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Assessment of seed system interventions for biofortified orange-fleshed sweet potato (OFSP) in Malawi

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Abstract

The International Potato Center (CIP) has collaboratively implemented various demand-pull and supply-push interventions since 2006 to develop the seed system for biofortified orange-fleshed sweet potato (OFSP) (*Ipomoea batatas*) varieties in Malawi. Consequently, the adoption of OFSP varieties has increased to 30%. Nevertheless, the actual adoption rates, the contribution of these interventions to the seed system development, and the extent to which the current policy and regulatory environment facilitated or impeded the availability and access to quality planting materials by smallholder farmers are not well understood. This study explored these critical issues using desk reviews and qualitative information with OFSP subsector stakeholders. The results reveal that most of the critical nodes of the OFSP seed system are underdeveloped. However, CIP backstopping interventions to the national research systems contributed significantly to building Malawi's capacity for producing clean early-generation seed materials. In addition, CIP has played a critical role in developing the community-level capacity to produce and disseminate clean vines through the introduction of decentralized vine multipliers and commercial vine multipliers. The study recommends integrating formal and informal seed systems for vegetatively propagated crops to improve access to quality planting materials by farmers. Second, government and development partners (CGIAR centers, Non-governmental Organization) should progressively promote/create demand for OFSPs among consumers because of the strong association between the biofortified OFSP varieties and nutrition. Lastly, there is need for government and development partners to establish and increase OFSP interventions in the Northern and Central regions of Malawi.

Abbreviations: APES, Agricultural Production Estimates Survey; ASWAp, Agriculture Sector Wide Approach; CIP, International Potato Center; CVM, commercial vine multiplier; DAES, Department of Agricultural Extension Services; DARS, Department of Agricultural Research Services; DCD, Department of Crop Development; DVM, decentralized vine multiplier; KULIMA, kutukula ulimi m'Malawi; NAIP, National Agriculture Investment Plan; NAP, National Agriculture Policy; NES, National Export Strategy; NGO, Non–Governmental Organizations; NRS, National Research System; OFSP, Orange-Fleshed Sweet Potato; QA, quality assurance; R&D, Research and Development; SSU, Seed Services Unit; VPC, vegetatively propagated crops.

1 | INTRODUCTION

Many countries in Sub-Saharan Africa have formulated seed policies to guide the development of the seed sector and improve farmers' access to quality seeds. Most of these countries have developed vibrant seed systems, whereas others are making steady progress in developing strong seed systems for cereal crops (Agrilinks, 2020). However, seed systems for vegetatively propagated crops (VPCs), such as sweet potatoes and cassava, are not well developed and are predominantly informal (farmer-managed, community-based systems). As a result, most farmers acquire their planting materials from the previous season's harvest (farm-saved seed), their social networks (including neighboring farmers), or occasionally from development projects implemented by governments and development partners (Hirpa et al., 2010; Mwangi et al., 2020). Farmers' access to high-quality sweet potato cuttings (the predominant planting material) of improved varieties (e.g., disease-free, true-to-type, physical quality, and physiological age and vigor) is generally limited. In most contexts, farmers' willingness to pay for the planting materials of these crops is also low (Almekinders et al., 2019; Mwiti et al., 2020). Thus, understanding the seed system for VPCs is critical for reforming seed policies and regulatory frameworks to facilitate farmers' access to quality seeds.

This paper studies the seed systems for biofortified orange-fleshed sweet potato (OFSP) (*Ipomoea batatas*) varieties in Malawi. The study comes at a time when the International Potato Center (CIP) has collaborated with national research and development (R&D) partners to develop seed systems for OFSP varieties in the country since 2006. Between 2006 and 2018, the seed sector was governed by the National Seed Policy of 1993 and the Seed Act of 1997 (GoM, 1993, 1997). The seed policy and Seed Act did not recognize seed systems for VPCs. As such, CIP collaborated with the government of Malawi and other development partners to implement interventions/projects aimed at developing the seed system for OFSP. A full list of interventions/projects can be found in Appendix 1.

The development of the OFSP seed system involved both supply-push and demand-pull interventions. Supply-push interventions included working closely with the national agricultural research system to develop and release new OFSP varieties suitable for different agroecological zones of the country, aligning with the preferences of farmers and consumers. This was complemented by developing standards and guidelines and strengthening inspection mechanisms for the sweet potato seed system. Further, other interventions included the provision of training and support (financial/technical/equipment) to private and public sector partners to develop business plans and revolving funds for sustainable production and maintenance of early-generation seed stock. Furthermore, training and support (financial and technical) were provided to commercial vine multipliers (CVM) and decentralized vine multipliers (DVM). Collaborative efforts were also made with regulatory bodies to establish more appropriate quality assurance (QA) and inspection systems (CIP, 2014, 2019a, 2019b, 2020).

Demand-pull interventions included farmer trainings and awareness/demand creation to create a market for clean planting materials to achieve higher yields. In parallel to these seed system interventions, nutrition interventions sought to raise awareness of the nutritional benefits of OFSP in reducing vitamin A deficiency and promote behavioral change for diversifying diets and investments into processing and market development (CIP, 2014, 2019a, 2019b, 2020).

One of the outcomes of these efforts has been the broad adoption of OFSP country-wide in Malawi, where today, more than 30% of all farmers grow OFSP varieties (Gatto et al., 2021b). However, the seed sector's contributions to this outcome are not well understood. Additionally, the extent to which the seed system has increased availability and access to high-quality planting material to increase yields and returns to OFSP cultivation, which are key factors in sustaining or enhancing the level of adoption, is also unknown.

This study is based on qualitative and quantitative data collected to answer the following research questions: (1) What is the current status of the seed system for biofortified OFSP varieties in Malawi?; (2) how have past OFSP interventions interacted with and contributed to addressing seed systems for biofortified OFSP varieties?; (3) how did different partnerships and seed delivery models influence the development of the OFSP seed system, and sustainable access by farmers to quality seed?; and (4) to what extent have the seed systems facilitated or impeded availability of and access to quality

Core Ideas

- Access to certified seed for vegetatively propagated crops is low in Sub-Saharan Africa.
- Various interventions were implemented to develop the seed system for orange-fleshed sweet potato.
- Seed system for orange-fleshed sweet potato is still in infancy stages.
- Integrations of formal and informal seed systems are critical to ensuring availability and access to quality seeds.
- Demand creation for orange-fleshed sweet potato as a nutritious food will trigger improvements in the seed system.

planting material and adoption of biofortified OFSP varieties by smallholder farmers?

