Chapter 14
Transforming Yam Seed Systems in West Africa

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Abstract The availability of clean planting materials and functional seed regulatory systems is indispensable for fostering a sustainable seed yam system. The Yam Improvement for Income and Food Security in West Africa (YIIFSWA) project of the International Institute of Tropical Agriculture (IITA) developed the capacity of National Agricultural Research Institutes (NARIs) in their use of standardized Temporary Immersion Bioreactor (TIB) and Vivipak (VP) systems for high-ratio propagation and post-flask handling of yam breeder seed plantlets. Foundation seed was enhanced by supporting five private seed companies in Nigeria and three in Ghana. They were equipped with aeroponic and hydroponic technologies for foundation seed tuber production using single-node vine seedlings. For certified seed, seed yam out-growers were trained in good agronomic practices and entrepreneurship for certified seed tuber production using the adaptive yam minisett technique (AYMT). New certification standards were established for various classes of seed produced using different propagation methods and quality assurance procedures in Ghana and Nigeria. The capacity of the national regulatory organizations in both countries was enhanced to implement seed quality control and certification. Increased public sensitization and advocacy were done to raise awareness among

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relevant stakeholders to enhance the uptake of the seed propagation technologies and ensure a smooth interaction between the public and private sectors. This chapter summarizes the accomplishments of YIIFSWA in Ghana and Nigeria and the spill-over impact on the yam belt of West Africa and beyond. The key lessons could inform the design and implementation of more effective seed projects, especially for vegetatively propagated crops.

14.1 Introduction

Yam (*Dioscorea* spp.) is a clonally propagated, high-value crop, cultivated for its underground edible tubers and planting materials. It is an essential source of income and food for millions of smallholder farmers, processors, and consumers in West Africa. Yams have been cultivated since 11,000 BC in West Africa (Coursey 1976). In the region, yam cultivation covers over 8.1 million hectares (ha), with a total annual production of over 67 million tonnes[1] (FAO 2020). More than 92% of the world's yams are produced in five countries (Nigeria, Ghana, Côte d'Ivoire, Benin, and Togo) in the yam belt of West Africa. Ghana and Nigeria alone account for 77%. The average per capita consumption of yam in major producing countries ranges from 193 kcal a day in Togo to 502 kcal per day in Côte d'Ivoire. The crop also contributes to much more protein to the region's diet than the more widely grown cassava and even more than meat protein (FAO 2021). Yam is also a culturally important crop in the region, used in many key ceremonies such as yam festivals, weddings, chieftaincy ceremonies, and sacrifices to the gods (Nweke 2016).

Although yam production is only 38% of cassava, its total crop value is slightly higher, making it the most valuable food crop in Africa (FAO 2021). In terms of the value of production (income to farmers), yam is far ahead of the other five main food commodities (maize, rice, cassava, sorghum, and millet) in Nigeria (Table 14.1).

Table 14.1 Comparison of average production value of five food crops in Nigeria from 1995 to 2016

Crops	Area × 1000 (ha)	Yield (T/ha)	Prod × 1000 tons	Price US$/ton	Prod value Million US$	Percentage to yam
Yam	3328	9949	31,898	398	12,694	100%
Cassava	4100	10,339	41,086	157	6462	51%
Maize	4425	1572	6918	334	2311	18%
Millet	4050	1163	4976	297	1480	12%
Sorghum	6303	1174	7401	301	2226	18%
Rice	2387	1651	3976	364	1448	11%

Source: FAOSTAT 2018

[1] 1 tonne (t) = 1000 kgs

The annual production value of yam is over US$12.7 billion in Nigeria and US$ 1.4 billion in Ghana. If quality seed of improved varieties were used with a 30% yield increase, the production value could increase to US$17.9 billion in Nigeria and US$1.9 billion in Ghana. Those increases would benefit primarily millions of smallholder farmers for whom yam is a cash crop. Of the yam produced in both countries, about 30% is allocated for seeds, 42% is sold at market, and the remaining 28% consumed at home (Mignouna et al. 2015).

Yam is the only vegetatively propagated crop in sub-Saharan Africa (SSA) with a regular cash-based seed system, and farmers expect that they will need to replace at least some of their seed each year (Nweke 2016). In Igalaland in Kogi, Nigeria, farmers buy seed yam each growing season rather than producing their own, seeking quality judged by physical inspection for symptoms of damage by pests and diseases (Nweke 2016).

The unavailability of quality seed is largely due to the traditional methods of seed yam production in West Africa. The first traditional method – milking – harvests physiologically immature tubers at between 60% and 70% of the growing season without destroying the feeding roots system. This early harvest of ware yam is consumed and sold at market (Aighewi et al. 2015). Before total senescence, the parental plant redevelops small new yam tubers used as seeds for the following planting season. The second traditional method of seed production uses small whole tubers from varieties that produce multiple tubers per stand or by sorting small tubers from a ware crop. This method is risky if the tubers are small and infected with pests and diseases in the field (Nweke 2016). The third traditional method – setts – involves cutting mature ware tubers into small portions (100–250 g) (Aighewi et al. 2002). These three traditional methods are slow, with a multiplication ratio of about 1:6, compared to some cereals which multiply at 1:200 (Mbanaso et al. 2011). As such, these methods cannot supply seed in sufficient quantity and quality needed for real growth of the yam sector throughout the yam belt of West Africa.

The prioritized constraints of yam production formed the basis for the interventions of the first phase of the Yam Improvement for Income and Food Security in West Africa (YIIFSWA) project. This work was funded by the Bill & Melinda Gates Foundation and managed by the International Institute of Tropical Agriculture (IITA) from 2011 to 2016 in Ghana and Nigeria and is continuing as a second phase through the end of 2021. The Project seeks to develop and establish a functional, commercial seed yam seed system in the two countries to benefit smallholder farmers through timely and affordable access to high-quality seed yam tubers of improved varieties.

14.2 Technologies for Breeder and Foundation Seed Yam Production

14.2.1 Tissue Culture and Temporary Immersion Bioreactor System

The YIIFSWA project developed and standardized tissue culture-based heat therapy combined with meristem tissue culture for cleaning yam of viruses at a 73% success rate for yam mosaic virus (YMV) (Balogun et al. 2017a). YIIFSWA also developed the Temporary Immersion Bioreactor System (TIBS) to scale up the propagation of breeder plantlets from which foundation and certified seed are generated (Balogun et al. 2017b). The cleaned plantlets constitute stocks for the rapid multiplication of superior varieties, ensuring that the virus is not passed on to subsequent generations. 25 genotypes of yam, including improved and local varieties, were cleaned of diseases using these approaches.

Plantlets from TIBS are of higher quality than those from conventional tissue culture (CTC), as they are more vigorous and resilient to post-flask acclimatization. Due to more efficient process control, large batches are handled more easily for scale-up propagation with lower risks of mix-ups. The propagation ratio in TIBS was five to six per plantlet every 8–10 weeks (Balogun et al. 2017b) compared to three to four every 12–16 weeks with CTC. In addition, the rate of subculturing in TIBS was 100 cuttings per person hour, double that of CTC, reducing the cost of labor as well, and the use of liquid without agar/geltrite reduces medium cost by 50%. All these advantages curried favor for the establishment of a laboratory for TIBS at NRCRI in Umudike, Nigeria, in 2019 (Fig. 14.1).

