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Production and availability of good quality seed potatoes in the East African region: A review

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Abstract

Demand for potatoes has grown rapidly in eastern Africa due to rapid population growth, urbanisation and life style changes. This has made potato an important commodity crop in the region contributing to food security and enhanced livelihoods. However, potato productivity in the region is low; ranging from 6 to10 t/ha against potential yields of over 30 t/ha. One of the major causes of low yields is the chronic shortage of good quality seed potatoes for planting, which also limits adoption of new and improved varieties. Therefore, the objective of this paper is to highlight the opportunities and progresses in the production and availability of good quality seed potatoes in the East African region to bolster the productivity and commercial value of the crop. The first section of the paper discusses the status of good quality seed potatoes production and availability in the East African region. The second section looks at the farmer-based seed potato production technologies while the third section focuses on the efforts of both the private and public sector in production of good quality seed potatoes. Availability of good quality seed potatoes constitutes < 1% of the requirement in eastern Africa. These seeds are mainly produced by public research institutions as well as some private players. Consequently, most farmers opt to plant seed potatoes from informal sources. However, seeds from informal sources are mostly of poor quality and often accelerate the spread of tuber-borne diseases, especially viruses and bacterial wilt. To improve seeds from informal system, some technologies have been identified and promoted to enhance farmer-based seed production and distribution. These include seed plot technology (SPT), positive selection techniques (PST) and Quality Declared Seed (QDS) systems. In addition, there has been adoption and promotion of rapid multiplication techniques (RMT) such as stem/shoot cuttings, aeroponics, sandponics, and hydroponics among others. Other measures that have been taken include importing seeds of new potato varieties. The imports increase the quantity of seeds and the number of potato varieties available to farmers. Despite these efforts, the quantity of good quality seeds available is still far below the requirements. There is need for the governments, private sector players as well as farmers to enhance their efforts and save the situation. Governments need to invest seriously in local breeding activities and multiplication of early generation seeds. These and other measures may increase availability of good quality and affordable seed potatoes in East African region.

Keywords: East Africa, Potatoes, Quality declared seed, Seed potatoes

Introduction

Potato (*Solanum tuberosum* L., 2n=4x=48) is the third most important staple food crop in the world after rice (*Oryza* species) and wheat (*Triticum* species) in terms of human consumption. Potato serves more than one billion people worldwide as the main food (Trapero-Mozos et al., 2018; FAO, 2019). More than half of the global potato production takes place in developing countries (Scott and Suarez, 2012). On continental basis, Asia and Europe are the major potato producers, accounting for more than 80% of world production, while Africa produces the least, accounting for about 7% (Devaux et al., 2014). In Africa, potatoes are grown under a wide range of conditions from irrigated commercial farms in Egypt and South Africa to intensively cultivated tropical highland zones of eastern and central Africa where it is mainly rainfed (Sanginga, 2015).

In Africa, potato production and harvested areas have more than doubled over the last 20 years (FAO, 2019). The increase in production has largely been due to an expansion of the cropping area (Harahagazwe et al., 2018a) rather than through enhancing productivity and crop management practices. Potato production has been rising with Egypt, Malawi, South Africa, Algeria, and Morocco producing more than two-thirds of continent's output (Devaux et al., 2020). Algeria more than doubled its production in 5 years while Rwanda almost doubled its output within the same period (PotatoPro, 2020). The production of potatoes in sub-Sharan Africa has more than doubled since 1994, with 70 % of this growth being concentrated in eastern Africa (Tesfaye et al., 2010). In the East African highlands, an estimated 2.5 million smallholder farmers depend on potato as both a cash and

subsistence crop. Potato has gained great importance in East African region where it contributes to the reduction of hunger and poverty. Potato production in the East African Community grew by 340 % over the past 20 years and average consumption increased at a similar pace, growing by approximately 300 % in the same period (GrowAfrica, 2021). Demand for potatoes has grown rapidly in eastern Africa due to rapid population growth, urbanisation and life style changes. Increased urbanisation has led to a high demand for fast-foods especially by the younger people who make a huge proportion of the population.