Our contributions to literature are twofold. First, we shed light on the difference between seed systems for true seeds and VPCs, particularly biofortified and non-biofortified varieties. This is because studies on seed systems for VPCs have focused on all varieties (biofortified and non-biofortified varieties) (Gatto et al., 2021a; McEwan et al., 2021; Spielman et al., 2021), and little has been done to date on biofortified varieties. Second, in Malawi, one study by Abidin et al. (2012) documented seed system interventions carried out under the Rooting Out Hunger Project. It is therefore important to understand how different OFSP programs implemented by the various institutions have contributed to shaping existing OFSP seed systems and facilitated or impeded availability and access to quality seed of biofortified OFSP varieties and adoption of the crop by smallholder farmers in Malawi.

2 | METHODOLOGY

2.1 | Conceptual framework

We first unpack what formal and informal seed systems are to develop a conceptual framework for understanding seed systems for OFSP. A formal seed system involves the production, distribution, and exchange of seed that is regulated and controlled by government agencies and/or private sector actors such as seed companies. In a formal seed system, seeds are produced, tested, certified, and marketed according to established standards and regulations and are often sold through established channels, such as seed companies, agricultural input dealers, or government agencies. On the contrary, an informal seed system is a network of farmers, traders, and other actors involved in the production, distribution, and exchange of seeds outside of formal channels such as seed companies and government agencies (AUC (African Union Commission), 2020; Louwaars & De Boef, 2012).

We analyze the seed systems for OFSP through the lenses of availability and access to high-quality planting materials by smallholder farmers. The main question we ask is as follows: Has the seed system for OFSP been able to effectively deliver clean planting materials to farmers? If the answer to this question is "yes," then the seed system is working, but if the answer is "no," then there is need for more effort to address the seed system challenges. To do this, we consider the key components of the system, the relationships that exist among the components, and the institutions and processes involved in the production, dissemination, and exchange of seeds. We also specifically examine the availability and access to seed and the resilience of the system to external factors, such as climate change.

2.2 | Sampling strategy

To ensure the representation of the different agroecological zones across the country, a two-stage stratified sampling strategy was employed. The first stage involved purposively selecting one district from each of the three regions of Malawi (the Southern, Central, and Northern regions). The districts where OFSP interventions by CIP and its partners were implemented were specifically selected at this stage. Accordingly, the three districts that were selected across the three regions are Nsanje (Southern region), Lilongwe (Central region), and Mzimba (Northern region).

In the second stage, respondents, who were knowledgeable about the OFSP seed system based on their interaction/involvement with the system, were purposely selected as key informants or members of a focus group in each district.

2.3 | Study approach

Desk reviews comprise published material, program/project documents/reports, gray literature, government policy, regulatory, and strategic documents (e.g., the Seed Act (2005), Seed Regulations (GoM, 2018a), the National Seed Policy (GoM, 2018b), the Plant Protection Act (2018), the National Agriculture Policy (NAP) (2016), the National Agriculture Investment Plan (NAIP) (2018), the National Export Strategy (NES) (I and II), Plant Breeders Rights Act (2018), the Agricultural Extension Development Officer's Handbook on Good Agricultural Practices, and the Guide to Agricultural Production and Natural Resource Management (2020), Agricultural Production Estimates Survey (APES) reports, and various review and end of project evaluation reports for projects coordinated by CIP and partners).

Key informant interviews (KIIs) with OFSP seed system actors include representatives from relevant government departments and agencies, regulatory bodies (variety registration and release, seed inspection bodies), international research centers, Nongovernmental Organizations (NGOs), seed producers (DVMs and CVMs), project/program staff for past OFSP projects, key OFSP projects' partners, among others. A total of 28 KII were conducted. Of these, three CVMs and two DVMs were interviewed using KII checklist. In addition, 12 were government officials performing various functions in the seed chain, 3 were representatives of partner NGOs implementing various OFSP activities, and 8 included current and formal staff of research centers (CIP and Harvest Plus).

Focus group discussions (FGDs) were conducted with a group of OFSP farmers with groups of farmers. A total of six FGDs were conducted, two in each district. From these FGDs, the study interviewed a total of 73 farmers (39 females, 34 males) who participated in FGDs.

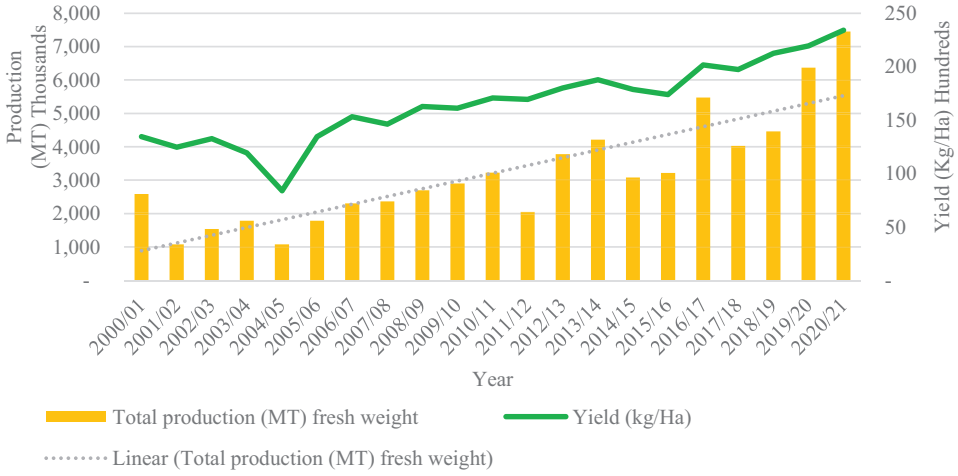

FIGURE 1 Total sweet potato production in metric tons (MT) and yield (kg/Ha), 2000/01 and 200/21 seasons. *Source*: APES (MoA) data, 2000/01 to 2020/21.

2.4 | Data analysis

The recorded interviews were subsequently transcribed to enhance and facilitate the cleaning up of the notes taken during the interviews. The consolidated notes were coded, and content was analyzed using a qualitative data analysis software called Atlas.ti.

3 | RESULTS

3.1 | Sweet potato production trend in Malawi

The APES (GoM, 2022b) data of the Ministry of Agriculture (MoA) indicates that Malawi has been experiencing an upward sweet potato production trend, regardless of the type of variety between 2000/01 and 2020/21 (Figure 1). Figure 1 also shows that after experiencing a sharp productivity slump between 2003 and 2005 and a corresponding near-stagnation of aggregate production between 2001/02 and 2005/06, Malawi experienced a sharp jump in sweet potato productivity and a correspondingly sharp increase in overall production in 2006/07. Since then, the overall production has continued to upsurge despite a few blips (e.g., in 2011/12, 2014/15, and 2015/16). FAOSTAT data for Malawi shows a similar upward production trend even though the data is only available from 2014 (FAO, 2022).