Fig. 14.1 The NRCRI TIBS laboratory at Umudike, Nigeria

For post-tissue culture operations, for acclimation to the outside environment, the plantlets from the TIBS are hardened in 50:50 carbonized rice husks in topsoil using perforated Vivipak that allows for adequate ventilation (Balogun et al. 2017b).

Technologies for breeder seed production were transferred to the National Center for Genetic Resources and Biotechnology (NACGRAB) and the National Root Crops Research Institute (NRCRI) in Nigeria and the Crops Research Institute (CRI) and Savanna Agricultural Research Institute (SARI) in Ghana through the provision of equipment and supplies for backup electrical power, TIBS, post-flask handling and documentation, and initial clean stock of planting materials. Solar/inverter systems were installed at NARIs to mitigate interruptions in power supply in operating the TIBS. The National Agricultural Research Institutes (NARIs) are now providing clean breeder planting materials to private seed companies for foundation seed production.

Each TIBS can produce at least 50 plantlets every 2 months, so up to 76,500 stock plantlets per year can be produced in the laboratory. When plantlets are introduced into aeroponic or hydroponic systems, combined with vine cutting, production is increased at least 100 times, up to 7.65 million (i.e., 6.12 million breeder planting materials with a buffer of 20% reserved against possible losses). Following installation of the TIBS at NARIs in 2019, 11,132 plantlets were produced from January through April 2020 (Table 14.2). This figure was projected to reach 100,188 by the end of 2020 at a multiplication ratio of three per cycle of 4 months. NARIs have also distributed clean seed yam among stakeholders and are better positioned to prime the seed value chain (Table 14.3).

14.2.2 The Aeroponic System for Seed Yam Production

Laboratory production of seed is continuous (Balogun et al. 2017b), while farmers' demand for seed yam is seasonal. Thus, aeroponic and hydroponic systems were developed for time- and cost-effective agronomic and quality-assured production (Table 14.4). The single-node-derived vine seedlings are generated from aeroponics and hydroponics after 3–4 months of plantlet growth. After 30–45 days in the nursery, the seedlings are transplanted to the field, maintained for 6 months, and harvested during December to February when most farmers harvest their ware yams and need seed tubers to replant (or expand) their harvested areas. Plantlets from TIBS are planted with aeroponics or hydroponics in the screenhouse, thus circumventing the use of soil and restricted seasonal production cycles (due to tuber dormancy and access to rainwater) because vine seedlings and tuber production in the screenhouse is continuous. Up to 300 vines were cut per plantlet of TIBS grown aeroponically (Maroya et al. 2014b, 2017), while the drip system hydroponics saves on electricity (Balogun et al. 2018, 2020). Up to 100 single-node vine cuttings were made per TIBS plantlet using hydroponics after 8 weeks of growth, with 95% rooting success followed by field planting. The seed tubers produced ranged from 5 g to 220 g per plant after 5 months of hydroponic growth.

Table 14.2 Early generation seed production by NARIs from January to April 2020

NARIs	Products	Quantity
NACGRAB	Plantlets in TIBS	657
	Plantlets in conventional tissue culture vessels	2307
	Directly hardened plants from TIBS or conventional tissue culture	401
	Vine cutting seedlings from hardened in vitro plants in trays	1687
	Subtotal	*5052*
NRCRI	Plantlets in TIBS	1850
	Plantlets in conventional tissue culture vessels	412
	Directly hardened plants from TIBS or conventional tissue culture	2025
	Subtotal	*4287*
CRI	Plantlets in TIBS	8535
	Plantlets in conventional tissue culture vessels	3025
	Directly hardened plants from TIBS or conventional tissue culture	9196
	Subtotal	*20,756*
SARI	Plantlets in TIBS	90
	Vine cutting seedlings from hardened in vitro plants in trays	3846
	Micro-tubers from hardened in vitro plants or vine cuttings	4199
	Plantlets hardened in Vivipak	156
	TIBS plantlets through Vivipak to pots	120
	Single nodes in pots	7318
	Subtotal	*15,729*
Grand total		*45,824*

Aeroponic yam propagation was started under the YIIFSWA project in January 2013 at IITA in Ibadan, Nigeria (Maroya et al. 2014a, b). Genotypes of both *D. rotundata* and *D. alata* were successfully propagated with aeroponics using both pre-rooted and fresh vine cuttings. Yam mini-tubers harvested from aeroponics varied from 0.2 g to 110 g, depending on the genotype, harvest age, and the composition of the nutrient solution (Maroya et al. 2014c).

Three types of planting materials are generated with aeroponics: mini-tubers harvested underneath the aeroponic boxes, the aerial bulbils on both water yam and white yam varieties, and one-node cuttings from vines. All these planting materials had a propagation rate of over 90%.

The single-node vine cuttings from aeroponic plants performed the best with an average of 200–300 cuttings per plant in 4–6 months. A *Manual for Clean Foundation Seed Yam Production Using Aeroponics System* is available to private seed companies (Maroya et al. 2017).

Table 14.3 Distribution of early generation planting materials of yam among public and private institutions in Ghana and Nigeria in 2019

Institution receivers		Distributors			
		IITA	CRI	NACGRAB	TOTAL
Public	NRCRI	2170		1000	3170
	SARI	1192	980		2172
	CRI	900			900
	NACGRAB	127			127
	UI	250			250
	Subtotal	4639	980	1000	6619
Private	PS NUTRAC	400		1200	1600
	BIOCROPS	150			150
	Hikma Farms		592		592
	Fosuah Food		588		588
	Strategic seeds	450			450
	GoSeed	856			856
	Iribov		420		420
	Others		2492	1000	3492
	Subtotal	1856	4092	2200	8148
Grand Total		*6495*	*5072*	*3200*	*14,767*

NB. *UI* University of Ibadan, *PS NUTRAC* PS Nutraceuticals International Ltd., *BIOCROPS* Biocrops Biotechnology Company Ltd.

Table 14.4 Model cropping calendar for seed and ware yam production showing non-seasonality in production based on novel high-ratio propagation technologies

<table>
<tr><th>Jan</th><th>Feb</th><th>March</th><th>April</th><th>May</th><th>June</th><th>July</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th></tr>
<tr><td colspan="12">Generation of clean stock plantlets in laboratory</td></tr>
<tr><td colspan="12">Scale-up propagation of breeder stock plants in TIBS in the laboratory</td></tr>
<tr><td colspan="12">Post-flask acclimatization of breeder plants in the screenhouse</td></tr>
<tr><td colspan="12">Production of clean breeder mother plants in aeroponics and hydroponics in screenhouse</td></tr>
<tr><td colspan="4">Single-node vine seedling production from clean aeroponic/hydroponic breeder mother plants in nurseries</td><td colspan="8">Field planting of breeder 1 vine seedlings under rain-fed conditions for foundation 1 seed tuber production</td></tr>
<tr><td colspan="12">Single-node vine breeder 2 tuber production from clean aeroponic/hydroponic breeder 1 mother plants in nurseries</td></tr>
<tr><td colspan="4">Dormancy of breeder and foundation seed tubers</td><td colspan="8">Field planting of breeder and foundation seed tubers under rain-fed conditions for foundation and certified seed production, respectively</td></tr>
<tr><td colspan="4">Dormancy of foundation and certified seed tubers</td><td colspan="8">Field planting of foundation and certified seed tubers under rain-fed conditions</td></tr>
</table>

In 2017, YIIFSWA-II project funded five selected seed companies with USD 30,000 each, half of the cost to build a screenhouse and an aeroponic system. Unfortunately, contrary to the letter of agreement that provided construction specifications, the seed companies used inferior materials to construct their screenhouse and other cost-cutting changes contrary to the guidelines. Consequently, plant mortality was very high, and the plants could not grow big enough to allow vines to be cut.

