INTRODUCTION

Yam is the generic name given to a range of *Dioscorea* species (family Dioscoreaceae), including *D. rotundata* (guinea yam, white yam), *D. alata* (water yam), *D. cayenensis* (yellow yam), *D. dumetorum* (bitter yam), and *D. esculenta* (lesser yam). All the yams are perennial species that produce vines and underground “stem” tubers rich in carbohydrate. The vines die at the end of each growing season, but the tubers can be harvested and used for food or for sale to provide income. Of these species, white yam (*D. rotundata*) is especially prevalent in West and Central Africa; West Africa alone accounts for some 90% or more of the global production (Hahn et al., 1987), although it is also grown in the Caribbean and Latin America (Mignouna et al., 2015; Onwueme, 1978; Orkwor, 1998). White yam is thought to be indigenous to West Africa, most notably the banks of the lowest reaches of the River Niger in Nigeria. This paper will focus specifically on white yam and from here on the term “yam” will be applied specifically to that species.

Abstract

Yam (*Dioscorea rotundata*) is a root and tuber crop throughout West Africa and has significant nutritional, economic, and cultural value, which underpins its importance for the food security of many people who live there. The crop is propagated vegetatively, primarily via the planting of small whole tubers (seed yams) and pieces (setts) cut from larger tubers. However, the use of such vegetative material means that a variety of pests (primarily insects and nematodes) and diseases (primarily fungal and viral) can carry over and multiply from season to season. This paper sets out the plant health issues associated with yam, and how these have been addressed by improving the availability of good quality planting material, especially via the Yam Minisett Technique (YMT) and the more recently developed Adapted Yam Minisett Technique (AYMT). Both approaches are based on the planting of “minisetts” treated with pesticide to produce seed yam free of pests and fungal pathogens, but there have been challenges regarding their adoption by farmers. The paper explores these challenges and how these attempts to improve plant health fit into a wider discussion of the sustainability of yam production in West Africa given that there are other driving forces of climate change, globalization, and urbanization at play in the region.

KEYWORDS

*Dioscorea rotundata*, food security, plant health, West Africa, yam
Yam tubers provide a major source of dietary energy for households as they are rich in carbohydrate (75% to 85% on a weight basis). They also contain the B-complex group of vitamins, vitamin A, vitamin C, β-carotene, and some minerals (Muzac-Tucker et al., 1993; Orkwor, 1998; Verter & Becvarova, 2014). While the tubers cannot be said to be rich in protein, they nonetheless have a significantly greater protein content than do tubers of the other major staple crop cultivated in West Africa – cassava (Manihot esculenta; family Euphorbiaceae). Food made from yam is highly desirable and demand is high. As a result, the tubers fetch a good price in markets, and the latter may be local or quite distant (hundreds of kilometres away) relative to the site of production (Ibane et al., 2012).

Indeed, there is a significant export industry of yams, especially from Ghana, to the West African diaspora in Europe and North America. As yam is thought to be indigenous to West Africa, mainly Nigeria, its production has a very long history in the region that predates the introduction, primarily during the slave trade, of nonindigenous crops such as cassava, maize, and rice, and yam has many associated stories, ceremonies, and other cultural attributes (Korieh, 2007). In many places throughout West Africa, prominent yam farmers can acquire a prestigious “title” (King of Yam) that reflects their skills and achievements (Hahn et al., 1987; Korieh, 2007). Even in many other ceremonies throughout the region, yam often plays a major role given its high status as a food. Yam is thus an important contributor to household food security in West Africa (Mignonu et al., 2013, 2015, 2020; Verter & Becvarova, 2014) and indeed culture.