Interestingly, the sharp increase in yield and overall production in 2005/06 coincides with the inception of CIP and SARRNET interventions in the OFSP seed systems. According to our KIIs with former CIP-Malawi Staff and Project Managers, CIP/SARRNET interventions in the OFSP seed systems started around 1994 through the Nairobi office of CIP and a SARRNET project in the Department of Agricultural Research Services (DARS) in Malawi.

The APES data was analyzed by Agricultural Development Divisions (ADD) to understand the contribution of OFSP interventions on overall sweet potato production in Malawi. Figure 2 shows that at around 2005, sweet potato production across the eight ADDs was almost the same in volume. However, we notice a sharp rise in sweet potato production for Blantyre ADD between 2006 and 2021. This is followed by Kasungu, Lilongwe, and Machinga ADDs. Coincidentally, most CIP interventions as shown in Appendix 1 were implemented in Blantyre ADD, particularly in Mulanje, Thyolo, Chiradzulu, and Phalombe districts.

A slightly lower number of OFSP interventions were implemented in Lilongwe and Dedza districts within Lilongwe ADD, Mangochi, Machinga, and Zomba districts in Machinga ADD, and Mchinji and Kasungu districts in Kasungu ADD. Fewer interventions have reached the Shire Valley ADD, Mzuzu ADD, Karonga ADD, and Salima ADD. Consequently, it may not be an implausible conjecture to conclude that a significant share of increases in sweet potato production since 2005/06 agricultural season may have been contributed by improving OFSP yields resulting from direct OFSP interventions in the seed system, even though national time series data on sweet potato production does not disaggregate sweet potato data by variety.

Table 1 presents the varieties of OFSP, their yield potential on farmer-managed plots, the dry matter, the average maturity period, and other special attributes as described in the Guide to Agricultural Production and Natural Resources (GoM, 2020). Kaphulira, Chipika, and Royal Choice are the highest yielding among the OFSP varieties but differ significantly in the other attributes. Zondeni is currently the lowest yielding variety in the OFSP family.

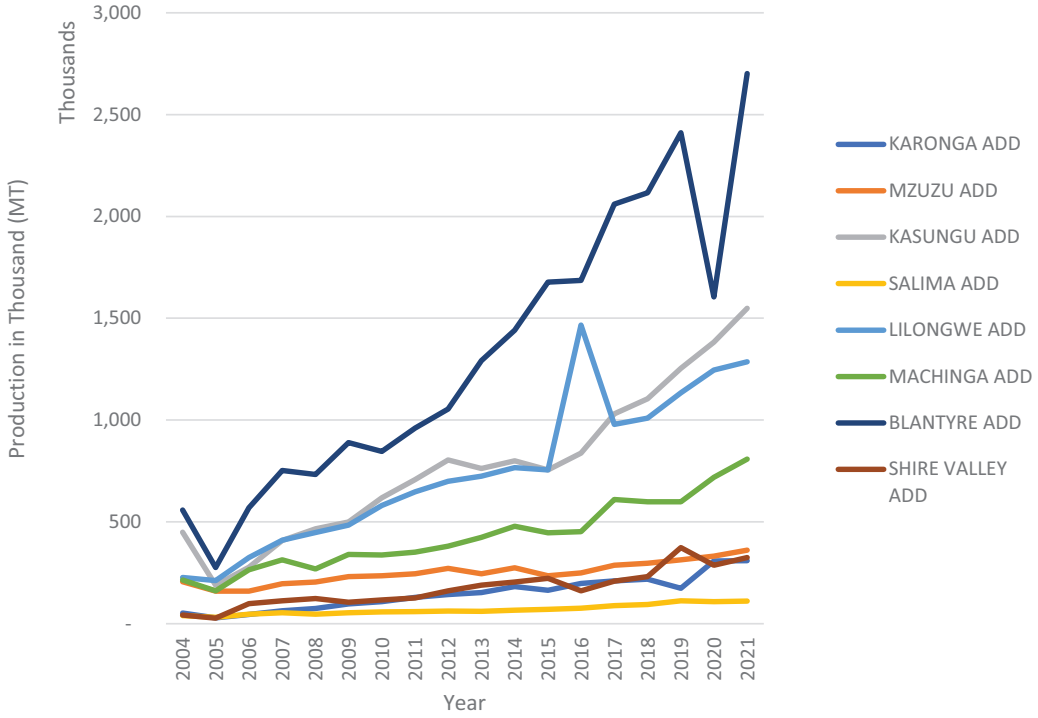

FIGURE 2 Sweet potato production at Agricultural Development Divisions (ADD) level between 2004 and 2021. *Source*: APES (MoA) data, 2004 to 2021.

TABLE 1 Common orange-fleshed sweet potato (OFSP) varieties, yield potential, and other special attributes of the varieties.

Variety	Potential yield (t/ha)	Dry matter (%)	Maturity period	Special attributes
Zondeni	8–16	32	5	Deep orange
Anaakwanire	25	30	6	Deep orange, 6–8 roots per plant
Mathuthu	25	29	5	Orange, soft
Kaphulira	35	30	3.5	Orange, early maturing
Chipika	35	30	5	Orange, high yielding
Kadyaubwerere	30	31	5	Deep orange, sweet taste
Msungabanja	30	31	4.5	Deep orange, beta-carotene, moderate tolerance to SPVD
Royal choice	35	31	3.5	Orange, high yielding, moderate tolerance to SPVD
Mthetsanjala	30	32	4.5	Deep orange, high yielding, beta-carotene

Source: Guide to Agricultural Production and Natural Resources, 2020 (GoM, 2020).

3.2 | OFSP seed system chain for Malawi

The main actors in the OFSP seed chain include government (through the DARS and the Department of Agricultural Extension Services—DAES, the Department of Crop Development-DCD); NGOs such as the Catholic Development Commission (CADECOM), United Purpose, AgDiv, NASCENT Solutions, Evangelical Association of Malawi, Ripple Africa, American Peace Corps, Concern Worldwide, World Vision, Plan Malawi, Self Help Africa, and Action Aid; the primary vine producers such as the DVMs and CVMs, and International Research Centers (CIP and Harvest Plus), among others. These actors play various unique roles to support the development of different nodes of the seed chain and the effective functioning and sustainability of the whole chain. DARS is the seat for breeding, varietal testing/trials and release, seed multiplication, registration, and certification of seed multipliers. CIP works with all players in the seed chain by providing technical and financial support to facilitate the development of new OFSP varieties and the multiplication and distribution until they reach the end user.