Despite the huge potential for potatoes in eastern Africa, productivity is low; ranging from 6 to10 t/ha against potential yields of over 30 t/ha. The major causes of low potato productivity are shortage of good quality seed potatoes of preferred varieties, poor adoption of the available improved varieties and limited awareness/application of good crop management practices by the farmers (Schulte-Geldermann et al., 2012; Thomas-Sharma et al., 2016; Tessema and Dagne, 2018). In potato production, the quality of seed potatoes planted is an important determinant of the final yield and quality (Lanteri and Quagliotti, 1997; Otazu 2010). Quality seed of an improved potato variety is key to increasing the productivity of the crop. The average yield increase from the use of good quality seed is 30 to 50 % compared to farmer' own seeds (Tessema and Dagne, 2018). A previous study showed that seed is the most critical factor in ensuring high yields with acceptable quality; good seeds can increase productivity by 15-25 % (Roy, 2014). Consequently, improving seed quality and availability would be one way of increasing the productivity of potato. However, good quality seeds are expensive. For example, in Tanzania's Lushoto district, seed potato prices are quite high at planting time and sometime can increase upto four times the normal prices; ranging from USD 2.5 to USD 10 per basket of approximately 10 kgs (CGIAR, 2016).

It has been recognized that seed potatoes contribute about 40-60 % of production costs (Kinyua et al., 2011; Gildermacher et al., 2011b; Sharma et al., 2015). Due to this high cost, most small-scale farmers in East Africa plant seed potatoes from informal sources; in most cases these seeds are cheaper but of inferior quality. There is need to increase availability of cheaper and good quality seed potatoes to small-scale farmers so as to increase the productivity of the crop. This can be achieved through deliberate government interventions such as increasing the capacity of public research institutions to produce more good quality seeds, subsidies to lower the cost of seeds and conducive environment to attract private investors into seed potato business, among others. In addition, ware potato marketing channels should be streamlined so that farmers can get fair prices for their produce, make reasonable profits and consequently appreciate use of good quality seeds. Therefore, the objective of this paper is to highlight the opportunities and progresses in the production and availability of good quality seed potatoes in the East African region so as to bolster the productivity and commercial value of the crop. First, the paper discusses the situation in East Africa as far as availability of good quality seed potatoes. It then discusses the various approaches that have been employed to increase availability of good quality seed potatoes.

Good quality seed a driver in potato productivity

Chronic shortage of quality seed of preferred varieties has been identified as the greatest bottleneck to potato production in eastern Africa (Harahagazwe et al., 2018a). Generally, good quality seed potatoes cater for less than 1 % of the requirements in eastern Africa. In addition, most of these are not subjected to quality control mechanisms, making seed health a major concern. In sub-Saharan Africa (SSA), over 95 % of seed potatoes planted come from the informal seed systems (Kaguongo et al., 2014). The informal system is the most prevalent where most farmers retain own "seeds" from previous harvests or buy from their fellow farmers. If these seed potatoes are used for several cropping cycles without renewing the seed lot from a reliable source, it will lead to accumulation of tuber-borne diseases which cause severe yield and quality losses (Gildemacher et al., 2009).The informal system is characterized by the supply of poor quality seed and often accelerates the spread of seed-borne diseases, especially bacterial wilt (Muthoni et al., 2009; Lung'aho and Schulte-Geldermann, 2016). In this system, farmers select seed tubers from the bulk of the ware potatoes after harvesting; the smallest tubers are mostly selected as seed. These small tubers are often latently contaminated with pathogens (Okiro et al., 2019) and once planted, they produce weak plants that are quite vulnerable to pests, diseases and harsh climatic conditions resulting in low yields. In addition, the small tubers produce few stems thus depressing yields even further. In east Africa the formal seed systems for potatoes are weak and inefficient making good quality seed less accessible to smallholder farmers. Production of early generation seed (EGS) potato is carried out primarily by the national agricultural research institutions (NARIs). The seeds are then sold to private and public investors for multiplication and production of certified seeds. However, the supply of certified seed potatoes remains far below the demand by potato growers. This is mainly because the NARIs have limited human and physical capacity to produce enough basic seed potatoes. Consequently, this formal seed system accounts for less than 2 % of the total seed potato demand in Africa (FAO, 2016). In the Eastern and Central Africa (ECA) sub-region, more than 95 % of seed potato come from informal sources (Kinyua et al., 2011; Kaguongo et al., 2015). In Kenya for example, the formal seed system produces about 2 % of all the seeds required by the local farmers (KEPHIS, 2016; FAO, 2013; TOF, 2013). Similarly, in Ethiopia, the informal system (e.g. farm saved seed, local markets, neighbours etc. accounts for 98.7 % of the total seed potato planted in the country (Hirpa et al., 2010; Gildemacher et al., 2009; Tessema et al, 2018). The remaining 1.3 % is met by the alternative system where relatively high quality seeds are produced by trained farmer groups. The formal system operates only in the central part of the country in a small area; its contribution to the overall seed system is negligible (Hirpa et al., 2015). In Rwanda, it is estimated that only 3 % of the potato planted area is provisioned by the formal system, while 97 % get seed from informal sources (Rwanda EGS, 2016). In Uganda, disease-free seed potatoes account for less than 5% of the local demand (Byarugaba et al., 2017) while in Burundi, certified seeds accounts for about 1 % of all the seeds required by the local farmers. In Tanzania, healthy seed is less than 1 % of total seed requirement. There is need to employ various strategies to increase and sustain availability of good quality seeds to potato growers in the East African region. This will ensure that potato growers get maximum benefits possible.

