Chapter 12
Potato Seed Systems

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Abstract Good quality seed is almost universally considered a requirement for high productivity in all potato production systems. Much of the yield gap currently constraining productivity in low-income countries is attributed to the poor quality of seed. Potato seed sector development is thus a major concern of governments, researchers, development agencies, and civil society organizations. Potato seed systems are often characterized as formal or informal, although the informal seed system is complex and particularly in low income countries there are many linkages between the two systems. Informal seed potato systems in the Andes have existed for centuries, and for a number of reasons often produce seed of relatively high quality. In other low-income countries, informal systems produce seed of variable and frequently poor quality, contributing to very large yield gaps, characteristic of those areas. In regions of high potato productivity (e.g., the USA and Europe), formal systems, with seed of certified high quality, are dominant, although some productions subsectors (e.g., organic producers) often use seed that is not certified. Efforts to implement formal seed systems in low-income countries have been largely unsuccessful; consequently the vast majority of low-resource potato farmers source their seed via the informal system. Sectors of the development community

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are pushing for alternative solutions, which generally involve some form of integrating formal and informal seed systems or semi-formal systems such as quality declared seed, and a policy structure that preserves farmers' rights to save and trade seed. Given the role that seed quality is currently playing in the low yields of potato in low-income countries, which is not the case in wealthier parts of the world, the review focuses primarily on seed sector development in resource-poor areas.

12.1 The Seed System Context

Seed system research and lexicon In keeping with the large social and economic dimensions of potato seed systems (discussed in more depth later in the article), research on seed systems is extensive and multifaceted, and terminology used to describe seed-related issues is varied and often confusing. Thiele (1999) broadly defined a seed system as "an interrelated set of components including breeding, management, replacement and distribution of seed." This definition is generally consistent with one established earlier at a workshop held in 1995 in Indonesia, "the total of physical, organizational and institutional components, their actions and interactions, that determine seed supply and use, in quantitative and qualitative terms" (Amstel et al. 1996), and with other definitions given since then (Camargo et al. 2004; Muthoni et al. 2010; Kromann et al. 2016). In recent years, patents and plant variety protection have added the additional dimension of intellectual property and germplasm ownership, and these impact plant breeding, crop management, seed replacement, and distribution of seed.

Seed systems have also been classified by type, with the major classes being formal and informal (Thiele 1999). The concept of a formal seed system is relatively clear, being characterized by components that are regulated by the public sector, usually by an inspection process known as "certification" and including controls over variety release, to ensure that available seed is of a recognized variety and with a low incidence of disease (Louwaars 1994; Amstel et al. 1996; Thiele 1999). The informal system is complex and conceptually less clear in that it basically includes all that is not formal, including self-saved seed, seed traded among farmers, and that acquired at local markets (Thiele 1999; Almekinders and Louwaars 2002; McGuire and Sperling 2016). While all seed outside the formal system is frequently referred to as "informal," it is also referred to using other terms, such as "farmers' seed" (Almekinders and Louwaars 2002), "local seed" (Almekinders et al. 1994), or "traditional seed" (McGuire and Sperling 2016). For this chapter, we will use the term "informal."

Several authors have highlighted the importance of the informal seed system in middle-low and low-income countries (hereafter referred to as low- income, Thiele 1999; Almekinders and Louwaars 2002; Louwaars and de Boef 2012; McGuire and Sperling 2016), including a particular focus on potato (Thiele 1999; Thomas-Sharma et al. 2015). The literature is also strongly supportive of the need to integrate formal and informal sectors in countries where the former provides only a small portion of seed that is needed (Louwaars 1994; Amstel et al. 1996; Thiele 1999; Louwaars and de Boef 2012; Thomas-Sharma et al. 2015; De Jonge and Munyi 2017). The strategy of integrating different seed systems has had practical implications in the development sector with reports on specific cases (e.g., Kromann et al. 2016) and through the development of programs focusing on an integrated approach to seed system development.