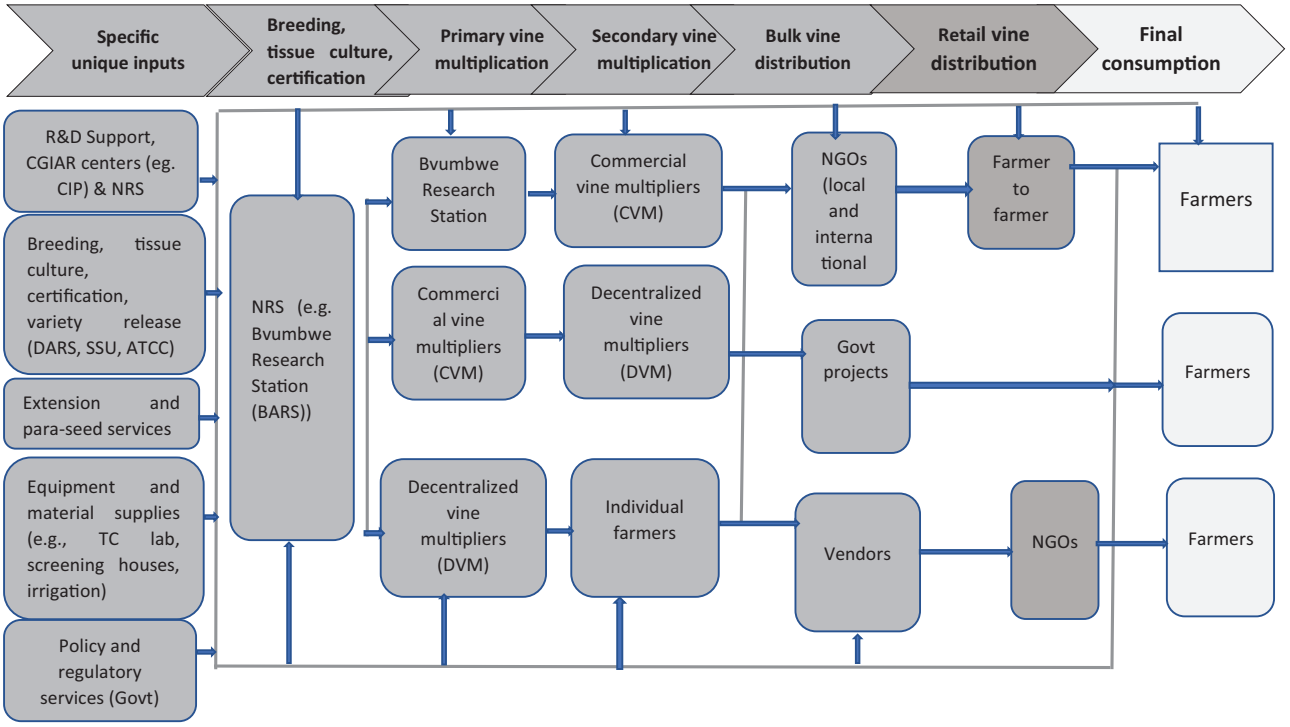

FIGURE 3 Orange-fleshed sweet potato (OFSP) seed chain for Malawi. *Source*: Authors.

The OFSP seed chain in Malawi has several nodes that play distinct roles in delivering clean planting materials to farmers. Figure 3 shows that the OFSP seed chain is anchored by a node that feeds the seed chain with "specific" unique inputs foundational to the effective functioning of upstream nodes. The elements of this node include R&D support, including breeding, varietal release, tissue culture (T.C.), and plantlets production and certification; cleaning of vines, extension, and para-seed services; laboratory and screen house equipment and material supplies; and policy and regulatory services.

3.2.1 | Research and development (R&D) support

The overall R&D support is mainly provided by CGIAR centers, such as CIP and the National Research System (NRS) (i.e., DARS). In this regard, CIP has collaboratively worked with technocrats from DARS to build and install laboratories (e.g., T.C. lab) for the production of OFSP T.C. and screen houses for multiplying plantlets, among others. It also supported government on- and off-station trials by providing laboratory equipment and chemicals, and refurbishing a T.C. laboratory at Bvumbwe Research Station. CIP also facilitated the introduction and maintenance of germplasm for OFSP breeding processes.

3.2.2 | Variety development and release

OFSP varieties are developed by scientists in the DARS with technical backstopping from CIP or collaboratively with CIP. DARS is also the holder of the authority to release the new varieties after rigorous testing (i.e., research trials) under research station and farmer conditions. The new varieties are released only after being cleared by the Agricultural Technology Clearing Committee in the MoA.

3.2.3 | Vine multiplication and distribution

Vine multiplication is divided into primary and secondary processes. The primary vine multiplication involves the propagation of plantlets from T.C. laboratories. This activity is performed by DARS and some CVMs and DVMs. The vines produced under these multiplication processes are called early-generation seeds. The secondary multiplication process is dominated by CVMs, DVMs, and individual farmers who multiply the vines in their fields. Records from CIP show that over 20 CVMs and 100 DVMs were established across the country, though it was not clear how many were still active at the time of conducting this study. The seed multiplied under the secondary multiplication process is known as the second-generation seed.

The main market for OFSP vines includes government projects, NGOs, CIP, and vendors. These markets usually arise when there is a large order from the government, NGOs, CIP, and occasionally vendors. Retail vine distributions refer to farmer-to-farmer or small-scale NGO-to-farmer distributions. There is a high degree of farmer-to-farmer exchange of seed at this level except when NGOs provide the seed. The price for OFSP vines is considered too high by farmers, and therefore, farmers resort to using farm-saved or conserved seeds. Prices are in the range of MK500 and MK1200 per bundle.

3.2.4 | Vine certification and quality assurance mechanism

Vine certification and QA processes are carried out by the Seed Services Unit (SSU) in the DARS. The certification process involves the registration of seed multipliers, an inspection of seed production, and certification. The inspection report acts as a certificate in the case of VPCs. Our interviews with SSU officials revealed that VPCs particularly sweet potato and cassava follow the same certification process without regard to varietals differences and whether the crops are biofortified or non-biofortified.

Our interviews with breeders revealed that vines of well-looked-after OFSP varieties are considered of certifiable quality 3 years after being introduced at a farm. However, the SSU requires seed multipliers to undergo the registration and certification processes every year.

3.2.5 | Agricultural extension

The main extension input into the OFSP seed chain is provided through a strategic partnership among CIP, DAES, and the NGOs in the sweet potato subsector. On the one hand, the OFSP root and vine producers are trained in all production and marketing aspects of OFSP. On the other, households are trained in all nutritional aspects of the OFSPs.

3.2.6 | Policy and regulation of the OFSP seed systems

The most important policy relevant to the OFSP seed system is the National Seed Policy, which was adopted in 2018. The National Seed Policy (2018) has clear general provisions for the seed systems for all crops, including cereals, legumes, and VPCs. The policy clearly states that it only recognizes formal seed systems for promoting farmers' access to and use of high-quality seeds. The policy also mentions that informal seed systems are only recognized as far as they relate to preserving known genetic purity (GoM, 2018b). As such, all government and partner organization interventions and the policy environment, in general, have tended toward developing formal seed systems for all crops, including OFSPs.