Access to quality seed in East Africa

1. Farmer-based production of good quality seed potatoes

To alleviate the shortage of quality seed potatoes of locally preferred varieties, technologies to enhance farmer-based seed production and distribution has been identified. Approaches such as seed plot technology (SPT), positive selection techniques (PST) and Quality Declared Seed (QDS) systems have the potential for improving access to better quality seed potato. The seed-plot technique maximises tuber productivity per unit area through high-density planting in seed plots (synonymous with a 'nursery') (Kinyua et al., 2011). Due to a higher planting density, this technology can increase land productivity of disease-free seed potato than the case under standard plant spacing (Kinyua et al., 2011). In a previous study, SPT achieved a 2.5 to 3 times increase in land productivity and about 50 % bacterial wilt reduction compared to conventional plant spacing (Tindimubona et al., 2014). In another study in Uganda, Kakuhenzire et al. (2005) reported 14.3 % bacterial wilt latent infection of seed tubers from SPT while conventionally planted tubers had 31.3 %. In Kenya, the SPT more than doubled yield per unit area and recorded lower incidence of both field and latent bacterial wilt infection compared to conventional plant spacing (Kinyua et al., 2001). In SPT, well-sprouted seed tubers are planted on disease-free land at a spacing of 30 cm x 30 cm and the plants are nurtured up to maturity to obtain seed for the following season. This is contrary to the ware potato fields where plants are grown under standard spacing such as 70 x 30 cm in Uganda; 75 x 30 cm in Kenya and 80 x 30 cm in Burundi.

Positive selection is an old technology that was used primarily in formal seed potato system where mother plants were selected from the best plot of potatoes as the starting point of the multiplication system (De Bokx and Van de Want, 1987). The best-looking potato plants in a field are marked at flowering time because crop senescence may obscure disease symptoms. The marked plants serve as source of seed to be planted in the following season. Positive seed selection involves identification and pegging of robust and healthy-looking plants during crop growth, just before flowering. Two weeks later, the health status of the pegged plants is checked in order to remove pegs from the plants that exhibit disease symptoms. At maturity, the plants that ultimately remain pegged are subsequently harvested individually, ensuring that plants with few, small or malformed tubers are disregarded. This methodology was developed by the international potato center (CIP) to train potato farmers to produce their own quality seed potatoes to bridge the huge gap of insufficient certified seed (Gildermacher, 2011a). Positive selection has been used in Central Africa as the starting point for a seed multiplication system (Haverkort, 1986).

In 2004, the Uganda National Seed Potato Producers Association (UNSPPA) with support from the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) began promoting positive selection and seed plot techniques in south-western Uganda; a major potato producing zone in the country. Ten years later, yield increase of about 34 % was recorded in the region (Tindimubona et al., 2014). Positive seed selection is credited for increasing potato yields to at least 30 % higher than farmers' practice in Kenya (Gildemacher et al., 2011b; Kinyua, 2011), 39 % in Ethiopia, 50 % in Uganda and 60 % in Burundi. According to Gebremedhin et al. (2008), positive selection resulted in a yield increase of about 40 % in Ethiopia. Farmers' practice involves selection of seed tubers from the bulk of the ware potatoes after harvesting with no regard to the health status of the mother plants (Schulte-Geldermann, 2012). In most cases, the smallest tubers are selected as seed. These tubers produce few stems and the weak plants are vulnerable to harsh climatic conditions, pests and diseases resulting in low yields. The benefits of positive seed selection are in terms of reduced disease incidences of bacterial wilt (BW) and viruses and increased productivity. In a previous study, positively selected seeds (PSS) yielded more than farmer selected seed (FSS); while yields between PSS and basic seed (BS) were not significantly different (Aheisibwe et al., 2015). Positive selection in potatoes during one cropping cycle resulted in an overall yield increase of 28 % (Gildemacher et al. 2011b), 30 % (Schulte-Geldermann et al., 2012) and 37 % (Siddique et al., 2017) compared to farmers' selection. In a study involving several selection cycles, the average yield increase resulting from positive selection was 12 % higher than farmer selected seed (Priegnitz et al., 2020).