In spite of broad recognition of the role of the informal seed system by the academic community, seed sector development has reflected "varied and often opposing philosophies" (McGuire and Sperling 2016). Many development projects have been designed only (or primarily) to support the formal seed sector in low-income countries and have relied on outside expertise, without significantly increasing the minimal role that certified seed plays in providing planting material to low-income farmers (McGuire and Sperling 2016); this is particularly true for potato seed systems (Thomas-Sharma et al. 2015). Even in countries with strong formal seed systems, the formal seed system can fail farmers who do not grow the crop as a commodity. For example, organic farmers in the US commonly use informal seed for specialty and heirloom varieties and this is yet more evidence that formal seed systems only work for growers who specialize in large acreages of potato.

Why are potato seed systems important? Healthy seed systems have been described as providing access to quality planting material, at the time needed, at a fair price, to all who need it (Sperling 2008). Access to quality seed is widely considered one of the main requirements for bridging large yields gaps for potato still found in most low-income countries (Hidalgo et al. 2009; Schulte-Geldermann 2013). Healthy seed systems also act as to reduce risk of disease outbreaks by keeping spread of a disease in check or even as part of a pest eradication plan. Conversely, seed systems without effective quality control can be very efficient at spreading seed-borne pathogens. Seed systems are also important for the diffusion of new varieties with beneficial traits and the maintenance of crop diversity in the landscape (Pautasso et al. 2013; Arce et al. 2018). In the case of a new or emerging pathogen in a region, the seed system acts as the conduit through which locally adapted resistant varieties can be distributed (if these are available).

Arguably, the primary impetus for development of seed systems in potato is the vegetative nature of propagation of the crop, and the phenomenon of what is now referred to as degeneration (Fig. 12.1). The importance and causes of seed degeneration, a process through which yield is lost in vegetatively propagated crops through pathogen accumulation in consecutive cycles of propagation, are of particular concern to informal seed systems. Globally, seed degeneration is among the leading limitations to potato yield (Thomas-Sharma et al. 2015; Bertschinger et al. 2017). In high-income countries, which have the highest potato yields, this problem has been effectively managed, at least for large commercial growers, through the utilization of seed certified to have high quality (low incidence of pathogens, varietal purity, and appropriate physiological age). This process has been highly successful for most producers in these countries by providing access to economically priced seed of high quality.

Fig. 12.1 Degeneration in potato. Small plants with low yield due to the accumulation of pathogens in consecutive cycles of vegetative propagation. (Photo credits: G. Forbes)

For smallholder farmers from low- to middle-low-income countries, certified seed is often not available, or the cost is prohibitive. Instead, farmers acquire seed of unknown quality via the informal system, either from the previous year's crop, or from other informal sources such as those mentioned above. In informal systems, degeneration is often a problem because seed is not tested and may be produced under conditions of high disease pressure with little or no quality control.

12.2 Traditional Potato Seed Systems in the Andes

The Andean region is the origin of the cultivated potato and represents an interesting case for studying potato seed systems (Fig. 12.2). Potato seed systems in the Andes have been informal for millennia, and even today only small amounts of formal seeds are used by Andean farmers (Hidalgo et al. 2009; Devaux et al. 2014). With even relatively low rates of disease spread, one could assume that high levels of degeneration would occur in areas where the informal system has been dominant for centuries. However, studies done in traditional Andean potato seed systems over the past 30 years often found relatively low frequencies of tubers infected with yield-limiting potato viruses (Bertschinger et al. 1990; Fankhauser 1999; Pérez et al. 2015; Navarrete et al. 2017).