However, for a variety of reasons yam is a challenging crop to grow, store, and transport. Yam production is demanding of good soil fertility (Orkwor & Adeniji, 1998; Oyetunji & Osonubi, 2008) and water conditions, and requires a relatively high level of labour at various stages during the production process (Asumugha et al., 2009; Nweke & Ezumah, 2012). Flooding in riverine areas, places where growing yam is especially beneficial given the soil fertility and water availability, can result in complete loss of the crop, as indeed can damage by the cattle of migratory pastoralists (the Fulani). The large size and relative fragility of tubers makes them vulnerable to physical damage during harvesting and transportation to storage, and the crop also suffers from a range of foliar and tuber pests and diseases (Morse, 2018, 2020).

Yam can be something of an agricultural enigma in West Africa. As the tubers are highly sought-after and valued nutritionally, culturally, and economically, this suggests that the crop would receive much attention from governments and researchers, especially given many of the challenges that farmers face in yam production noted above. Yet yam can still arguably be thought of as a relatively neglected crop that historically has rarely featured in government policies and programmes, and funding agencies have often failed to provide support for researchers, preferring instead to focus on crops such as cash crops for export (cotton, oil palm, coffee, cocoa, etc.), cassava, and grain crops. This is changing and in more recent years yam has been prioritized as a key export crop in the 2016 to 2020 Agricultural Promotion Policy (APP) produced by the Federal Government of Nigeria. In fairness, a demanding crop like yam is not easy to work with and as well as the challenges noted above, plant breeders have faced challenges in getting yam to cross-fertilize and produce seeds, and this has slowed the production of new improved cultivars (Darkwa et al., 2020), although there are many local cultivars throughout the region, with a single cultivar often having a number of local names depending on where it is grown. Nonetheless, there is much potential for improvement in yam via plant breeding and cropping systems (Ekanayake & Asiedu, 2003) and there has been progress in the development and application of a number of tools to help support breeding programmes (Darkwa et al., 2020). However, the one topic that has perhaps attracted most attention in yam research, especially since the late 1970s, has been the provision of good quality planting material, free from pests and diseases (Morse, 2018; Morse et al., 2020). The latter can be especially problematic for yam given that most farmers propagate the crop using vegetative material, typically small whole tubers (seed yams) or pieces of tuber (setts). As with many crops propagated vegetatively, there is strong potential in yams for pests and diseases to be carried over into the subsequent cropping season and multiply, and it is understandable that the issue of plant health has been at the forefront of research in root and tuber crops to date, as evidenced by a major programme of research entitled “Roots, Tubers and Bananas” (RTB) facilitated by the Consultative Group on International Agricultural Research (CGIAR) system (www.rtb.cgiar.org/). Given the importance of yam as part of household food security and culture throughout West Africa, and given the importance of plant health, the crop provides a nexus between all of these.

The focus of this paper will be to set out some of the main developments that have taken place over the past 30 years in the provision of clean planting material as a foundation for improving yam production. The paper will specifically address the question as to whether these developments have resulted, or could result, in a supply that can be considered to be sustainable. The paper begins with a summary of the yam production cycle along with an outline of the major pests and diseases that attack the crop and how these interact to govern plant health. This is followed by a history spanning some 50 years setting out how researchers sought to provide help to farmers by improving plant health of yam and hence its production and in turn support for household food security. The story of these interventions is a complex one, and while there have been successes there have also been failures. The paper then moves on to explore some of the issues that surround one of the foundations for improving plant health – the use of pesticide treatment. The final section of the paper will explore what all of these interventions mean for the establishment of a sustainable supply of clean planting material in West Africa. How will the nexus between plant health of yam and food security play out into the future?