The Quality Declared Seed (QDS) is an improved seed where some flexibility is allowed in implementing quality standards compared to the formal system. The QDS system is mainly implemented by trained farmers for production of seed that meets at least a minimum standard of quality but does not entail a formal inspection by the official seed certification system. The intent behind the QDS system is to provide farmers with the assurance of seed quality while reducing the burden on government agencies responsible for seed certification. The QDS system is considered by FAO to be part of the informal seed system. Quality declared systems differ from a formal seed certification scheme in that QDS protocols allow for less rigorous and lower cost inspection regimes, by taking into consideration local conditions to ensure they are appropriate for target users. Quality declared seed has the potential to bridge the formal and informal systems by catalyzing the development of the former while simultaneously upgrading the latter to a higher quality semi-formal level (FAO, 2016). For vegetatively reproduced crops such as potato, it is called Quality Declared Planting Material (QDPM) (Fajardo et al., 2010). The overall goal of QDS is to raise the physiological and phytosanitary quality of the seeds available to smallholder farmers, and as a consequence, increase agricultural production and productivity (Fajardo et al., 2010). The QDS system is meant to be implemented primarily by seed producers at community level or field extension workers. Ethiopia adopted the QDS in a new seed law passed in 2016 without distinction of crops (Devaux et al., 2020), while in Uganda, the government recognizes both the formal and informal seed supply channels in its policies and programmes (FAO, 2016). Consequently, farmers can buy quality-declared seed tubers from UNSPPA (CIP, 2011). However, the supply of these seeds often does not meet the high demand (Kakuhenzire et al., 2015) and they are too expensive for most farmers. Although the near-formal system practised by UNSPPA provides improved seed, it satisfies less than 2 % of national demand (Tindimubona et al., 2014). In Kenya, informal seed and QDS systems are not officially recognised by the law and trade in such seeds is illegal (KEPHIS, 2016). In Tanzania, QDS are recognised by the law.

2. Public and private sectors involvement in seed potato production

In East Africa, production of seed potatoes in the formal system is mainly carried out by the public research institutions. In Kenya, for example, the main public bodies involved in production of certified seed potatoes are Kenya Agricultural and Livestock Research Organization (KALRO), Kenya Plant Health Inspectorate Service (KEPHIS), Agricultural Development Corporation (ADC) and Ministry of Agriculture, Livestock and Fisheries (MoALF). The KALRO conducts potato breeding activities and also produces breeders and basic seeds. It carries out testing and evaluation of the breeding material and submits potential varieties to KEPHIS for further trials and official release of successful candidates; KEPHIS regulates seed certification in Kenya. The ADC multiplies breeder seed (or basic seed) obtained from KALRO and then bulks and sells certified seed potatoes to ware potato farmers. To facilitate seed multiplication, ADC uses its own farms and contracts out growers. However, ADC lost most out growers over time due to financial constraints and their capacity to produce certified seed potatoes was hampered even further by re-allocation of their own multiplication farms to other uses (KEPHIS, 2016). Private sector players have come up to complement the efforts of public sector. There are about 28 registered seed potato producers in Kenya of whom 4 are public institutions (NPCK, 2021). The private companies are local, foreign, large and small. Some large companies, both local and foreign include Agrico East Africa Ltd, Kisima Farm Ltd, Suera Flowers farm, Genetic Technologies International Ltd and Stockman Rozen Ltd, among others (KEPHIS, 2016; NPCK, 2021).