These undesired alterations also led to overheating in the screenhouse and in the nutrient solution tank. To remedy this issue, the project staff developed an air-conditioning cooling system that kept the nutrient temperature between 22 °C and 26 °C. All the materials needed for the nutrient tank cooling system can be sourced locally in Ghana and Nigeria. Eventually, the seed companies asked IITA to help them build a standard aeroponic unit with a 10 KVA solar energy panel (Fig. 14.2). All the materials for constructing this unit, including the solar panels, were purchased locally.

By 2020, all the private seed companies both in Ghana and Nigeria were producing first generation of foundation (FS1) seed and second generation of foundation (FS2) seed yam tubers, simultaneously using single-node vine seedlings under irrigation for FS1 and adaptive yam minisett technique (AYMT-see Sect. 14.3.2) under rain-fed conditions for FS2. Generally, the seed companies used out-growers to produce the FS2 seed yam tuber. These companies would supply certified seed entrepreneurs, out-growers, some NGOs, and local governments with tubers. NGOs and local governments typically requested more seeds than could be supplied.

The major persisting challenge for the aeroponic screenhouse is the heat. Temperatures can reach 42 °C and above during the warm season of January to March. The project used two approaches to keep screenhouses cool enough to avoid damaging the plants in AS:

1. An automated screenhouse cooling system with showers and misters (Fig. 14.3). The system kicks in when the temperature reaches 32 °C and stops when it decreases to 28 °C.
2. Adjusting the dimensions of the screenhouse to 5 m high, 8 m wide, and 30 m long and providing a double roof to facilitate air circulation.

Fig. 14.2 The solar panels (left) and the aeroponic unit with cooling powerhouse for Da-Allgreen Seeds (right)

Fig. 14.3 An aeroponic screenhouse cooled by showering and misting systems

14.2.3 Potential of Semi-autotrophic Hydroponics

Semi-autotrophic hydroponics (SAH) is a robust, low-cost technique for efficient and rapid multiplication of clonally propagated crops (see Chap. 15 in this book on EGS in cassava). SAH is a high-ratio multiplication of true-to-type, virus-free plants of tissue culture-derived material. SAH was originally developed for potato multiplication by a company in Argentina called SAHTecno LLC. SAHTecno licensed the technology to IITA and IITA modified it to suit propagation of cassava through the Building an Economically Sustainable Integrated Cassava Seed System in Nigeria (BASICS) project and later with yam through the Yam Breeding Program and AfricaYam Project. The BASICS project helped design and establish commercial early generation seed (EGS) enterprises known as GoSeed at IITA and Umudike Seeds at NRCRI.

For yam, the SAH facility has the potential to complement the other propagation technologies. The current SAH lab at IITA-Ibadan can produce 600,000–720,000 seedlings per year (50,000–60,000 per month) within a laboratory space of 39.5 m^2 (Fig. 14.4). The technology can generate one million plants per year within 50 m^2, making it suitable for commercial seed production and enhanced multiplication in breeding programs. Apart from the fast multiplication rate and low production cost, SAH offers less than 2% plant loss with no contamination. Tissue culture (TC) plantlets introduced as single nodal cuttings (SNC) into SAH boxes develop new shoots that are ready for cutting after 30 days. The mother plants then regenerate new shoots in 14 days or fewer. By conservative estimate, a rack of 40 test tube plantlets can plant 10 SAH boxes, which translates into 150 boxes within 120 days. Requests for SAH seedlings have been on a steady increase from February to August 2019 due to the attractive look of the SAH yam plantlets. So far, the SAH lab had generated USD 9965 from seedlings sold in 2019 (Table 14.5).

Fig. 14.4 Staff at the SAH laboratory at IITA-Ibadan manage the production of SAH plantlets under controlled conditions

Table 14.5 SAH yam plantlets distribution from IITA-Ibadan lab to end users between February and August 2019

SAH plantlet buyers	Number of plantlets purchased or granted	Period of purchase	Purpose of purchase	Amount paid in Naira (N)*
Da All-Green Seeds Ltd.	4000	Feb–July 2019	Seed production	100,000
PSN International Ltd.	70,250	Feb-–Aug 2019	Seed production	3,000,000
Lecturer UI	2250	Jul–Aug 2019	Seed production	67,500
Ecoprime	5000	Jul 2019	Seed production	125,000
ART	30,000	Aug–Sept 2019	Seed production	270,000
Internal IITA various uses	39,180	Feb–Aug 2019	Trials and demos	Free
GoSeed/Ecoprime	18,000	Jul–Aug 2019	Out-grower tests	Free
Total	168,680	Feb–Sept 2019	Various uses	3,562,500

Source: SAH lab record; * 1$ = 360 N

14.3 Seed Yam Actors Strengthened on Seed Production and Commercial Seed Marketing

14.3.1 Training in Production of Early Generation Seed Yam

The training on breeder and foundation seed yam production organized by IITA included the breeder and foundation seed modules and the day-to-day management of aeroponics (Maroya et al. 2017) and TIBS (Balogun et al. 2017b). The modules included step-by-step procedures for establishing pathogen-free cultures, scale-up propagation in TIBS, and post-flask management of plantlets. 49 trainees from NARIs were trained on breeder seed production between 2017 and 2020, and another 49 trainees from private sector on foundation seed.

The Human Resource Capacity Development on breeder and foundation seed yam production include the breeder seed module and the day-to-day aeroponic system management. The breeder seed training module included:

- Step-by-step procedures of establishment of pathogen-free cultures: virus elimination using heat therapy, practical aspects of virus elimination using thermotherapy, medium preparation, explant collection and disinfection, culture initiation, meristem excision, thermotherapy, and plantlet regeneration
- Step-by-step procedure of scale-up propagation in SETIS Temporary Immersion Bioreactors: indexing for endophytes, setting up of the SETIS bioreactor unit, medium preparation, autoclaving vessels and instruments, introduction of explants to TIBs in the laminar flow hood, assembly on the shelf, changing medium in bioreactor cultures, and cleaning bioreactor vessels
- Post-flask management of plantlets: practical aspects on hardening, pre-hardening medium (PHM) preparation in TIBS, subculturing plantlets into PHM, preparing acclimatization chamber and transfer of plantlets, and identifying hardened plantlets
- Documentation, including creation of spreadsheets, use of bar codes, and tracking the cost of production

In partnership with Context Global Development, business advisory support was provided to NARIs in 2019 to develop business plans for breeder seed yam production using TIBS. These were based on an institution-specific, cost-tracking templates for financial and operating models.

14.3.2 Private Seed Companies Strengthened for Seed Business and Commercial Seed Marketing

The private seed companies were selected through a due diligence process and were supported to develop business plans based on the project promoted seed production technologies. After review, eight businesses with the soundest plans were engaged in the YIIFSWA-II project. The business plan format used for the private seed companies was an FAO document titled *Small-Scale Seed Enterprise: Start-up and Management* (2007).