Furthermore, the main legal document guiding the seed systems in Malawi is the Seed Act of 2022 (GoM, 2022a). Before April 2022, when the Seed Bill was enacted, enforcement of seed regulations was problematic. To address this gap, the government, in partnership with CIP and other organizations, developed and promoted seed multiplication and inspection guidelines (DARS, 2019).

However, government interventions in the sweet potato subsector and the OFSP seed chain are mostly short term. They are mostly implemented during major seasonal crises such as droughts and floods, in the form of emergency response. In addition, none of the key government strategic documents in the agriculture sector (e.g., the NAP, NAIP, and NES) has explicit provisions regarding sweet potatoes in general and OFSP in particular, despite the biofortification and promotional effort of OFSPs by CIP and its partners as an important functional food.

3.3 | Status of seed systems for biofortified OFSP

The study shows that the seed system for biofortified OFSP is still in its infancy relative to seed systems for cereals, such as maize (*Zea mays*), and grain legumes, such as groundnuts (*Arachis hypogaea*), beans (*Phaseolus vulgaris L.*), and soybeans (*Glycine max*), among others, for three main reasons. First, there is a lack of an effective market for OFSP vines in Malawi due to low farmers' willingness to pay for certified sweet potato vines. Farmers prefer recycling the planting materials (i.e., conserving their vines) or sourcing through their social networks instead of replacing them with new and certified seeds. Our interview with officials in the SSU shows that sweet potatoes are unlike cereal hybrid seeds; they can be recycled for about 3–5 years before losing vitality. However, as farmers recycle the vines, they need to be on the lookout for disease build-up; otherwise, they need to source certified vines each season.

Second, the vines of sweet potatoes are so perishable that the time lag between harvest and delivery to the farmer is a matter of a few days (at most 3–5 days, roughly), and the transportation can be problematic because of bulkiness. For this reason, it is usually difficult to find agro-dealers selling seeds of VPCs.

Third, the SSU is constrained in human resources to adequately cover all crops in Malawi. Consequently, CIP supported SSU in training Extension officers in all aspects of seed inspection to complement the inspection efforts of SSU. The trained officers, called para-seed inspectors, have provided a fit-for-purpose system for monitoring, inspecting, and

assuring the quality of the seed (vines) produced by various players in the OFSP seed system. However, these officials are not mandated to produce a final seed certificate for the seed producer. Only an SSU official can produce the final certification. The strict requirement to have a seed certificate from an SSU official is met with limited human resources which makes an enforcement of seed regulations for OFSP difficult.

Furthermore, the seed system for the VPCs in Malawi has been fashioned under the blueprint of regulatory frameworks for cereal crops. For example, the seed inspection guidelines of the Seed Service Unit follow a similar fashion for all crops from registration to inspection. The only difference is in the final inspection documentation that SSU produces. For cereal crops, SSU issues a laboratory analysis report and a certificate. The analysis report gives the details of the genetic percentage, percentage of inert matter, and if there are some off-types. For VPCs, SSU issues an inspection report that acts as a certificate. The inspection happens in the field, and the certificate has to be issued not more than a month before selling the vines. Normally, the inspector indicates on the report that the crop has been inspected, is clean, and can be used as planting material or certified seed.

The review of policy and regulatory instruments reveals that seed systems for VPCs differ from that for cereals. The main difference exists because of the nature of VPCs in that vegetatively propagated seeds are sold at the farm or within a reasonably short period to avoid perishability. As such, only an inspection report is issued, and it acts as a seed certificate.

Furthermore, Malawi has not developed separate seed systems for different VPCs. They all follow similar processes from varietal development, multiplication, registration, inspection, and quality control mechanisms. As all VPCs follow the same seed system stem, there is no merit in developing a separate seed system from biofortified OFSP.

3.4 | Contribution of OFSP interventions to the development of seed systems for biofortified OFSP varieties

CIP has played a very influential role in contributing to the current status of the seed system for biofortified OFSP. Production and productivity of sweet potato, in general, started increasing after 2006. Interviews with key informants revealed that very little was known about OFSP varieties in Malawi, and very little was happening to develop the seed system chain for OFSPs before 2006. Among other things, CIP with the support of development partners, including Irish Aid, USAID, AGRA, and the Bill and Melinda Gates Foundation, has actively backstopped the NRS in building Malawi's capacity for producing the early-generation seed and has developed the capacity of communities to produce their seed, first through the introduction of DVMs and CVMs.

Second, CIP trained farmers in positive and negative selection of vines to maintain the quality of their seed for planting. That is, the identification of clean vines with desirable attributes for further multiplication by farmers and the isolation of contaminated vines and off-types in farmers' fields for destruction. CIP has also implemented several projects since 2009 in partnership with government agencies and NGOs. Nevertheless, CIP is yet to extend its influence to most of the districts in the Central and Northern regions, as most of its impact seems to be localized to areas where its interventions are concentrated.

> The training of scientists by CIP has increased the country's knowledge and capacity to breed and multiply early-generation seeds for biofortified OFSP varieties. Additionally, the training of para seed inspectors has been particularly critical in increasing the country's capacity to monitor and control the quality of the vines being produced by farmers at a time when the numbers of the country's seed inspectors are too low; to adequately undertake farm-level seed inspection activities. (KII with DARS official)

Government interventions in the OFSP systems are progressively intensified through Agriculture Sector Wide Approach (ASWAp-II) and the "kutukula ulimi m'Malawi" (KULIMA) projects. Both projects have OFSP components as one of interventions to ensuring food and nutrition security. The ASWAp project is implemented in 12 districts, whereas the KULIMA project is implemented in 10 districts. There are intersections in some of the implementation districts for both projects, and CIP intervention districts as well. However, there are some districts that have had no OFSP interventions, including Rumphi, Likoma, and Dowa. It is important to emphasize that, previously, most of the interventions by the government in the OFSP seed system came in the form of emergency response to droughts and floods.

Even though most of the districts in Malawi have had an OFSP intervention, our results show that those efforts have been concentrated in the southern region, which coincides with the increase in sweet potato yields in those districts.

3.5 | Partnerships and seed delivery models in the OFSP seed system

CIP has adopted an operational model that relies on partnerships with the government and other players in the OFSP seed system subsector. This partnership has come in several ways, including integrating MoA activities into CIP activities and joint implementation of projects with government, NGOs, and communities. For example, CIP works directly with

government scientists and extension workers in the development of new cultivars and the provision of extension advisory services to farmers, respectively.