In Tanzania, the biggest producer of certified seed potatoes is Mtanga Farm Ltd, a private company located in the Southern highlands of the country. It is the only modern, commercial seed farm with an output of over 1200 tons of seed potatoes produced from minitubers. Mtanga seed potatoes are grown from tissue cultures and multiplied under controlled conditions on their farmland. The company deals in locally bred and imported varieties. It supplies seed potatoes to the Southern highlands zones of Njombe, Iringa and Mbeya districts; these are the major areas for production of ware and seed potatoes in Tanzania (Harahagazwe et al., 2018b). The second biggest seed potato producer is the Agricultural Research Institute-Uyole (ARI Uyole) also located in the Southern highlands. This is a public institution and produces limited quantities of early generation seed. It is involved in production of quality declared plating materials. The third producer is The National Agricultural Research Service (NARS), a public institution. These public institutions produce in-vitro materials and minitubers, resulting in limited amounts of healthy seed for farmers.

In Rwanda, the seed potato system is heavily funded by the government. The formal seed sector is mainly organized and managed by the Rwanda Agricultural Board (RAB) within the Ministry of agriculture and animal resources (MINAGRI). The RAB is in charge of the breeding program; it also carries out seed multiplication together with the private sector (Ferrari et al., 2018). In 2013, the International Fertilizer Development Center (IFDC), in collaboration with RAB and the extension service (IMBARAGA and BAIR), supported the entry of private entrepreneurs in the formal seed sector by providing financial and technical support. The private sector is hardly involved in production of certified seeds due to the low effective demand from farmers, low availability of pre-basic and basic seeds for multiplication and restrictions on import of pre-basic and basic seeds. In Uganda, basic seed is produced by Kachwekano Zonal Agricultural Research and Development Institute (KAZARDI) under the National Agricultural Research Organisation (NARO). Kachwekano Zonal Agricultural Research and Development Institute is mandated to conduct research on potatoes. The basic seed is then sold to registered seed multipliers such as UNSPPA who multiply it for one more season before selling to ware potato growers (Byarugaba et al., 2017).

In Ethiopia, there is no public formal seed potato supply system. This is because the legal framework for a formal root and tuber seed certification scheme has not been implemented (AgroBIG, 2016). Solagrow Private Limited Company (PLC) is the only modern commercial seed potato producer in the formal seed potato system in Ethiopia (Hirpa et al., 2016). It was established in 2006 by a group of Dutch investors in collaboration with the Dutch potato breeding company HZPC Holland BV. Solagrow PLC obtains basic seed from HZPC Holland BV and Holetta Agricultural Research Centre. Holetta Agricultural Research Centre (HARC), Solagrow PLC and the District Bureau of Agriculture (DBARD) are the main institutions that provide support to the formal and alternative seed potato systems. Solagrow PLC provides inputs and technical advice to the seed potato out-growers to ensure good quality produce. Holetta Agricultural Research Centre provides seed potatoes to smallholder farmers and commercial seed growers. Holetta Agricultural Research Centre, in collaboration with CIP, has been developing new potato varieties and introducing new technologies to the farmers. The role of Holetta is to test CIP potato clones for Ethiopian growing conditions. The land administration section of DBARD is responsible for providing land for seed potato production (Hirpa et al., 2016). The public tissue culture laboratories actively involved in seed potato production are at Holetta Agricultural Research Centre, Amhara Regional Agricultural Research Institute and Mekelle Agricultural Research Center. Other tissue culture laboratories are owned by a local non-governmental organization called Organization for Rehabilitation and Development of Amhara (ORDA) and the private company, SOLAGROW (Harahagazwe et al., 2018b). The Burundi formal seed supply system is one of the most robust and functional programs in sub Saharan Africa. In this country, public investments play a key role at initial stages of the chain (i.e., from micropropagation to the second field generation). Almost all *in vitro* plantlets are produced by the National Agricultural Research Institute (ISABU) through its Potato Research Program. However, private investments are minimal (Harahagazwe et al., 2018b).