The NRCRI and IITA developed an effective and affordable propagation technique, the yam minisett technique (YMT), for yam growers to produce their seed yam (IITA 1985). Using this technique, the multiplication ratio increases from 1:5 in traditional methods to 1:30 (Orkwor et al. 2000). A refined model, the adaptive yam minisett technique (AYMT) (Odu et al. 2016), was introduced under YIIFSWA project to strengthen quantity and quality assurance in the yam seed system, especially for farmer seed growers in Ghana and Nigeria, and research has led to further improvements (Aighewi et al. 2020). Since seed was mainly obtained from dual crops of ware and seed yam, the AYMT was promoted at the start of the project to introduce the notion of producing sole crops of seed yam for commercial purpose, while research on high-ratio propagation techniques for yam was going on.

The project established partnerships with several non-governmental organizations (NGOs) in major yam-growing regions of Ghana and Nigeria to scale out the AYMT as well as to encourage the commercial production of seed yam. The NGOs received training of trainers on the technique before they conducted several training activities for extension officers and individual farmers or cooperative seed yam growers with backstopping from IITA. At the start of the project in 2012, one NGO worked in Nigeria, Missionary Sisters of the Holy Rosary (MSHR), and, in Ghana, Catholic Relief Services (CRS). Over 3 years, 35,135 farmers were trained on the AYMT in Ghana and Nigeria. Based on recommendations of an external evaluation of the project, three more NGOs in Nigeria and two in Ghana were added.

These NGOs trained an additional 43,625 farmers during the last 2 years of the project, bringing the total to 78,760 (40% women) (Table 14.6). Considering that yam is generally considered a man's crop in West Africa, the high percentage of women in the training was encouraging as few women are involved in the value chain.

Table 14.6 Farmer seed growers trained by YIIFSWA through the AYMT demonstrations in Ghana and Nigeria

	Number of farmer seed growers trained		
Year	No. male	No. female	Total
2012	1555	605	2160
2013	9700	6542	16,242
2014	9562	7171	16,733
2015	17,793	11,488	29,281
2016	8961	5383	14,344
Total (5 years)	47,571	31,189	78,760
Percentage	60.4%	39.6%	100%

14.3.3 Challenges to Farmers Capacity Development in Seed Production and Resolution

After 4 years of training farmers and extension officers, project staff realized that most farmers were not convinced that seed yam production could be more profitable than ware yam, even though all the farmers knew how expensive it was to buy seed yam (as much as 60% of production costs). We found the farmers had difficulty grasping three concepts:

1. Specialized seed yam production improves quality and yield.
2. Seed yam is more profitable to produce than ware yam.
3. Seed yam should be produced on ridges.

Having isolated these barriers, we invited farmers and extension staff from Ghana and Nigeria to Illushi, Edo, in Nigeria; seed yam production is the primary economic activity. They learned seven key ideas to encourage more seed yam production:

1. A new method of staking using pieces of bamboo (pyramidal staking) to minimize the cutting of trees for staking.
2. Small tubers (up to 50 g) that were normally discarded by the visiting farmers were displayed and sold at the market.
3. Seed yams were planted on ridges and growing well.
4. Illushi seed yam farmers select and tag apparently healthy plants from which seed yam will be harvested and good tubers selected to plant the next crop.
5. The quality of seed yam sold in the market was evidence of a good selection of disease- and pest-free seed tubers after harvest.
6. Seed tubers in the whole market were well-protected from the sun, a major cause of rot, using palm fronds to cover the market area.
7. Minisett technology is a profitable business venture, and farmers are now ready to adopt it at a commercial scale.

Farmers and extension staff indicated that site visit had been more valuable than earlier trainings. Farmers trusted the information that came from practicing farmers more than they trusted “theories” from researchers. Illushi had many seed yam farms 3–5 ha in size and a well-structured 1-hectare market that prohibited the sale of anything but seed yam.

14.3.4 Ware Yam Demonstrations Using Good Agronomic Practices and Improved Varieties to Drive the Demand for Released Varieties

Awareness of improved varieties may drive demand for improved seed. Baseline studies conducted at the start of the YIIFSWA project showed average yam yields of 9.4 tonnes (t)/ha in Nigeria and 7.0 t/ha in Ghana, for local varieties were less than 25% of the yield of improved released varieties, which ranged from 30 to 40 t/ha (Mignouna et al. 2014a, b). Yet, farmers were not aware of the 19 improved yam varieties that had been selected by plant breeders in Nigeria between 2001 and 2010. Adoption failed because there was no formal yam seed system to rapidly multiply large quantities of quality seed for farmers at an affordable price.

The yields for improved varieties can be further increased if farmers adopt better seed quality and good agronomic practices. To sensitize farmers on the superiority of improved varieties, seed tubers of selected released varieties [two *Dioscorea rotundata* (TDr 89/02665 and TDr 95/19177) and one *D. alata* (TDa 98/01176)] bred by IITA were planted in 80 on-farm demonstration plots to compare with the best local varieties by state in Nigeria (Oju-Iyawo in Oyo, Nwaagba in Enugu, Hembakwase in Benue, Meccakusa in the Federal Capital Territory (FCT), Nasarawa, and Niger) (Fig. 14.5). Farmers were identified to establish the demonstration plots in consultation with the National Root Crops Research Institute (NRCRI)-Umudike, NGOs, and local farmers who had participated in previous project activities. A deliberate effort to involve women in the demonstrations resulted in a proportion of 89% men and 11% women (Table 14.7).

A questionnaire to participating farmers revealed, on average, 23 years' experience with yam cultivation. About 46% of farmers claimed said their yam production had increased over the past 5 years (mostly due to an increase in the area cultivated), 36% noted said their productivity was decreasing, and 18% reported fluctuations due to climate change, increased pest and disease infestations, declining soil fertility, low yield potential of local varieties, and labor scarcity. Farmers said they selected yam varieties that resulted in high yields, big tubers, and good performance in dry years, with high market demand, early maturity, and white flesh that does not oxidize.

The project wrote a protocol describing good agricultural practices to follow in establishing seed plots. After planting, plots were monitored regularly by the IITA technical staff and the seed companies (including farmers' groups linked to the plots) to assess the growth and development of the crop.

At each locality, one of the best demo plots was selected for field days at the peak of the crop's vegetative growth and again at harvest. About 5 months after planting, the crop foliage was assessed, and 58% of the farmers preferred the improved variety TDr 95/19177, while 32% preferred TDa 98/01176. Ten percent were undecided between the local variety and TDr 89/02665. Although most ranked the improved varieties better during the vegetative stage, some farmers ranked the local varieties best, claiming that they were more certain of its tuber

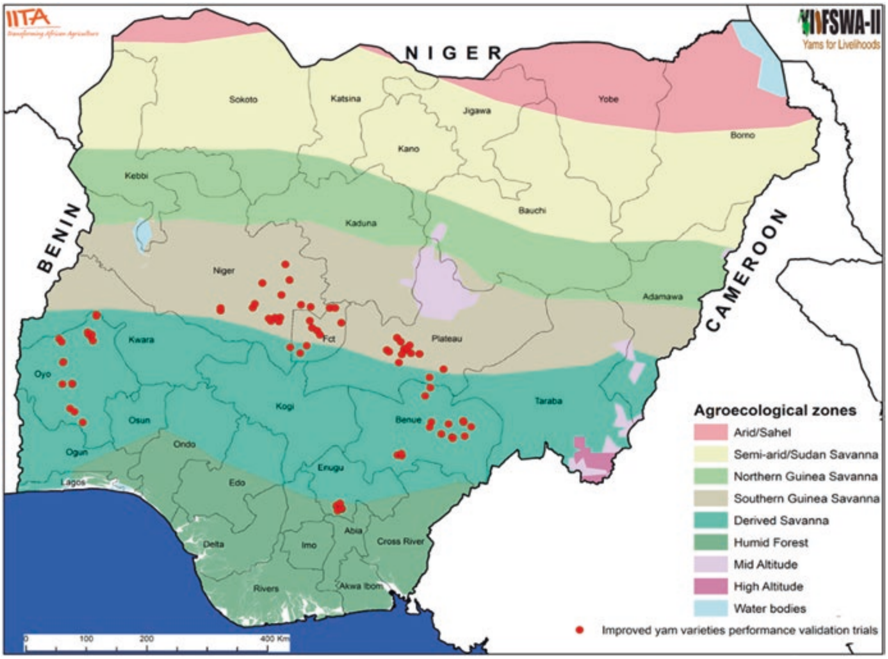

Fig. 14.5 Improved yam varieties were sown in 80 demonstration plots across six states in Nigeria