CIP has also relied on CVMs (e.g., Nankhwali farms, Bunda Farm limited, Kapunula estate, and among others) and DVMs to facilitate the dissemination and diffusion of OFSP seed into communities. CVMs and DVMs have been critical in supplying certified OFSP vines to the government and NGOs during emergencies, such as floods and droughts. On the other hand both the ASWAp and KULIMA projects have relied CIP to train farmers in seed multiplication. These partnerships have been influential in the development and sustenance of the OFSP seed system, harmonization and unification of extension messages, rapid dissemination and diffusion of OFSP varieties into communities, and increasing the knowledge and the capacity of the MoA and the country overall in all aspects of the OFSP value chain, and created donor attention into biofortified OFSPs varieties (Gatto et al., 2021a; Gatto et al., 2021b).

3.6 | Access and use of certified OFSP seed by farmers

Most farmers interviewed in the study indicated that access to certified OFSP planting materials has been problematic. Most of them lauded the presence of projects that distribute free OFSP seed as their major certified seed source. They cited the high cost of certified seed, low levels of seed multiplication in their communities, and long distances to sources of certified OFSP seed as the major constraining factors.

> Sometimes, when we harvest our crop from the wetlands, we plant it in gardens to keep the seed for the next season. The other thing is that Nsanje is a flood-prone district. Most of the time, the crop is destroyed by floods, so we are forced to look for new vines every season. (FGD with Wangisa cooperative-Nsanje district)

As highlighted above, farmers have resorted to conserving their OFSP seed in net tunnels for planting during the main production season. Our interviews also reveal that the demand for OFSP in certain districts has been as high as 12,000 bundles,[1] but only around 6000 are supplied yearly.

Furthermore, KIIs and FGDs revealed that there have been cases when there is more demand for vines than supply. For example, during times of emergency like floods or drought, NGOs buy most of the vines from seed multipliers for distribution in areas affected by a disaster. This means that farmers from certain areas looking for seed cannot access it because it has already been sold. On the other hand, sometimes, vine multipliers do not have a market to sell their vines because farmers consider the price for vines as high and "generally" low demand from smallholder farmers, as most of them do not consider sweet potato as a primary crop. This can be explained by a dependency syndrome that gets incarnated in communities that face disasters from time to time (Acaye, 2015; Ireni-Saban, 2019). Such a situation may reduce the effective demand for seed from smallholder farmers and undermines the commercial viability of seed producers.

The study also revealed that the use of OFSP vines in Malawi is district specific, with some districts where CIP and partners have worked having a higher percentage of farmers planting OFSP, whereas others, where CIP and partners' presence is minimal, have a low penetration of OFSP varieties. Our findings reveal that all five CIP OFSP projects were implemented in the Southern region, whereas only three were implemented in the Central region, and only two were implemented in the Northern region. Moreover, interviews with stakeholders revealed that the adoption rate of OFSP varieties in the areas where OFSP has been heavily promoted is roughly between 30% and 40%. However, Gatto et al. (2021a) and Gatto et al. (2021b) reported an OFSP adoption rate of 54%.

Several key informants argued that farmers who access OFSP vines use certified seed because vines can be recycled for 2–5 years. However, for seed multipliers, SSU requires vines to be certified yearly because of registration and inspection requirements. This means that it is easy for farmers not to demand a seed certificate from seed producers. Indeed, the study found that some NGOs and vendors do not ask for a seed certificate when buying vines even though CIP sensitized most NGOs on the importance of asking for a seed certificate. Further, the study found that some vine multipliers do not know the seed certification requirements of SSU.

4 | DISCUSSION

The study reveals that much as the policy and regulatory environment seeks to develop a formal seed system for all crops, including OFSP, there is generally weak enforcement of these regulations. Our interviews revealed that farmers, including NGOs, do not demand documented evidence that the seed from producers has been inspected and certified. In addition, some seed producers are unaware of the registration and inspection requirements of the SSU. In such contexts, it becomes difficult to enforce seed regulations. Consequently, there are high seed recycling levels, which may lead to pest and disease build-up. McEwan et al. (2021) showed that there is a seed health knowledge gap among farmers, which needs to be addressed if seed systems for VPCs are to be sustained. Likely, farmer training in the form of farmer field schools

[1] A sweet potato bundle contains 100 vine cuttings of 30 cm in length.

where the performance of certified vines can be compared to that of uncertified vines would be critical in addressing this gap.

In as much as the National Seed Policy in Malawi only recognizes formal seed systems for all crops, the body of evidence suggests that the informal nature of the seed systems for VPCs calls for reforms that consider the hybridization of the formal and informal seed systems (Gatto et al., 2021b; McEwan et al., 2021). In so far as VPCs are not like hybrid cereal seeds and can be recycled for a number of years, seeds that can be declared to be of good quality at the community level by para-seed inspectors (quality declared seed) seem to be an efficient way to ensure farmers' access to high-quality seed in the circumstances of resource-constrained formal regulatory and inspection mechanisms of the SSU. In addition, strict and centralized quality control regulations limit the market size (Spielman et al., 2021). Countries, including Vietnam, India, Tanzania, Kenya, Brazil, Peru, and Myanmar, have embraced a differentiated registration or a partially flexible registration system for both formal and informal seed systems (Kuhlmann & Dey, 2021). Within flexible registration systems, officials at the level of para-seed inspectors are mandated to certify quality-declared seeds, which can then be passed to farmers for sweet potato production.

Furthermore, systems that integrate internal (seed producer-level) quality control mechanisms with the formal system seem to be the more promising models of quality standardization (Spielman et al., 2021). It is important to emphasize the importance of seed traceability and seed "certification-whether formal or quality declared" to avoid the build-up of pests and diseases (Almekinders et al., 2019).

McEwan et al. (2021) showed that partnerships in the seed system for VPCs are key in sustaining the whole seed chain. The current study reveals that CIP has worked closely with partners to develop the seed system for OFSP, including working with CVMs and DVMs to popularize OFSP. However, these models of seed delivery may not be sustainable because of the weak effective demand for vines from farmers (Almekinders et al., 2019; McEwan et al., 2021).

5 | CONCLUSION

The study has shown that the seed systems for vegetatively propagated varieties in Malawi are still in their infancy stages and will continue to rely on the support of development partners for their sustenance in the near future. The study has also revealed that CIP plays a fundamental role in backstopping the national research system (NRS), the extension services (DAES), and relevant NGOs to develop the seed chain. CIP provides critical R&D inputs that anchor the seed chain and are critical to its development and sustainability. Some of the R&D backstopping support provided by CIP include breeding, varietal release, T.C., and plantlets production and certification, cleaning of vines, extension and para-seed services, laboratory and screen house equipment and material supplies, and policy and regulation.