2.1 Seed multiplication techniques employed by public and private sector players

A prerequisite to a successful and sustainable seed potato scheme is a continuous supply and maintenance of pathogen-free seed. Potatoes have a low multiplication ratio; about 1:10 to 1:15 tubers per plant per season. The conventional way of producing quality pre-basic seed potato is to multiply clean *in vitro* plantlets in the greenhouse. The plantlets are planted in pots or trays; these are then placed under protective structures such as greenhouse or screenhouses to produce minitubers. This method is slow and usually produces of 5 to 10 minitubers per plant. Consequently it takes long, about five to seven seasons of

seed production (i.e. five to seven field generations) before certified seed potato is affordable. In addition, the high number of field multiplications increases the likelihood of contamination with soil-borne pathogens such as bacterial wilt. This bottleneck called for adoption of accelerated seed potato multiplication systems. Some rapid multiplication techniques (RMT) that are being used in different countries include stem/shoot cuttings, aeroponics, sandponics, and hydroponics among others; these methods are used to produce minitubers from tissue culture-produced in-vitro plantlets. The RMTs are used to increase the amounts of nuclear seed stocks and hence reduce the number of field multiplication cycles. In the 1970s and 80s use of stem cuttings became a rapid way of producing minitubers in substrate in greenhouses. These stem cuttings mainly originated from a sprouted tuber. The mother plant always had compound leaves indicating physiological maturity. Due to maturity, the yields from stem cuttings were low, about 2–5 tubers per stem cutting (Van der Zaag et al., 2021). Some RMTs provide higher multiplication ratios (1:40 or more) and also lower the rate of seed contamination particularly from soil-borne pathogens. Aeroponics is a fairly recent technology. It consists of a soilless culture in which the underground part of the plant is enclosed in a dark chamber and supplied with nutrients through a misting system. The plants produce minitubers on the roots hanging in the dark chamber. The minitubers are harvested regularly as they reach the desired size by opening the dark chamber without destroying the plant. With an aeroponics system, productivity may be very high averaging over 45 minitubers per plant (Mateus-Rodriguez et al., 2013). Consequently, the system can produce high minituber yields, more quickly, and at lesser cost than conventional growing methods. At the International Potato Center, Peru, yields of more than 100 minitubers/plants have been obtained from aeroponics (Otazu, 2010). Between 2008 and 2011, CIP with financial support from the USAID, partnered with Kenya, Uganda, Rwanda, Ethiopia and Malawi and implemented a "3 Seed Potato Generation Revolution'' (3G) approach that hoped to reduce the time taken to produce certified seed potatoes. With the 3G strategy, a large number of minitubers are produced in one generation using rapid multiplication techniques (RMT) from *in vitro* plantlets. The minitubers are then multiplied in the field for two generations (hence a total of three generations) to produce the same quantities of seeds that under conventional practices would require from four to six field generations. The 3G strategy reduces the cost of production and reduces the build-up of soil-borne diseases in the field. The introduction of the '3G' concept led to a drastic increase in the number of minitubers produced in all five countries (Uganda, Rwanda, Malawi, Kenya and Ethiopia), from 187,000 in 2008 to 2,110,000 minitubers in 2013 (Demo et al., 2015; Table 1). In addition, the project introduced and promoted the use of sand hydroponics and aeroponics in the region. Introduction of aeroponics in sub-Saharan Africa resulted in a large increase in minituber production (Harahagazwe et al., 2018b). However, the total numbers are still low and minitubers are expensive. Large scale use of aeroponics system in low-income countries such as those found in East Africa is costly and unsustainable. This is because resources are scarce, the technology requires skilled labour and electricity supply is unreliable and/or unavailable in most cases (Mateus-Rodriguez et al., 2013). Sand hydroponics is an attractive alternative because it does not require electricity power and highly skilled labour. In recent times, another technology, use of rooted apical cuttings, was introduced in East Africa to enhance minitubers production even further. Apical rooted cuttings have long been used in South East Asia (Vander Zaag and Escobar 1990), and particularly in Vietnam (Tran et al., 1990). Instead of allowing tissue culture plantlets to mature and produce minitubers, cuttings are produced from the plantlets. The two-node apical cuttings (4–5 cm long) are harvested several times at intervals of 2–3 weeks from in vitro-derived mother plants. Cuts should be obtained as soon as apical shoots have grown 5–7 cm high, or if the shoot has 4–7 complete leaves with 2–3 internodes. The mother plant is maintained physiologically young and apical cuttings are taken repeatedly for several months. It is critical to maintain the mother plants in a juvenile simple-rounded leaf state so as to increase the productivity of the apical rooted cuttings in the field. The apical cuttings are then rooted in trays containing a substrate of coconut sawdust, clean subsoil, and sterilized decomposed manure. Once rooted, the apical cuttings are transplanted directly in the field, thereby saving one generation as minitubers are no longer needed (Parker, 2017). Consequently, rooted apical cuttings produce more disease-free seed tubers in less time and for less money than other seed multiplication technologies. This technique is being promoted by CIP in sub-Saharan Africa to provide a simple but effective technique for multiplying early generation seed (Parker et al., 2019). In Kenya and Uganda there is a rapid adoption of this technology by seed producers, smallholder farmers and youths. In Kenya, the technology is being used by KALRO's Tigoni Potato Research Centre and some private companies such as Stokman Rozen Kenya (SRK) Ltd, Kisima Farm Ltd, and Genetic Technologies International Ltd (GTIL). The rooted apical cutting are then sold to individual farmers for seed potato production. Yields obtained from rooted apical cuttings have been robust and average 8–18 tubers per plant depending on the variety and management (Van der Zaag et al., 2021). Consequently, apical rooted cuttings have been endorsed by the Kenya Plant Health Inspectorate Service (KEPHIS) into the seed certification protocol to bulk up seed potato for multiplication and distribution to potato growers. In a bid to promote this technology even further, about 10 satellite nurseries investing in production of apical cuttings have been setup in major potato growing counties in Kenya. These nurseries were initiated by bodies such as Farm Inputs Promotions Africa, CIP, World Food Program as well as private companies (Van der Zaag et al., 2021). The private sector in Kenya plays a major role in seed potato systems. Companies like SRK and GTIL have large-capacity tissue culture laboratories and seed production is determined by the orders they receive from their customers (Harahagazwe et al., 2018b). In addition to apical rooted cuttings, other methods used to multiply seed potato in Kenya include aeroponics, hydroponics and the conventional pots in the screenhouse. Despite private investors' entry into the potato value chain in Rwanda, RAB's potato program is still considered to be the hub of the formal seed production (Ferrari et al., 2017). Rwanda Agricultural Board (RAB) is the major producer of minitubers in the country with facilities located in three research stations. The tissue culture laboratory owned by RAB and located at Musanze is most likely the largest of national laboratories producing in vitro potato plantlets in SSA.