Table 14.7 Number of male and female farmers involved in the demonstrations for ware yam production

State	Benue	Enugu	FCT	Nasarawa	Niger	Oyo	Total
Male	14	6	9	14	15	13	71
Female	1	0	1	2	0	5	9
Total	15	6	10	16	15	18	80

quality. It was only after harvest that this group of farmers selected the improved varieties when they could confirm the tuber yield and quality. Although the *D. alata* variety, TDa 98/01176, had the highest mean yield of 19.1 t/ha (maximum of 34.6 t/ha), the most preferred variety was *D. rotundata* TDr 95/19177, with an average yield of 18.0 t/ha (maximum of 31.5 t/ha). The farmers' best local variety yielded 12.1 t/ha. All the farmers who participated in the study were convinced of the improved varieties' potential and requested more seed to plant. The three improved and released varieties TDr 95/19177, TDr 89/02665, and TDa 98/01176 were later named by farmers as Kpamyo ("provides wealth"), Asiedu (in honor of the scientist who bred many of the yam varieties), and Swaswa ("fast," i.e., provides food and wealth fast).

14.3.5 Creating Awareness for the New Seed Technologies Among Stakeholders of the Yam Value Chain

Apart from the few ware yam farmers, seed growers and NARIs were not aware of recent developments in the seed yam subsector, so an awareness-raising campaign was carried out to (1) explain the economic impact of yam in Ghana and Nigeria; (2) advocate for an increased priority to yam in government investment plans for sustained funding by the public and private donors; and (3) popularize YIIFSWA's improved seed yam technologies for increased adoption by private seed companies and commercial ware yam farmers. The campaign engaged policymakers and other stakeholders with more emphasis given to Nigeria, where yam is prioritized as a key commodity in the 2016–2020 Agricultural Promotion Policy (APP) by the Ministry of Agriculture and Rural Development.

For sustainability of the improvements of seed production technologies, the YIIFSWA project assigned the role of connecting the yam value chain actors to the seed regulatory services: the National Agricultural Seed Council (NASC) in Nigeria and the Plant Protection and Regulatory Services Directorate (PPRSD) in Ghana. The public sector has the responsibility of regulating formal seed production, which needs the patronage or services of other stakeholders to thrive.

Stakeholders of the yam value chain were brought together to brainstorm on how to form partnerships and linkages to establish coordinated networks. The new business opportunities in seed yam production (for yam producers, processors, marketers, and transporters) using available new technologies to produce high-quality seed yam tubers of released varieties were demonstrated to intensify yam production for economic gain and food security as well as to facilitate a demand-driven seed system. The participants included researchers, public and private seed yam producers, ware yam dealers (producers, marketers, exporters, processors, input dealers, service providers, yam commodity associations and transporters), the Ministry of Agriculture's Yam Value Chain Department, and consumers and other relevant institutions. Recommendations were made to overcome the challenges for each value chain actor such as formalizing sales by weight, develop improved storage systems, improve knowledge sharing among stakeholders, improve extension education to farmers, build capacity and equip certification officers, and encourage the private sector to provide extension services, among others.

14.4 Advances in Seed Quality Assurance and Seed Certification

The formal yam seed system being developed in Ghana and Nigeria is promoting two generations of breeder seeds (BS1; BS2) followed by two generations of foundation seeds (FS1; FS2) and finally three generations of commercial seeds (CS1, CS2, and CS3). The chronology accepted by all project partners is BS1 → BS2 → FS1 → FS2 → CS1 → CS2 → CS3.

14.4.1 Managing Pests and Diseases Through Quality Seed

Pests and diseases are major bottlenecks that reduce yam tuber yield and quality (Mignouna et al. 2019). Severe leaf diseases can significantly reduce yields. If the quality of the tubers is affected, then they lose commercial value. The most important diseases in West Africa are yam mosaic virus (YMV) and yam mild mosaic virus (YMMV). A third disease, yam anthracnose disease (YAD), is caused by the fungus *Colletotrichum gloeosporioides.* Nematode pests to yam include *Scutellonema bradys, Meloidogyne incognita,* and *M. javanica* and rot fungi, *Botryodiplodia theobromae* and *Aspergillus niger*. All these endemic threats are carried from one generation to another by recycling infected planting materials. Pests such as nematodes, mealybugs, and scale insects are transferred from the field on tubers into storage where they continue to multiply and cause damage, leading to higher tuber losses and reduced market value (Ampofo et al. 2010; MEDA 2011). Lack of pest- and disease-free seed tubers is a significant constraint to yam production in West Africa. In the absence of durable resistance, the use of pest- and disease-free seed yams, often referred to as "clean" seed yams, is the best alternative for enhancing the yields and quality of yam.

Various efforts have been made to improve the quality of seed yams, including the selection of healthy-looking yams and the treatment of seed yam tubers (setts and minisetts) with insecticides (e.g., chlorpyrifos) and fungicides (e.g., mancozeb) as part of the AYMT. These methods are useful to eliminate fungi, nematodes, and insects but ineffective against viruses. The YIIFSWA project made the first concerted effort to generate virus-free seed yams. The procedure, detailed in the previous section, involves in vitro production of virus-free plants used as sources for high-ratio propagation of virus-free seed yams (Aighewi et al. 2015; Balogun et al. 2017a). Plants are propagated hydroponically; then vines are cut from them to generate rooted vines for direct planting in the field or to produce mini-tubers in screenhouses.

Before the YIIFSWA project, the seed yam system in West Africa was mainly informal and entirely market-driven (Nweke et al. 2011). There was no quality control, and pest- and disease-infected tubers moved back and forth from field to storage. With YIIFSWA, a formal seed system was established in Ghana and Nigeria to control quality and provide certifications for all categories of seed yam (breeder, foundation, and certified seed) by the regulatory agencies.

14.4.2 Seed Certification for Sustainable Production of Quality Seed Yam

Seed certification schemes have been introduced to regulate the production and marketing of quality seeds and to reduce the use of diseased planting materials. For vegetatively propagated crops in sub-Saharan Africa, seed certification is emerging as an important tactic to prevent the further perpetuation of pathogens and pests in planting materials, to reduce disease inoculum in the fields, to prevent losses due to virus diseases, and ultimately to contribute to sustainable and profitable production (Almekinders et al. 2019; Bentley et al. 2018). There was no seed certification for most vegetatively propagated crops, including yams, until the 2000s in Ghana and Nigeria, when the first schemes were established to certify seed yams produced as part of an IFAD-funded root and tuber improvement program. These early schemes were tailored for the certification of the foundation seed (FS) and the certified seed (CS) tubers produced in open fields. The yam certification schemes were later adopted as part of the ECOWAS harmonized seed regulation procedures, which included standards for breeder seed (BS), FS, and CS.