**YAM PRODUCTION CYCLE**

Figure 1 is a summary of the yam production cycle and the range of options open to farmers in terms of sourcing planting material.
The dark arrows to the right-hand side of the diagram set out the yam production process from land preparation through to harvesting. But the centre of the diagram comprises the sourcing of planting material, a major issue in yam production. Propagation of yam is primarily through the planting of small whole tubers (seed yams) and cut pieces of tuber (yam setts) to produce the larger tubers (ware yams) that households consume and sell (McNamara & Morse, 2018; Morse, 2018). Yam tubers have meristematic tissue in loci ("eyes") close to the tuber surface that can germinate once apical dominance is removed. Some farmers remove ware tubers from the plant towards the end of the growing season and cover the roots again with soil so as to allow growth of new seed yam tubers; a process referred to as "milking" (McNamara & Morse, 2018; Nwokea & Okonkwoa, 1978). There have been efforts to use vine cuttings for propagation, and the most recent approach in this area involves the use of aeroponic systems for growing vines that are in turn transplanted into the field to produce seed yams. However, the majority of small-scale farmers use seed yams and setts.

However, the use of tuber-based planting material can result in the passing of pests and diseases within the tubers from one generation to the next. Also, the use of setts, while a cheaper way of generating planting material than seed yams, is potentially problematic, as once the tubers have been cut it provides an opportunity for infestation from soilborne pests and diseases, and if severe this can cause a loss of the material and a waste of resource. Hence, from the perspective of the subsistence farmer the ideal is to use seed yams as planting material, as whole tubers are generally less susceptible to reinfection. As noted in Figure 1, seed yams can be sourced in various ways. Most farmers will simply set aside smaller tubers harvested from the yam crop and use those as seed yams in the subsequent growing season. However, the saving of smaller tubers in this way can be problematic as not enough may be produced. Alternatively, farmers may purchase seed yams in local markets although they can be relatively expensive, especially if the quality is good. Specialist seed yam producers do exist, but most yam growers prefer the ware yam crop as it is this one that helps provide for food security of the household.

3 | YAM PESTS AND DISEASES

Insects can damage both the yam vine and the tubers, and for the latter there are a number of repercussions (Korada et al., 2010). Direct insect damage can reduce the size as well as the quality of the tubers, and both size and quality influence the market value. Although the critical damage is assumed to take place in the field, other insect and nematode pests can cause tuber damage during storage (Ano, 2019; Bridge, 1972; Korada et al., 2010; Osagie, 1992; Sauphanor & Ratnadass, 1985), and may provide additional avenues for pathogen infection. Yam tubers do not have much of a protective cuticle and the corky periderm is only a few millimetres thick, hence damage to the surface need only be relatively slight to breech these barriers (Coursey, 1967; Morse et al., 2000; Osagie, 1992). Any kind of damage to the tuber, either by pests or indeed by humans during harvest and transport, provides an entry point for fungal pathogens. As well as reducing the market value of yam tubers, fungal
rots of yam can produce mycotoxins, which in turn generate safety concerns for both humans and animals (Ibeh et al., 1991; Onyeke, 2020). When preparing food, households will typically cut out rotten segments of yam tubers and feed them to animals, but food can be so scarce that mildly rotted material will be eaten by the household after cooking (McNamara & Morse, 2018). Indeed, toxins have been identified in food products prepared from yams, such as yam “chips”, in local markets in Nigeria (Mestres et al., 2004; Omohimi et al., 2019). Fungal infection can reduce or prevent sprouting and emergence when tubers are used as planting material (Iktotun, 1983).

While most of the pest and disease issues with yam have often focused on production, other parts of the cycle shown in Figure 1 can also be important. Harvesting and transportation of yam tubers from the farm to the household or indeed from the household to markets provide more sources of mechanical damage. The bulky nature of yam tubers means that they are expensive to transport but an additional reason for the high cost is the need to treat them with care. Storage is also an important issue given that ware yam tubers may be stored and consumed over some months. This provides ample opportunity for pest and disease attack, including by rodents. The high value of yam means that households will put much effort into storing yams to minimize these risks but also to avoid theft. Yam stores are typically located near to the living accommodation, but that can in turn create issues if there is a rodent infestation as this can attract venomous snakes (McNamara & Morse, 2018). Traditional methods of yam tuber storage are highly labour-intensive, involving tying individual tubers to stems of trees growing as a hedge or storing in a granary. Tying tubers to a frame structure (yam barn) means that they will be well aerated and also allows infested and rotting tubers to be easily spotted. Despite these efforts, losses in storage can be considerable and 40% has been claimed as common (Bonire, 1985), although losses of 50% have been noted (Olurinola et al., 1992; Osagie, 1992). More typical losses of yams in storage are said to be between 2% and 25% (Nwankiti & Arene, 1978).