Table 1. Number of minitubers produced in five African countries between 2008 and 2013.

Country	Number of minitubers produced (x 1000)	
	2008	2013
Kenya	33	789
Uganda	11	104
Rwanda	75	715
Ethiopia	68	389
Malawi	0	113
TOTAL	187	2110

Source: Demo et al., 2015.

Most of minitubers are produced at Musanze, which is the headquarters for the potato program. It is also in Musanze where the two biggest aeroponics units in SSA are located (Harahagazwe et al., 2018b). Rooted apical cuttings technique is being tested by a parastatal agricultural company, Horizon SOPYRWA. In Tanzania, seed potatoes are mainly produced from tissue culture *in-vitro* plantlets and minitubers. The conventional technique for producing minitubers is no longer in use (Harahagazwe et al., 2018b). For minituber production, three institutions are very active: ARI–Uyole, Mtanga Foods Ltd, and Beula Seed Company. In Ethiopia, minitubers are produced from stem cuttings and tissue culture *in-vitro* plantlets. The *in-vitro* plantlets are planted either in pots in screen houses or under aeroponics facility (Chindi et al., 2014) to produce minitubers. In 2010, the Ethiopian Institute of Agricultural Research (EIAR), with support from the Common Fund for Commodities (CFC) and USAID, established two aeroponics units at Holetta Agricultural Research Center (HARC) for production of minitubers (Chindi et al., 2014). Later, sand hydroponics was introduced from CIP and established at HARC in 2013 (Chindi et al., 2014) to enhance minitubers production. In Uganda, seed potato production mainly relies on the conventional production of minitubers from *in vitro* plantlets in the screenhouse. The minitubers are then multiplied in the field for two seasons to produce basic seed (Van der Zaag et al., 2021). At the National Agricultural Research Organisation (NARO) -Uganda minitubers are produced using both the conventional and aeroponics techniques; although the former is prominent. Apical rooted cuttings are currently being experimented by public and private entities in Uganda (Van der Zaag et al., 2021). In Burundi, minitubers are produced through conventional methods as well as aeroponics. Sand hydroponics were established in 2017 (Harahagazwe et al., 2018b).