The official seed yam certification schemes stipulate parameters to produce quality seed, which include:

1. Requirements for registration and accreditation of seed producer as BS, FS, or CS
2. Registration of seed production fields
3. Parameters for source seed used for seed production
4. Parameters for agronomic management of seed fields
5. Maximum threshold levels for notified pest and diseases in the seed production field

The seed yams can be reused for a maximum of seven generations: two generations each for BS (BS1 and BS2) and FS (FS1 and FS2) and three generations for CS (CS1, CS2, and C3). However, this procedure was challenged by the lack of virus-free source seed, so seed production remained mainly informal. Furthermore, existing seed certification procedures did not meet the needs of yam propagation material generated using newly established high-ratio propagation methods such as TIBS, aeroponics, hydroponics, and SAH. To overcome these challenges, revised certification procedures have been established by YIIFSWA-II and the CGIAR Research Program on Roots, Tubers, and Bananas' (RTB) initiatives, coordinated by IITA with national program partners in Nigeria (NASC) and Ghana (PPRSD).

14.4.3 Adapting Certification Procedures to Products of New Propagation Technologies

Emerging commercial seed yam enterprises fostered by the new wave of high-ratio propagation technologies require fit-for-purpose certification schemes. Revised seed yam certification procedures were developed after in-depth consultations between government regulators in Ghana and Nigeria and seed producers from public and private sector organizations, NGOs, and IITA in 2018 and 2019. The revised seed yam certification scheme aims to certify seed yams of registered varieties, which are true-to-type and meet the phytosanitary status concerning notified pathogens and pests, and ensure the supply of virus-free seed yams for ware yam production (Table 14.8).

The revised certification scheme introduces a new class of seed termed "nucleus seed (NS)" as the progenitor of BS. NS is allowed to reuse stock in perpetuity as long as they remain true-to-type and disease-free. BS and FS seed can be reused for an additional generation each, while the CS can be used for three generations.

Table 14.8 Basic parameters for seed yam quality assurance

	Nucleus seed (NS)	Breeder seed (BS)	Foundation seed (FS)	Certified seed (CS)
Propagation	Laboratory (TC, TIBS)	Laboratory (TC, TIBS, SAH) and screenhouse (aeroponics, hydroponics, SAH, and vine propagation)	Screenhouse (aeroponics, hydroponics, SAH, and vine propagation) and field (mini-tubers and minisetts)	Field (mini-tubers and minisetts)
Registration of seed producer	Required	Required	Required	Required
Source seed verification	Required	Required	Required	Required
Isolation distance (for field propagation)	NA	NA	5 meters	5 meters
Number of inspections	Lab accreditation	Screenhouse accreditation	Three inspections (1. preplanting; 3 to 4 months stage; at harvest)	Three inspections (1. preplanting; 3 to 4 months stage; at harvest)
Maximum number of generations	Perpetual[a]	Two generations (BS1 and BS2)	Two generations (FS1 and FS2)	Three generations (CS1, CS2, and CS3)
Virus (mosaic virus)	0	0	<10% of plants with symptom severity score (SSS) 2[b]	<20% of plants with SSS 2
Fungi (anthracnose etc.*)*	0	<10% of plants with symptom severity score 2	<10% of plants with SSS 3	<20% of plants with SSS 2
Nematode and fungal damage (tuber rot)	0	0	<10% of plants with SSS 2	<20% of plants with SSS 2

NA not applicable
[a]If material remains true-to-type with zero incidence of pest and diseases
[b]On a scale of 1 to 5 where 5 = most severe

The NS are produced in vitro in the laboratory or controlled environments with TIBS, which allows perpetual propagation of disease-free seed yams. Most BS is produced in laboratory using TIBS or SAH and in screenhouses with aeroponics and hydroponics. FS and CS are grown in screenhouses or open fields depending on the business model. Seed entrepreneurs (SE) and local seed producers are required to register seed fields, and the fields are inspected three times for suitability of field, varietal purity, and plant health.

14.4.4 Tools for Enabling Seed Certification

Tools and procedures have been established to assure seed qualities which are useful for seed producers and seed regulators.

Determination of genetic purity Morphological keys and DNA markers have been established to determine the identity of yam cultivars.

Seed health testing Tools for the reliable detection of yam viruses have been established based on polymerase chain reaction (PCR), loop-mediated isothermal amplification (LAMP), recombinase polymerase amplification (RPA), and rolling circle amplification (RCA) methods for the reliable and sensitive detection of yam viruses of importance to seed production (Bömer et al. 2019; Nkere et al. 2018; Silva et al. 2018).

Seed tracker The Yam Seed Tracker (YST) was developed as an innovative ICT solution to enable the digital integration of various value chain actors of the formal seed yam systems (Ouma et al. 2019), including institutions and entrepreneurs formally recognized to produce and market seed of released varieties. The YST is usable on any Internet-enabled device and offers real-time tracking of the seed production database, generates geographic maps, and offers analytics. The tool has been tailored to the regulatory procedures used for seed quality assurance and certification in Ghana and Nigeria. YST is suitable for registering seed producers and seed fields, organizing field inspection, and certification of seed lots. The tool has been adopted by the NASC of Nigeria as the national e-certification platform, making it easy for seed yam producers to ensure compliance with regulatory procedures and has been piloted to register seed yam value chain actors and for seed certification in Nigeria. Seed Tracker is one of the 11 tools of the RTB Seed System Toolbox.[2]

[2] https://www.rtb.cgiar.org/seed-system-toolbox/: The toolbox (11 tools) for seed systems of roots, tubers, and bananas that brings together proven strategies and tools that work to successfully diagnose, plan, and develop new vegetative seed systems.

14.4.5 *Promotion of Seed Quality Assurance for Mainstreaming Seed Systems*

The procedures for seed yam quality assurance by state seed certification agencies were new in West Africa. Therefore, YIIFSWA-II, AfricaYam, RTB, and other initiatives have made efforts to generate awareness about seed certification among growers, buyers, and seed yam users through the Yam Forums established in Ghana and Nigeria. The forum is comprised of all the seed value chain actor ware producers, traders, processors, input suppliers, policymakers, regulators, government agencies, private sector, NGOs, and representatives from the Ministry of Agriculture and serves as an excellent platform for sharing new advancements and benefits of adoption. Training courses have been organized in seed yam certification, virus diagnostics, and the use of YST for the seed certification officers from Ghana and Nigeria.

14.5 Outcomes and Value Added to Farmers Including Women and Youth

14.5.1 *The Framework Established for Sustainable Value Creation in the Yam Sector*

The YIIFSWA project has created products, services, and solutions in the yam sector by providing new technologies, organizing training events, and finding solutions that address challenges of the sector, to improve food security. However, there is still need (1) to produce yam differently using new high-ratio propagation techniques (HRPTs) and (2) to use these new technologies to bring yam to consumers and increasing efficiencies in the food chain.

Despite the COVID-19 pandemic during 2020, the early generation seed system (EGS) performed better than in 2019, generating 68% of the expected EGS of 5.8 million seeds. The performance is very high (309%) in terms of breeder seed production but below expected target levels for foundation seed production (65%).