Several factors have been identified that could contribute to the continued quality of seed potato in the informal systems in the Andes. Andean farmers have

Fig. 12.2 Native varieties in the Andes. Seed for producing most of these varieties come from informal systems, but major yield-limiting potato viruses, which are the most common cause of seed degeneration and are often found in relatively low frequencies. (Photo credits: J.L. Gonterre, in association with the International Potato Center)

traditionally had complex farming practices that conceivably help reduce the soil-borne phases of diseases leading to degeneration, such as sectoral (Orlove and Godoy 1986) or other types of fallowing and rotation (Thurston 1990), high hilling, or reduced cultivation methods (e.g., Cartagena et al. 2004). Other factors characteristic of Andean potato systems may contribute to reduce disease spread among plants or pathogen transmission within plants. Resistance to PVY and PLRV have been found in *S. tuberosum* subsp. *andigena,* and *Ry* genes have been found in other Andean taxa making up local potato landraces (Machida-Hirano 2015), which may partly explain low incidences of PVY and PLRV found in these varieties. Bertschinger et al. (2017) also found that virus transmission from infected mother tubers to daughter tubers was greatly suppressed at high altitudes in the Andes. This is consistent with traditional practices in which farmers moved virus-infected seed to higher altitudes to reduce infection (Thiele 1999). High levels of agrobiodiversity may also help mitigate degeneration in traditional Andean potato fields. One study found that Peruvian farmers growing native "floury" cultivars between 3500 and 4250 m altitude had on average between 8 and 20 different genotypes per field (de Haan et al. 2010). This biodiversity is "uneven" in that it is highly dependent on the type of farmer, but it is also an important component of a complex seed exchange network that represents "a strong safety net through which smallholders can respond to crop failure and seed stress" (Arce et al. 2018).

12.3 Potato Seed Systems in Europe and North America

The basic outline of the seed system used in Europe and North America for potato was developed in the late nineteenth and early twentieth centuries and has its roots in how seed potatoes are grown in the Andes (Shepard and Claftin 1975; Frost et al. 2013). Considerable advances were made in the 1980s, when both pathogen testing and potato micropropagation became widespread. Despite the use and availability of technology, seed potatoes are produced primarily in the northern agricultural regions of these two continents to avoid insect virus vectors, and a wide range of bacterial and fungal diseases common in warmer climates. In Europe and North America, commercial growers who plant large acreages of potato almost exclusively use certified seed. However, in the United States, farmers who manage mixed vegetable farms, and particularly organic farmers, generally use informal seed, demonstrating that current seed systems tend to best serve growers who produce potato as a commodity.

In these seed systems, potato varieties are maintained in tissue culture as micropropagated plantlets. These initial plantlets, often called mother plants, are tested for all pathogens of concern, including the major potato viruses, potato spindle tuber viroid, and common bacterial and fungal pathogens (Frost et al. 2013). Propagation in tissue culture is relatively inexpensive, requires little space, and the plantlets grow quickly, so hundreds of thousands of plantlets can be produced annually in a relatively small facility of tens to a few hundred square meters (Naik and Buckseth 2018). The micropropagated plantlets are then planted into greenhouses or screenhouses into either pots or into hydroponic or aeroponic systems. The potatoes harvested from these greenhouse-grown plants are called nuclear seed or minitubers. The minitubers must be stored until the subsequent season to break tuber dormancy. Minitubers are planted into seed potato fields and the progeny from these plants are generally field-multiplied another 2–5 years before being sold to farmers who grow potatoes for fresh use or processing.

At each stage, specific inspections and pathogen tests are required for the certification schemes used in each country, state, or province where potatoes are grown. Generally accepted protocols are collected and verified by entities such as the European and Mediterranean Plant Protection Organization (EPPO), the North American Plant Protection Organization (NAPPO), and the United Nations Economic Commission for Europe (UNECE) to aid in trade in certified seed potato. The efforts have had some success, with increases in yield and near-elimination of diseases such as spindle tuber and bacterial ring rot (Frost et al. 2013). Policy harmonization has also engendered debate in low-income countries (De Jonge and Munyi 2017) and in Europe (Prip and Fauchald 2016). In the United States, seed potato producing states still have relatively little similarity in their certification regulations across the different states. Currently, potato virus Y is the most important potato virus on these continents, but losses due to this virus are relatively small (Zeng et al. 2018).