2.2. Seed imports

Importation of seed potatoes mostly from the European countries is becoming increasingly important. For instance, Algeria, Egypt, Morocco and Tunisia are the major importing countries of seed potatoes in Africa while Canada, Netherlands, France and the United Kingdom export considerable quantities of seed (Kees 2007). European varieties, mainly from the Netherlands, are being introduced and registered in SSA countries (Harahagazwe et al., 2018b). Commercial importation of seed potatoes in East Africa by private sector players started in recent times. In the East African region, there has been a limited number of potato varieties with good processing qualities. This is because public research institutions in the region gave priority to breeding for traits such as disease resistance, early maturity and high yields while little attention was given to processing attributes (Kaguongo et al., 2008). In addition, the processing industry which is growing rapidly in the East African region requires a regular supply of quality potatoes of suitable varieties. To bridge the gap, these processing companies have been importing potatoes from countries such as Egypt, and South Africa. There have also been imports of finished products from Asia and other regions. On the contrary, countries such as The Netherlands, Germany, Scotland and South Africa have bred many potato varieties that are suitable for processing. With proper arrangements, these varieties could be accessed, evaluated, and released in the East African countries. Seed companies, mostly from European countries, noticed this business opportunity and took advantage of their countries' political and economic might to negotiate for favourable importation terms. For example in 2011, Kenya and The Netherlands entered into a bilateral agreement whose goal was to increase and diversify availability of the potato varieties to meet the dynamic market demand and food security against a surging population and changing climatic conditions. The agreement provided the guidelines to be followed in order to prevent possible introduction of quarantine pests and diseases. The agreement stipulated that introduced candidate varieties have to be tested in National Performance Trials alongside varieties from local breeders, and that only small quantities of new varieties from limited sources are regularly imported for planting in designated locations and with initial inspections performed jointly by inspectors from Kenya Plant Health Inspectorate Service (KEPHIS) and General Inspection Service for Agricultural Seeds and Seed Potato (NAK) (Komen et al., 2017). Thereafter, some other European countries such as Scotland followed suit.

Between 2011 and 2015, 33 new Dutch varieties were released into the Kenyan market (KEPHIS, 2016). In Burundi, there were no imports of seed tubers by 2017 (Harahagazwe et al., 2018b). In other East African countries importation of seed potatoes is at different stages.

Lack of a well-developed local formal seed potato system is used to further justify the seed importation initiatives (Kaguongo et al., 2015). The importation is meant to boost seed volumes available to farmers and introduce new varieties in the local market (KEPHIS, 2016). However, most of these seeds are imported as minitubers. The major threat to importation of seed potatoes in this form is the risk of disease transmission across countries. There is need for importing countries to put in place effective phytosanitary measures to mitigate against risks of pest entry.

Way forward

Increasing availability of good quality and affordable seed potatoes to small scale farmers in East Africa calls for concerted efforts of the governments, private sector players as well as farmers. Governments need to invest in local breeding activities and multiplication of early generation seeds. Public breeding of locally adapted and market

demanded varieties will spur uptake of new varieties as issues of breeders' right will be sorted. Public multiplication of early generation seeds will increase availability of basic seeds to certified seed multipliers. Seed multiplication methods that are affordable, efficient and locally sustainable should be embraced. This is because some technologies such as aeroponics, though highly productive, may not be sustainable in areas with no electricity. In addition, seed certification by the governments should be relatively cheap; this will encourage the private sector players to invest in certified seed potato production. Where possible, farmers' groups should be trained on production of good quality seeds, such seeds should be officially recognised by the governments. Seed imports are not sustainable and should only be encouraged in case of emergencies. In addition, imported seeds should not be in form of minitubers as the danger of introducing new tuber-borne pests and diseases is high. In case seed imports are needed, they should be in form of *in-vitro* plantlets, these can be easily indexed and cleaned of any viruses.

Conclusion

Availability of good quality seeds of preferred varieties in adequate quantities is key in improving potato productivity. Production of good quality seed potatoes in East Africa had been the responsibility of public institutions for a long time; however, these seeds have been inadequate and expensive. Consequently, most potato farmers have been planting seeds from informal sources. These seeds are often of poor quality resulting in low potato yields and widespread incidences of viruses and diseases such as bacterial wilt. To salvage the situation, promotion of mass production of clean seed from *in-vitro* plantlets using rapid multiplication techniques should be embraced. In addition, involvement of the private sector and community-based organizations in production of good quality seeds will go a long way in increasing seed availability. Seed imports, mostly from European countries, do not appear sustainable in the long term and may introduce new pests and diseases if not properly handled.

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