In Nigeria, this is the first time that National Root Crops Research Institute (NRCRI-Umudike) has a facility established for breeder seed yam production using TIBS. It generated up to 22,663 seeds production level above its set target of 21,840 seeds. NACGRAB reached 98% of the 2020 seed yam production target of 8736. As for Ghana, in 2020, CRI was able with assistance from YIIFSWA-II to achieve a seed yam production level of 350% of its target of 21,840 seeds. SARI with its first TC Laboratory since inception attained 399% of its target of 8736 breeder seed plantlets.

In total, 221,735 breeder seeds were produced by IITA and NARIs in 2020. This total exceeded the target production by 309%. In terms of nucleus stock plantlets, production was higher in TIBS than conventional TCs at all NARIs. Nucleus stock was provided by IITA to NRCRI and SARI to enhance production before the COVID-19 travel constraints. Highest production of breeder seeds was through Vivipak and vine cuttings.

For foundation seed production, a total of 3,631,284 seed tubers were produced in 2020. The project partnered with eight commercial seed companies in Ghana (3) and Nigeria (5). The NARIs supplied the private seed companies with breeder seed to allow them generate foundation seed. However, it was observed that the seed companies of Nigeria are not performing well in term of single-node vine cuttings. Some of them (Da-Allgreen and PS Nutraceuticals) generated enough vines with their hydroponics and aeroponics but lost the single-node vines during the process of rooting: only 30% survived. With this low level of foundation seed production, the SE were not able to receive foundation seed from private seed companies to produce certified seed.

14.5.2 Cleaned Seed Delivery, Yield Gains, and Reduced Poverty

The most important challenge of the seed yam value chain is the scarcity of high-quality seed yam. This obstacle undermines farmers' ability to gain higher yields and generate sustainable incomes. Most farmers are not familiar with producing sole crops of seed yam due to the widespread traditional practices of obtaining seed yam from ware crops.

Based on the proven benefits of high-quality seed yam, IITA and its partners are establishing a robust seed yam system in Ghana and Nigeria that uses a market-based, integrated approach to deliver clean seed yam of improved varieties to at least 320,000 smallholder farmers by 2021. After the first phase of the project, the mean productivity advantage was about 18% in Nigeria and 13% in Ghana. The AYMT adoption rate was about 18% in Nigeria and 43% in Ghana. The private seed companies are being encouraged and backstopped for production of high-quality of quantities of target varieties for specific market segments.

Quality assurance standards of seed yam of improved varieties are resulting in increased productivity at the farm level. High-quality breeder seed is gradually improving productivity through lower losses to viruses and nematodes. Three improved yam varieties (*Asiedu*, *Kpamyo,* and *Swaswa*) are being promoted by the project and proving to be up to 38% more productive than local varieties.

Research by YIIFSWA-II has left a legacy of better technologies to address far-reaching yam concerns. At the end of the first phase of the project, the rural poverty had been reduced by 10% in Ghana and Nigeria (25,040 and 119,117 households, respectively). The project will move an estimated one million people out of poverty by 2037 in West Africa, and more than 96 million people are expected to benefit from yam technologies in all the yam-producing countries (Mignouna et al. 2020).

14.5.3 Trust of End Users and Informed Decision-Making for Sustainable Stakeholder Enterprises

Activities such as field days and demonstration plots were organized to educate certified SEs, local seed producers, and seed company out-growers on good agronomic practices required for quality seed yam production. The integration of women in the operation of demonstration sites was strongly encouraged to make informed decisions on how to decrease the constraints and increase the benefits to female and male farmers.

14.5.4 Sustainable Seed Yam System

Prior to interventions, the yam sector had a fragmented seed value chain, but the YIIFSWA project has upgraded portions that cover activities from the use of plant genetic resources to the marketing and/or distribution of improved yam varieties to farmers.

Through scaling out the high-quality seed production technologies developed in YIIFSWA, seed companies, in partnership with national regulatory agencies, delivered foundation and certified seed yam tubers to seed entrepreneurs. Private seed companies were trained to understand pricing, contracting, and demand forecasting. Demand forecasting is critical given the high downstream demand variability for each variety and the length of time between when foundation seed is produced and when demand for certified seed is satisfied. Further training is ongoing to:

- Strengthen capacities of the seed yam value chain actors to support the development of commercially viable seed businesses. Business models developed with seed yam value chain actors are providing good practice models for further replication.
- Disseminate the results of YIIFSWA (improved varieties and clean seed) through scaling to flow commercially beyond the project areas. YIIFSWA-II outputs (such as high-quality breeder seed production using TIBS and clean foundation seed production by private companies using aeroponics, virus diagnostic tools, and seed quality certification systems) are being appropriated, adapted, and extended to other places in the world where yam is an important crop.[3]
- Ensure efficient partnerships and coordination between seed actors along the value chain. Quality control and quarantine regulators, seed producers, seed sellers, seed yam buyers, and yam processing businesses are collaborating effectively. Record-keeping, sharing of information, and accountability are facilitating

[3] www.wecrop.com.au. Multinational company, source of 100% organic tropical food staples, for all lovers of yam, taro, cassava, and plantain (Accessed on 10 January 2021).

seed traceability and creating an enabling environment for seed yam businesses (Aighewi et al. 2017) to thrive even beyond the project's life.

14.5.5 Advocacy and Awareness Creation

The project's advocacy and awareness creation activities were aimed at communicating the results of YIIFSWA and are being scaled in YIIFSWA-II to sustain investments in yam and to raise investments to reach new areas in Ghana and Nigeria. It is expected that by the end of the project, the activities under this component should have raised at least $2 million.

14.5.6 Gender Mainstreaming in the Production and Commercialization of Seed Yam Systems

Gender is an important consideration for looking at how social norms and power structures differentially impact the lives and opportunities available to groups of men and women. Gender and diversity were built into the project through several strategies, tools, and resources to ensure that project activities specifically benefit women. These strategies included organizational gender mainstreaming and gender assessments aiming at increasing awareness and gender equality.

Women were provided various opportunities to earn income in commercial yam seed production and distribution. Of the eight private commercial seed companies are partnering with YIIFSWA-II, one in Nigeria and one in Ghana are female-owned. Moreover, 13% of staff contracted by these private companies in the seed yam value chain were women as heading toward the gender mainstreaming target of *40%*.

An assessment was conducted in Ghana and Nigeria in 2019 to understand and address gender issues in seed yam production, delivery, and access. The study used a gender-sensitive questionnaire for individuals and focus group discussions to assess the role and status of gender in the seed yam sector and to understand the gender dynamics within yam production in the study area. States/regions and communities/districts were selected purposively, while male and female respondents (farmers) were randomly selected. In total, 226 male and 220 female individual respondents were interviewed, while separate focus groups comprised of a total of 55 men and 53 women were interviewed from 6 states in Nigeria. In Ghana, the groups of a total of 37 women and 165 men were interviewed from 3 regions.

Results revealed that decision-making for all the farm operations are controlled primarily by men and that men carried out most of the activities related to yam production (fertilizer application, harvest, storage, marketing). In some rare cases, the household head was a woman, and, in such situations, they were either divorced or widowed.