These certification systems primarily focus on diseases that are only spread by seed potatoes and not on important soil-borne pathogens. As a result, diseases such as powdery scab, corky ringspot, golden cyst nematode, and other difficult-to-control diseases are now widespread and increasing in importance (e.g., Beuch et al. 2014; Contina et al. 2018). A second challenge is that plant variety protection has resulted in the proliferation of similar, but protected varieties, for which little information on disease response is available. This poses a significant challenge to certification agencies, which are tasked with insuring varietal purity and disease thresholds on an ever-increasing number of new potato varieties. Finally, growers in both Europe and North America are investing in the development of inbred and hybrid diploid varieties that can be produced through true seed rather than plant micropropagation (Lindhout et al. 2011; Jansky et al. 2016). If these varieties become popular, they will alter the current seed system.

12.4 Potato Seed Systems in Low-Income Countries

Earlier we stated that low-income countries are characterized by informal seed systems with very low use of certified seed. This is generally the case, but it is worth examining in some detail efforts that have gone into establishment of certified seed programs in some of these countries, as well as a number of recent innovations aimed at improving seed systems of resource-poor farmers.

The highly conspicuous absence of certified seed in the potato seed sector in most low-income countries has recently been documented, at least in part. In specific reference to potato, Thomas-Sharma et al. (2015) list percentages of formal and informal seed in 14 low- income countries. In China and India formal seed usage is listed at 20%, but in all other countries it is below 10% and in most it is below 5%. McGuire and Sperling (2016) provide a more extensive examination of how farmers source many kinds of seed in low-income countries and note that for potato over 95% of seed comes from own stock, friends, neighbors, relatives, or local markets, i.e., the informal system (Fig. 12.3). It is worth noting for context that

Fig. 12.3 Informal seed potato in a local market in Bangladesh. (Photo credits: J. Andrade-Piedra)

these authors also show that in low-income countries there is a similar pattern for all vegetatively propagated crops and, somewhat surprisingly, for legumes and cereals as well.

The lack of certified seed for potato and other crops in low-income countries is not easily attributed to a lack of effort on the part of governments and development agencies. McGuire and Sperling (2016) provide an impressive list of projects funded by the World Bank and by the Alliance for a Green Revolution in Africa (AGRA) as an indication of development support to seed systems in low-income countries. In the preparation of this document we were not able to find data on investments specifically in the potato seed sector in developing countries, but there is no doubt that many millions of dollars have been spent by development agencies over the last half a century to improve the potato seed sector in low-income countries.

Seed sector actors, and specifically donors, in low-income countries take different approaches to the problem, which may be generally classified into two types: those that predominantly support development of a formal seed sector and those that support a broader approach to seed sector development (McGuire and Sperling 2011; Thomas-Sharma et al. 2015; Otieno et al. 2017). While a number of donors subscribe to broad seed sector development (Lossau et al. 2000), it is the experience of the authors that the large majority of projects, and certainly the larger projects supporting potato seed sector development, tend to focus primarily on formal seed sector development.

12.5 Perspectives on Potato Seed System Development

Policy Low-income countries are struggling with numerous policy issues related to seed. Many governments and regional organizations are developing policies and laws modeled on the guidelines of the International Union for the Protection of New Varieties of Plants (UPOV). This has led to much concern in civil society and in the research community of the impacts that such policies could have on resource-poor farmers and informal seed trade (Tripp and Louwaars 1997; De Jonge and Munyi 2017; Otieno et al. 2017; Vernooy 2017). The controversies surrounding these policies have given rise to both proponents and opponents of regional harmonization laws based on UPOV standards; opposing actors apparently rarely meet to debate options (De Jonge and Munyi 2017).

