alternativas al uso del bromuro de metilo en la producción de semilla de papa de calidad. International Potato Center (CIP). Documento de trabajo 2007–2, Lima, pp 35–45
Parker ML (2019) Production of apical cuttings of potato. International Potato Center, Lima. https://doi.org/10.4160/9789290605195
Parker ML, Low JW, Andrade M, Schulte-Geldermann E, Andrade-Piedra J (2019) Climate change and seed systems of roots, tubers and bananas: the cases of potato in Kenya and Sweetpotato in Mozambique. In: Rosenstock T, Nowak A, Girvetz E (eds) The climate-smart agriculture papers. Springer, Cham, pp 99–111. https://doi.org/10.1007/978-3-319-92798-5_9
Ritter E, Angulo B, Riga P, Herran C, Relloso J, San Jose M (2001) Comparison of hydroponic and aeroponic cultivation systems for the production of potato minitubers. Potato Res 44(2):127–135
Sartas M, Schut M, Proietti C, Thiele G, Leeuwis C (2020) Scaling readiness: science and practice of an approach to enhance impact of research for development. Agric Syst 183:102874
Schulte-Geldermann E (2013) Tackling low potato yields in Eastern Africa: an overview of constraints and potential strategies. Proceedings. National Workshop on Seed Potato Tuber Production and Dissemination. Bahir Dar (Ethiopia), 12-14 Mar 2012, (Ethiopia), Ethiopian Institute of Agricultural Research (EIAR), Amhara Regional Agricultural Research Institute (ARARI), International Potato Center ISBN 978-99944-53-87-x. pp 72–80.
Schulte-Geldermann E, Wachira G, Ochieng B, Barker I (2013) Effect of field multiplication generation on seed potato quality in Kenya. Proceedings of the National Workshop on seed potato tuber production and dissemination, 12-14 March 2012, Bahir Dar, Ethiopia. ISBN: 978-99944-53-87-x, pp 81–90
Sharma K, Atieno EO (2020) Dissemination of climate-smart consumer-demanded potato varieties in Kenya. Second Annual Progress Report to Syngenta Foundation for Sustainable Agriculture. January 1st–December 31st 2019, Lima
Singh S, Singh V, Singh B, Panday SK (2010) Aeroponics for potato seed production. In Council Agric Res Newsletter 16:1–2
Soffer H, Burger DW (1988) Studies on plant propagation using the aero-hydroponic method. In: Symposium on High Technology in Protected Cultivation 230. pp. 261–270
Struik PC, Wiersema SG (1999) Seed potato technology. Wageningen Academic Publishers, Wageningen, p 383. https://doi.org/10.3920/978-90-8686-759-2
Tessema L, Dagne Z (2018) Aeroponics and sand hydroponics: alternative technologies for pre-basic seed potato production in Ethiopia. Open Agric 3(1):444–450
Thiele G, Labarta R, Schulte-Geldermann E, Harrison G (2011) Roadmap for investment in the seed potato value chain in Eastern Africa. Lima (Peru), International Potato Center, p 27
Thiele G, Dufour D, Vernier P, Mwanga RO, Parker ML, Schulte Geldermann E, Teeken B, Wossen T, Gotor E, Kikulwe E, Tufan HA, Sinelle S, Kouakou AM, Friedmann M, Polar V, Hershey C (2020) A review of varietal change in roots, tubers and bananas: consumer preferences and other drivers of adoption and implications for breeding. Int J Food Sci Technol 56:1076–1092. https://doi.org/10.1111/ijfs.14684
Thomas-Sharma S, Abdurahman A, Ali S, Andrade-Piedra JL, Bao S, Charkowski AO, Crook D, Kadian M, Kromann P, Struik PC, Torrance L (2016) Seed degeneration in potato: the need for an integrated seed health strategy to mitigate the problem in developing countries. Plant Pathol 65(1):3–16
Thomas-Sharma S, Andrade-Piedra J, Carvajal Yepes M, Hernandez Nopsa JF, Jeger MJ, Jones RAC, Kromann P, Legg JP, Yuen J, Forbes GA, Garret KA (2017) A risk assessment framework for seed degeneration: informing an integrated seed health strategy for vegetatively propagated crops. Phytopathology 107(10):1123–1135
Tibbitts TW, Cao W (1994) Solid matrix and liquid culture procedures for growth of potatoes. Adv Space Res 14:427–433. https://doi.org/10.1016/0273-1177(94)90332-8

Tsegaw T (2006) Response of paclobutrazol and manipulation of reproductive growth under tropical conditions. PhD Thesis University of Pretoria

Uwimana J (2020) Evaluation of the quality and availability of potato seed to respond to the dynamics of farmer's needs and production increase in communities of Musanze district, Rwanda. Master Thesis at Bingen University of Applied Sciences, Bingen am Rhein, Germany, March 2020

Van Ittersum MK, Scholte K (1993) Shortening dormancy of potatoes by haulm application of gibberellic acid and storage temperatures regimes. Am Potato J 70:7–9

Van Minh T, Van Uyen N, Vander Zaag P (1990) Potato (*Solanum spp*.) production using apical cuttings and tuberlets under three contrasting environments of Vietnam. Am Potato J 67(11):779. https://doi.org/10.1007/BF03044529

Vander Zaag P, Escobar V (1990) Rapid multiplication of potatoes in the warm tropics: rooting and establishment of cuttings. Potato Res 33:13–21

Wiersema SG, Cabello R, Tovar P, Dodds JH (1987) Rapid seed multiplication by planting into beds micro tubers and in vitro plants. Potato Res 30(1):117–120

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