Table 14.9 Seed yam production and objectives for growing seed yam in Nigeria

	Gender	Response	Benue	Enugu	FCT	Nasarawa	Niger	Oyo	Average
Produce seed	Female	No	32.5	16.2	6.3	50	36.5	3.8	24
		Yes	17.5	32.4	43.8	5.3	12.2	43.9	26
	Male	No	30	6.8	0	31.6	27	4.6	17
		Yes	20	44.6	50	13.2	24.3	47.7	33
Objective of growing seed	Female	Planting	47.5	21.6	39.6	55.3	47.2	41.7	42
		Sales	2.5	27.1	10.4	0	1.4	6.1	8
	Male	Planting	50	18.9	35.4	39.5	43.3	28.8	36
		Sales	0	32.4	14.6	5.3	8.1	23.4	14

Forty percent of the female respondents interviewed in Ghana and 26% in Nigeria reported that they produced seed yam, while 56% of the male respondents in Ghana and 33% in Nigeria said the same. In this gender study, seed yam in Nigeria is perceived as a nascent business because many farmers get their seeds from the previous season to plant and buy only a few for planting. Some leftover seeds are sold seed after planting by other farmers. Table 14.9 presents the situation of seed yam production and utilization in the project states in Nigeria.

In terms of gender participation in yam production, about 46% and 24% of men and women, respectively, reported full participation in Nigeria. Similarly, in Ghana, about 92% and 21% of men and women, respectively, reported full-time participation. Those women who participated full-time were either divorced or widowed. Few women owned their yam farms.

Concerning access to financial resources (such as lending), fewer people in Nigeria reported having access compared to those in Ghana. In Nigeria, only 15% and 13% of men and women, respectively, said they could access bank assistance while those numbers in Ghana were 32% and 30% of men and women, respectively.

14.6 Lessons Learned From Scaling Improved Seed Yam Production Technologies

The lessons learned included the following:

- Overall, provision of key infrastructure for the private seed companies, training as a component of the mechanism for delivery of the new technologies to next users, strong partnerships (especially with national regulatory agencies), and learning through monitoring and evaluation were important to progress.
- We underestimated the time needed to establish formal yam seed systems in countries with underdeveloped seed certification for clonally propagated crops, which required developing, validating, and scaling out high-ratio technologies; building capacity of key actors; and producing clean stock materials of registered varieties.

- Control of high temperatures in screenhouses of the aeroponic systems (using methods developed in the project) is critical, as is the timing of field planting of rooted single-node vine cuttings in relation to ambient weather conditions.
- Closer interaction of project staff with the private seed companies at the early stages of their engagement could have forestalled the setbacks that resulted from their ignoring some of the specifications for construction and operation of their aeroponic systems.
- Business plans for efficient and sustained breeder seed production using the novel technologies must pay attention to the costs and access to laboratory reagents, skilled technical capacity, and power (electric and/or solar).

14.7 Conclusions, Recommendations, and Emerging Issues

14.7.1 Conclusions

The aim of YIIFSWA project has been to transform seed yam systems by facilitating availability and access to high-quality seed of improved yam varieties in yam-growing areas of Ghana, Nigeria, and beyond. High-ratio propagation technologies and seed health management techniques developed during the first 5 years (2011–2016) were scaled out during the second phase (2017–2021). Thus, the elements for sustainable formal seed systems for yam are in place in Ghana and Nigeria:

- Temporary Immersion Bioreactor System (TIBS) have been established in laboratories at two NARIs in each country to produce breeder seed. Eight private seed companies have been provided with technical training and infrastructure for aeroponic (AS) and hydroponic (HS) systems to produce foundation seed. Seed entrepreneurs have been trained in commercial seed yam production using the adapted yam minisett technology (AYMT).
- Improved seed health management methods that incorporate virus indexing and virus elimination techniques (including heat therapy combined with meristem tissue culture) have been established. The regulatory bodies in Ghana and Nigeria have been trained and provided with equipment for yam virus diagnostics, and protocols are available for seed yam quality assessment and certification.
- The COVID-19 pandemic limited many planned interactions among implementing agencies and potential beneficiaries, but actors in the seed sector have been trained to facilitate scaling the seed production technologies. Technology uptakers were first trained in specifications and procedures for producing seed yam. These trainees can be service providers in scaling the production technology to new or existing actors. Seed producers were then trained in daily management of a seed production system. SOPs and a manual of procedures have been produced and disseminated.

- Males are more involved in yam production and benefit more from all factors of production than females in Ghana and Nigeria. Active efforts have been made through the project to enhance gender equity by involving women at more stages of yam systems.

14.7.2 Recommendations

Additional research is needed on the following topics:

- Studies of the purchasing power of farmers for adequate pricing and recurrent purchases to encourage replacement of their degenerated planting materials.
- Fine-tune processes in the new propagation technologies, as well as associated agronomy, postharvest handling, and storage of seed tubers (especially micro- and mini-tubers), and produce SOPs to facilitate adoption.
- Assess the cost-effectiveness of the use by seed companies of aeroponic, hydroponic, or semi-autotrophic hydroponic systems in foundation seed production under their conditions.
- Identify the conditions or methods to break seed tuber dormancy to allow planting shortly after harvest as may be necessary to speed up seed production cycles.
- Estimate the rate of seed degeneration as the basis for deciding optimum timing for replacement of seed stocks at various stages along the seed value chain.
- Conduct ex ante analysis of the prices for quality seeds of newly released varieties in the formal seed system relative to those of traditional varieties in the informal and later the formal, system. For seed potato, Almekinders et al. (2019) noted that certification requirements increased the cost of planting materials prohibitively.

Scaling should focus on the following areas:

- On-farm demonstrations of the superiority of high- over poor-quality seed yams in terms of productivity, postharvest losses, and overall profitability when used in producing ware yams.
- Engage with major yam processors, especially companies who are linked or could be linked with networks of ware tuber producers, to expand opportunities for commercial seed producers to supply healthy seeds of their desired varieties to the producers.
- Continue advocacy for policy and institutional support of the nascent formal seed sector, and target more women and the youth in efforts to promote commercial production of quality seed.
- Advocate for increased transparency in, and enforcement of, seed quality control and certification to limit competition in the seed markets between high-quality seeds and cheaper but poor-quality or contaminated seeds.

- Monitoring of uptake of certified seed production and foster stronger links between seed entrepreneurs and local seed producers to other key actors in the seed sector.

14.7.3 Emerging Issues

The establishment and growth of a formal seed system for yam in Nigeria and Ghana creates some issues that need to be addressed going forward. According to Nigerian seed regulations, a seed company cannot sell seeds in more than one class. Ahead of enforcement of this regulation in the formal yam seed sector, the seed companies need to identify and use the combination of inputs and growth conditions that maximize the production of seeds with the desired attributes (e.g., weight) for the class they target to specialize in. In addition, breeder seed tubers are currently produced by public institutions (NARIs) in Ghana and Nigeria. Fair prices for these seeds are yet to be determined and applied consistently for their sale to the private sector. Sustainable breeder seed production and sale need to be established as a business, for example, through private companies affiliated with the public breeding institutions. Alternatively, the national governments could provide temporary subsidy to the public institutions to continue to perform this function while the formal sector gets established.

There is need for much increased awareness of the emerging formal seed sector by yam growers' associations and actors in the informal sector, especially marketers, who have operated for decades. Likewise, the few improved varieties being promoted in the formal seed system are yet to earn recognition in the markets in West Africa. The high-ratio propagation technologies can be applied to registered traditional varieties that are already popular with farmers as requested by some seed companies. This will build confidence of the seed companies in the profitable use of the technologies at large scale, strengthen their links with their clients, and bring the health benefits from the new technologies to large numbers of farmers through clean seeds of already popular varieties.

The exciting opportunities offered by the formal sector calls for strong linkage with the yam breeding programs in West Africa and regular feedback toward the maintenance of a pipeline for new and superior market-preferred varieties that would sustain demand for certified seeds.

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