It is unclear what the eventual effects of this struggle will have on resource-poor potato farmers in these countries. Because of its vegetative nature, perishability, and bulkiness, seed potato (namely tubers whereas potato seed refers to true, botanical seed) presents particular difficulties for establishing breeding programs, implementing certified seed systems and marketing seed in a way that is commercially viable in low-income countries where the infrastructure and other elements of the business ecosystem are not favorable. This could be a major reason why there has been very little activity of major seed potato companies in low-income countries (Thomas-Sharma et al. 2015).

Funding for seed sector development represents an area where seed policy and seed sector development philosophy can affect resource-poor potato farmers. As noted, most funding in potato seed sector development over the years has been in support of the formal sector, with relatively little funding to optimize and promote on-farm seed management, which has been shown to be effective in slowing down or even reversing seed degeneration important in areas without access to certified seed (see below).

Underlying the struggle over seed regulation in low-income countries is the contrast, often seen as a dichotomy, between formal and informal seed systems. As noted, integration of seed systems (Louwaars and de Boef 2012; Kromann et al. 2016; Ferrari et al. 2017) has been proposed as a way to find common ground between those promoting commercial seed industry, plant variety protection, and harmonization of seed standards, and those promoting farmers rights to save and trade their own seed.

Although it was not intended as a mechanism to integrate seed systems, the quality declared seed (QDS) approach offers a more flexible alternative for seed quality assurance than strict certification programs. Developed by FAO (2006) and later adapted for potato and other vegetatively propagated crops (Fajardo et al. 2010), the QDS approach is being used in Ethiopia (Schulz et al. 2013) and some elements of it are applied in Ecuador (Kromann et al. 2016) and Peru (MINAGRI 2018). Seed potato produced under a QDS approach was shown to be a profitable business for seed multipliers in Kenya, but at the same time it has been ineffective in limiting the dissemination of bacterial wilt (*Ralstonia solanacearum*) and potato cyst nematode (*Globodera pallida*), which points out the need of rigorous testing and validation of the QDS approach to local conditions. However, formal seed systems also are unable to effectively limit the dissemination of pathogens such as *R. solanacearum* and *G. pallida*, so the QDS approach is not deficient compared to formal seed systems in this respect.

Technology Innovations A number of the technological innovations have been or are being evaluated and promoted to improve seed potato quality in low-income countries. Many of these are relatively old but have been recently revisited, and often adapted, for their application to certain situations, particularly where resources are scarce. Some of these technologies are reviewed here under two categories: those that relate to on-farm management of seed, and those relating to rapid multiplication of early generation seed.

On-Farm Seed Management Some relatively old technologies are receiving renewed consideration by seed specialists. Positive selection is implemented by farmers and consists of identifying and marking plants that have no visible symptoms of disease or abiotic stress. Seeds for the next planting are then taken from these plants. This sounds relatively simple and the activity itself is simple, however, the efficacy of selection can depend on many factors including, the type of virus, environmental conditions, and farmer skill. Positive selection is particularly important in areas where there is no access to seed produced under a quality control system, thus the impetus is on the farmer to manage quality control. Nonetheless, a number of studies have demonstrated significant improvements in seed quality at the farm level as a result of positive selection implemented by farmers (Gildemacher et al. 2011; Schulte-Geldermann et al. 2012; Okeyo et al. 2018; Priegnitz et al. 2018), which could be due to the fact that it is easier to identify a fully healthy plant than it is to identify symptoms potentially caused by virus or that could also be due to abiotic stresses (Gildemacher et al. 2011). When positive selection is used by farmers there is an increase in yield that could be attributed to several factors, one of these being a reduction in the incidence of virus infection (Schulte-Geldermann et al. 2012). To improve the utility of this relatively old approach, CIP and its partners developed a number of training guides for positive selection aimed at both farmers and trainers (Gildemacher et al. 2007).