The nature of VPC (i.e., it would be difficult to sell vines through seed companies and agro-dealer shops) demand the recognition of the importance informal seed systems can play in delivering clean planting materials to farmers. However, the current policy and regulatory environment do not recognize informal seed systems (GoM, 2018b). Although formal seed systems can deliver high-quality planting materials to farmers, informal seed systems can provide farmers with access to a wide range and quantity of planting materials.

The study has also shown that CIP has been the lead center in stimulating and guiding the development of the country's formal seed systems for biofortified OFSP varieties since 2006. This can be emphasized by the fact that CIP has a footprint at almost every OFSP seed system chain level in Malawi despite its interventions being localized to a few areas in Malawi.

Under normal circumstances, one would expect farmers to have easy access to certified OFSP vines just as they do with local varieties, including Kenya. However, this has been problematic because of the country's inadequate capacity to produce good quality early-generation seed for eventual propagation by DVMs and CVMs within communities despite the creation of sustainable early-generation seed business plans and revolving funds. Thefund faced institutional challenges in the early years of its establishment (CIP, 2019b). This suggests the need for concerted efforts to integrate demand-supply interventions to sustainably stimulate the demand and supply of clean planting materials in Malawi. This includes efforts to enhance the capacity to develop early-generation seed to increase the supply stock to the seed multipliers in the communities.

One of the key lessons learned is that there are certain key entry points for improving the OFSP seed system and enhancing farmers' access to quality OFSP planting material. These include training farmers in positive and negative selection of vines; increasing the number of vine multipliers (DVMS and CVMS), especially in the communities; training vine multipliers in business development; and raising the demand for OFSP roots through the nutrition pathway and market-driven approaches.

6 | POLICY IMPLICATIONS

First, there is a need to recognize the value of both formal and informal seed systems for OFSP. The approach can help accelerate the availability and access to clean planting materials by farmers. To achieve this, there is a need to foster collaboration and partnership between formal and informal seed actors to promote knowledge-sharing and technology transfer. For example, seed companies can work with farmer organizations

to test and adapt new seed varieties to local conditions, and NGOs can work with government agencies to promote seed diversity and conservation.

Second, there is a need to develop seed certification systems that recognize informal seed systems. Seed certification systems can help to promote quality control and ensure that farmers have access to high-quality seeds. However, many small-scale farmers in informal seed systems may not be able to afford the cost of seed certification. There is therefore need to reform the seed regulations to allow para-seed inspectors to produce seed certificates for quality declared seed whether from seed multipliers or farm served seed. Developing certification systems that recognize and incorporate informal seed systems can help to promote seed quality and diversity while ensuring that small-scale farmers have access to affordable seed.

Third, government and development partners (CGIAR centers, NGOs) should progressively promote/create demand for OFSPs among consumers including in prenatal clinics of the Ministry of Health and school feeding programs because of the strong association between the biofortified OFSP varieties and nutrition (e.g., vitamin A). Such demand will trigger demand for vines and potentially sustain vine production by DVMs and CVMs beyond project life.

Relatedly, there is a need for government and development partners to establish and increase OFSP interventions in the Northern and Central regions. This includes expanding the number of DVMs and CVMs in communities to ensure that seed is produced right in communities. Expanding interventions to the Northern and Central regions will increase overall sweet potato production like ithas been the case where CIP has implemented its interventions.

Lastly, there is a need to raise the position of OFSPs in government policy and strategic documents. For example, there is a need to start collecting sweet potato data by variety in the APES, just like it is done for cereals and tobacco. This will help provide accurate production statistics for sweetpotato. This can be achieved through lobbying by the Root and Tuber Crops Development Trust.

AUTHOR CONTRIBUTIONS

Zephania Nyirenda: Conceptualization; data curation; formal analysis; investigation; methodology; writing—original draft; writing, review and editing. **Christone Nyondo**: Conceptualization; writing; review and editing. **Wellingtone Jogo**: Project administration; supervision; validation. **Guy Hareau**: Funding acquisition; resources. **Julius Okello and Marcel Gatto**: Supervision.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest. The interest of the study was to understand seed systems for OFSP. The Author's from CIP provided funding and guidance during data collection.

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REFERENCES

Abidin, P. E., Chipungu, F. P., Benesi, I. R. M., Mwenye, O., Todd, R., Thomas, J., Chimsale, R., Daudi, A., Nkhomam, P., Mkumbira, J., Botha, B., & Carey, E. E. (2012). *Building a sustainable sweetpotato seed system in Malawi: Experiences from the "Rooting out hunger in Malawi" project. The Roots (and Tubers) of Development and Climate Change*. 16th Triennial Symposium of the International Society for Tropical Root Crops (ISTRC), Nigeria. https://cgspace.cgiar.org/handle/10568/66273

Acaye, R. (2015). Relief Aid Dependency Syndromes: A Case for Disaster–Prone Moroto District in Uganda. Walden Dissertations and Doctoral Studies. https://scholarworks.waldenu.edu/dissertations/1872

Agrilinks. (2020). Towards a *vibrant, private-sector led seed industr*y in Africa. https://agrilinks.org/post/towards-vibrant-private-sector-led-seed-industry-africa

Almekinders, C. J. M., Walsh, S., Jacobsen, K. S., Andrade-Piedra, J. L., McEwan, M. A., De Haan, S., Kumar, L., & Staver, C. (2019). Why interventions in the seed systems of roots, tubers and bananas crops do not reach their full potential. *Food Security*, *11*(1), 23–42. https://doi.org/10.1007/s12571-018-0874-4

AUC (African Union Commission). (2020). The seed sector in Africa. [Status Report and Ten-year Action Plan (2020-2030): A Summary]. https://au.int/sites/default/files/documents/41357-doc-Africa_Seed_Industry_Report_summary_April_2020_submFeb2021_a_signed_and_posted_202111.pdf

CIP (International Potato Centre). (2014). *Rooting out hunger in Malawi with nutritious orange-fleshed sweetpotato*. [End of Phase 1 Report (October 1, 2009–April 30, 2014)]. International Potato Centre.

CIP (International Potato Centre). (2019a). *Feed the future – Malawi improved seed systems and technologies – Orange – Fleshed sweetpotato component*. [Final Report (December 2014–June 30, 2019)]. International Potato Centre.

CIP (International Potato Centre). (2019b). *Root and tuber crops for agricultural transformation in Malawi (RTC-ACTION Malawi)*. [Year 3 Annual Progress Report]. International Potato Center.

CIP (International Potato Centre). (2020). *Developing integrated value chains to enhance rural smallholders' incomes and food (DIVERSIFY) project*. [Final Project Report (January 1, 2017–May 31, 2020).]. International Potato Centre.