Another old tactic that has received some renewed attention is the seed plot technique, which consists of producing small amounts seed of relatively high quality in a confined area that is free of or has a low incidence of soil-borne pathogens (Vashisth 1979; Bryan 1983; Kakuhenzire et al. 2005; Ali et al. 2013). There are many variations on this very simple principle that can be applied to devise flexible systems that adapt to different contexts. The initial seed may be purchased or may be derived from positive selection (Bryan 1983). The best seed coming from the seed plot, i.e., that produced with positive selection in the seed plot and further post-harvest selection, can be used for a new seed plot in the next season. The remaining seed from the seed plot is used for ware production. The seed plot technique can very easily be integrated with the purchase of small amounts of high-priced certified seed (Kinyua et al. 2015; Ochieng-Obura et al. 2016).

Rapid multiplication technologies Aeroponics is a more recent technology that has made inroads into the potato sector in the last few decades. This technique 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. Plants grown in this way produce minitubers in the dark chamber, which are harvested as they reach the desired size. Within an aeroponics system, plants may produce very high numbers of minitubers, with plants on average sometimes producing over 45 tubers (Mateus-Rodriguez et al. 2013). There is no shortage of research (and opinion) expounding the benefits of aeroponics (Muthoni et al. 2011; Chiipanthenga et al. 2012; Kakuhenzire et al. 2017; Lakhiar et al. 2018), but implementation of aeroponics in low-income countries where resources are scarce and power supplies unreliable is costly, difficult and risky (Mateus-Rodriguez et al. 2013). The introduction of aeroponics in sub-Saharan Africa has resulted in a large increase minituber production (Harahagazwe et al. 2018), although total numbers are still low and minitubers are expensive.

Unfortunately, feasibility and even economic analyses of rapid multiplication technologies used in development projects generally do not consider the role of the development community's purchase of seed, which is often a market-distorting factor in fledgling seed programs in low-income countries (Bentley and Vasques 1998; Bentley et al. 2001). Aeroponics is just one form of hydroponic plant production and other forms are also used in seed potato production (Lommen 2007; Corrêa et al. 2009), many of which are simpler than aeroponics and may be more appropriate for many low-income countries (Mateus-Rodriguez et al. 2013). For example, nutrient film hydroponic systems are widespread in North America and also present in Brazil and China. These systems are relatively easy to manage and yield and cost of production information is available (Guenthner et al. 2014). The appropriateness of a complex technology like aeroponics appears to depend on the capacity of local players and local infrastructure (Mateus-Rodriguez et al. 2013), hence sand hydroponics not relying on power and highly skilled labor is an attractive alternative.

Rapidly growing young vegetative tissue of potato can be cut and rooted in a number of ways (Bryan et al. 1981). Apical rooted cuttings have long been used in SE Asia (Vander Zaag and Escobar 1990), and particularly in Vietnam (Tran et al. 1990). This technique is being introduced into sub-Saharan Africa to provide a simple but effective technique for multiplying early generation seed (Parker et al. 2019) (Fig. 12.4). In the current application used in sub-Saharan Africa, two-node apical cuttings (4–5 cm long) are harvested several times at intervals of 2–3 weeks from in vitro-derived mother plants. The cuttings are then rooted in trays with a substrate of coconut sawdust, clean subsoil, and sterilized decomposed manure. Once rooted, the cuttings can be transplanted directly to the field to produce the first generation of tubers.

Cuttings are penetrating the seed system, and opportunities they present are being validated in Kenya to scale out the technology through diversified use (Fig. 12.5).

Strategic innovations Given the contrasting approaches of seed sector development actors (McGuire and Sperling 2016), it is not surprising that many people interested in this subject have called for greater integration, both in development and research. Thomas-Sharma et al. (2015) proposed an integrated approach to managing the problem of degeneration through a strategy called integrated seed

Fig. 12.4 Cutting almost ready for transplanting (left), and soon after transplanted in nursery beds in the field (right). (Photo credits: M. Parker)

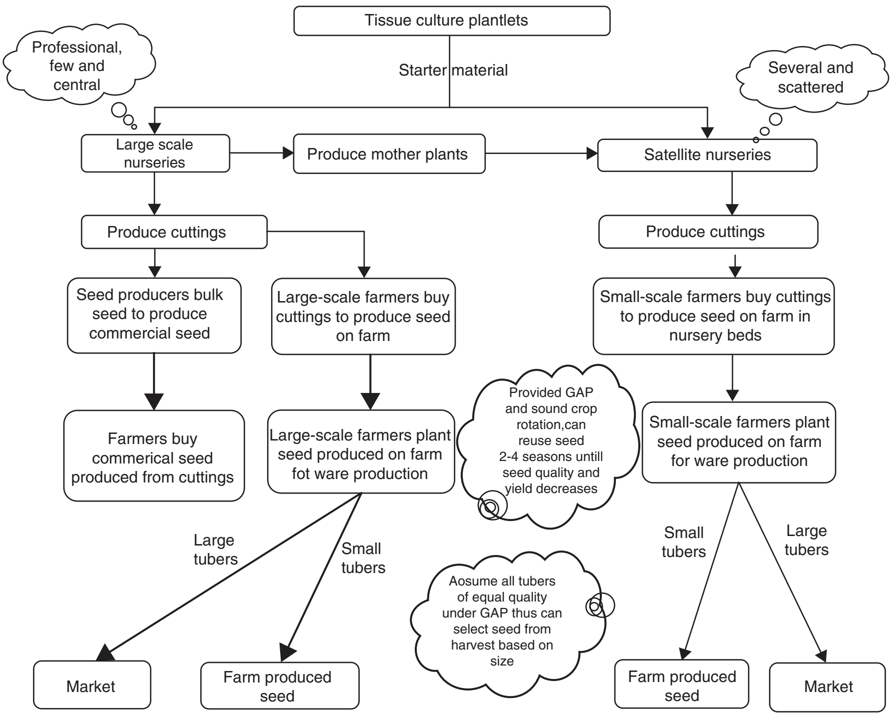

Fig. 12.5 Diversified pathways to use cuttings in seed production to scale out the technology; GAP: good agricultural practices

health. This involves the integration of three different classes of tactics farmers may employ to maintain or even improve seed quality: (1) on-farm practices such as seed plot technique or positive selection; (2) the use of varieties that degenerate slowly due to their natural resistance to degeneration-causing pathogens; and (3) a more strategic use of certified seed. The latter may involve the less frequent purchase of clean replacement seed, or purchase of small quantities that may be put in a designated seed plot (Ochieng-Obura et al. 2016).

At a higher level, researchers have also called for integration throughout the seed sector, with emphasis on the interaction between formal and informal systems (Louwaars 1994; Tripp 1996; Munyi and De Jonge 2015). The most visible incarnation of this approach is the Integrated Seed Systems Development (ISSD) program.[1] This program is managed globally by the Centre for Development Innovation (CDI), Wageningen University & Research (WUR) and the Royal Tropical Institute (KIT), but has many local partners in Africa and country programs in Uganda and Ethiopia.

The CGIAR has long been another major player in seed sector development in low-income countries, with CIP leading the potato component. For many years seed

[1] See ISSD Website http://www.issdseed.org/.

programs resided within specific centers but this has been consolidated to some extent within the CGIAR Research Programs. All potato work resides within the Roots, Tubers and Banana program (RTB), which initiated a project in 2012 to address biophysical (especially seed degeneration) and socioeconomic constraints of seed production in RTB crops. This led to fruitful collaborations with advanced research institutions in the US and Europe and has produced some novel approaches to studying seed systems, including a conceptual framework for intervening in RTB seed systems (Bentley et al. 2018), a multi-crop analysis (Almekinders et al. 2019), the integrated seed heath approach explained above (Thomas-Sharma et al. 2015), epidemiological modeling of seed potato degeneration (Thomas-Sharma et al. 2017), and the geographic analysis of seed system dynamics using network analysis (Buddenhagen et al. 2017). Hence, since seed systems are complex, more research is needed to identify the right entry points and multiple angles for innovations to enhance the systems as a whole and according to local conditions.

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