DARS (Department of Agricultural Research Services). (2019). Sweetpotato Handbook for Seed Multiplication and Inspection.

FAO. (2022). Crop production, yield, harvested area (global - national - annual) - FAOSTAT - crop production, yield, harvested area - "FAO catalog". https://data.apps.fao.org/catalog/dataset/crop-production-yield-harvested-area-global-national-annual-faostat/resource/45e995e9-1021-4288-abed-ab933d3a3c01

Gatto, M., Le, P. D., Pacillo, G., Maredia, M., Labarta, R., Hareau, G., & Spielman, D. J. (2021a). Policy options for advancing seed systems for vegetatively propagated crops in Vietnam. *Journal of Crop Improvement*, *35*(6), 763–789. https://doi.org/10.1080/15427528.2021.1881011

Gatto, M., Okello, J. J., Pradel, W., Kwikiriza, N., Mgomezulu, W., Nyirenda, Z., Okuku, H., Suarez, V., van Vugt, D., Chipungu, F. P., Kapalasa, E., Kumwenda, W., Hareau, G., & Heck, S. (2021b). *Adoption and effects of orange-fleshed sweetpotato varieties in Malawi* [Working Paper]. Centro Internacional de la Papa. https://doi.org/10.4160/02568748CIPWP20211

GoM (Government of Malawi). (1993). *National* seed policy *1993*. https://cepa.rmportal.net/Library/government-publications/National%20Seed%20Policy%201993.pdf

GoM (Government of Malawi). (1997). *Seed* act. https://malawilii.org/akn/mw/act/1988/5/eng@2014-12-31

GoM (Government of Malawi). (2018a). *Seed* regulations. https://faolex.fao.org/docs/pdf/mlw199883.pdf

GoM (Government of Malawi). (2018b). *The* national seed policy *2018*. https://faolex.fao.org/docs/pdf/mlw180417.pdf

GoM (Government of Malawi). (2020). *The guide to agricultural production and natural resources*. Ministry of Agriculture, Government of Malawi.

GoM (Government of Malawi). (2022a). *Seed* act. Ministry of Agriculture. Government of Malawi.

GoM (Government of Malawi). (2022b). *The agricultural production estimates survey (APES)*. Ministry of Agriculture. Government of Malawi.

Hirpa, A., Meuwissen, M. P. M., Tesfaye, A., Lommen, W. J. M., Oude Lansink, A., Tsegaye, A., & Struik, P. C. (2010). Analysis of seed potato systems in Ethiopia. *American Journal of Potato Research*, *87*(6), 537–552. https://doi.org/10.1007/s12230-010-9164-1

Ireni-Saban, L. (2019). Contextualizing dependency syndrome in international disaster management: Support from Sen's capability-based approach. *International Journal of Political Science*, *5*(3). https://doi.org/10.20431/2454-9452.0503004

Kuhlmann, K., & Dey, B. (2021). Using regulatory flexibility to address market informality in seed systems: A global study. *Agronomy*, *11*(2), 377. https://doi.org/10.3390/agronomy11020377

Louwaars, N. P., & De Boef, W. S. (2012). Integrated seed sector development in Africa: A conceptual framework for creating coherence between practices, programs, and policies. *Journal of Crop Improvement*, *26*(1), 39–59. https://doi.org/10.1080/15427528.2011.611277

McEwan, M., Almekinders, C. J. M., Andrade-Piedra, J. L, Garrett, K. A., Kumar, L., Mayanja, S., Omondi, B. A., & Rajendran, S. (2021). Breaking through the 40% adoption ceiling: Mind the seed system gaps -a perspective on seed systems research for development in One CGIAR. *Outlook on Agriculture*, *50*(1), 5–12. https://doi.org/10.1177/0030727021989346

Mwangi, C. W., Ateka, J., Mbeche, R., & Ateka, E. (2020). Seed security for vegetatively propagated orphaned crops and its implication for household food security in rural Kenya: A case of sweet potato (*Ipomoea batatas*). *Journal of Agriculture and Food Research*, *2*, 100087. https://doi.org/10.1016/j.jafr.2020.100087

Mwiti, F. K., Okello, J. J., Munei, K., & Low, J. (2020). Farmer demand for clean planting material of biofortified and non-biofortified vegetatively propagated crop varieties: The case of sweetpotato. *Scientific African*, *8*, e00400. https://doi.org/10.1016/j.sciaf.2020.e00400

Spielman, D. J., Gatto, M., Wossen, T., McEwan, M., Abdoulaye, T., Maredia, M. K., & Hareau, G. (2021). *Regulatory options to improve seed systems for vegetatively propagated crops in developing countries*. International Food Policy Research Institute. https://doi.org/10.2499/p15738coll2.134441

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APPENDIX 1
OFSP intervention districts in Malawi

Projects and donor	Timeline	Project target districts		
		Northern region districts	Central region districts	Southern region districts
Technologies for African Agricultural Transformation (TAAT) Donor: AfDB	2018–2021		Lilongwe, Dedza, Salima, Nkhotakota	Nsanje, Chikwawa, Mulanje Phalombe, Thyolo, Blantyre, Zomba, Neno, Mwanza, Balaka
DIVERSIFY Donor: EU	2017–2020			Balaka, Thyolo Chiradzulu
SUSTAIN I and II Donor: FCDO	2014–2019	Nkhata-bay, Mzimba south and North, Karonga, Chitipa	Kasungu, Salima, Dedza, Lilongwe, Nkhotakota, Ntchisi, Mchinji	Mulanje, Blantyre
RTC action Donor: Irish AID	2016–2021			Nsanje, Chikwawa, Blantyre, Thyolo, Mulanje, Phalombe, Zomba, Chiradzulu, Neno, Mwanza
MISST Donor: USAID	2015–2019		Lilongwe, Ntcheu, Dedza, Mchinji	Balaka, Mangochi, Machinga
Rooting out hunger Donor: Irish AID	2009–2016		Dedza	Phalombe, Chikwawa, Mulanje
KULIMA Donor: EU	2020–2022	Mzimba, Chitipa, Karonga, Nkhata Bay	Nkhotakota, Kasungu, Salima	Mulanje, Thyolo, and Chiradzulu
SASHA Donor: Bill & Melinda Gates Foundation	2014–2019			Thyolo
SARRNET Donor: USAID	1994–2003	Mzuzu ADD, Karonga ADD	Lilongwe ADD, Salima ADD, Kasungu ADD	Machinga ADD, Blantyre ADD, Shire Valley ADD
ASWAP II Donor: multi-donor trust fund	2018–2021	Chitipa, Mzimba	Kasungu, Ntchisi, Mchinji, Lilongwe, Dedza, Ntcheu	Zomba, Phalombe, Mulanje, Thyolo