Some of the common invertebrate pests that damage yam tubers are shown in Table 1. While the pests have been divided into field and storage categories, there is a significant degree of overlap between these two, and field pests such as nematodes, scale insect, and mealy bug can continue to multiply and cause damage during storage. In terms of pathogens, a common foliage disease of yam is anthracnose, caused by the fungus Colletotrichum gloeosporioides (Amusa et al., 2003; Green & Simons, 1994). Anthracnose can cause severe dieback of foliage but can also spread to tubers where it causes a form of dry rot. Microbial pathogens, especially fungi, are regarded as the main cause of tuber loss during storage, but as noted above this is often linked to tuber damage (Amusa et al., 2003). Many of them are opportunistic pathogens and/or saprophytes that are often found in tropical soils and plant samples (Ogundana et al., 1970, 1971). Many fungal pathogens have been isolated from yam tubers showing dry rot, including Fusarium oxysporum, F. solani, Penicillium spp. (Penicillium pinophilum, P. sclerotigenum, P. variabile) and Aspergillus spp. (Aspergillus flavus, A. japonicus, A. melleus, A. niger and A. terreus) (Acholo et al., 1997; Morse et al., 2000). Other fungal pathogens that have been found on yam include Botryodiplodia theobromae (Green & Simons, 1994; Noon, 1978), Cylindrocarpon spp., Acremonium spp., Cladosporium cladosporioides, Cunninghamamella echinulata, Rhizopus oryzae, Scytalidium lignicola, Cochliobolus verruculosus, Cochliobolus hawaiienis, and Paeclomyces variotii. In addition to the fungal pathogens, yam is also the host for a number of viral pathogens, and these have been claimed to be the most significant factors influencing yam yields (Eni et al., 2010). The complex of viruses found in yam includes yam mosaic virus, yam mild mosaic virus, beet mosaic virus, and cucumber mosaic virus.

Controlling yam pests and diseases in the field has proved to be challenging. Crop rotation and careful choice of farm site and planting material are important, and good quality tubers (i.e., those having less signs of pest and disease damage) as the basis for planting material tend to fetch a price premium in markets (McNamara & Morse, 2018).

### Table 1 Some of the common field and storage pests which attack yam tubers

| Field pests | Species and authority | Order: Family |
|-------------|-----------------------|---------------|
| Yam beetles | Heteroligus meles Billb. | Coleoptera: Dynastidae |
| Prionoryctes spp. | Coleoptera: Sciaridae |
| Termites | Amitermes evuncifer Silvestri | Isoperta: Termitidae |
| Pseudancthotermes militaris Hagen | Isoperta: Termitidae |
| Nematodes (root knot) | Meloidogyne spp. | Tylenchida: Heteroderidae |
| Pratylenchus spp. | Tylenchida: Pratylenchidae |
| Scutellonema bradys Steiner & Le Hew | Tylenchida: Hoplolaimidae |
| Scale insect | Aspidiella (Aspidius) hartii Ckll. | Homoptera: Diaspidae |
| Mealy bug | Planococcus (Pseudococcus) citri Risso | Homoptera: Pseudococcidae |

| Storage pests | Species and authority | Order: Family |
|---------------|----------------------|---------------|
| Storage beetles | Sitophilus zea | Coleoptera: Curculionidae |
| Brachypterus pilosellus Murray | Coleoptera: Nitidulidae |
| Araecerus fasciculatus De Geer | Coleoptera: Anthribidae |
| Carpophilus dimidiatus Fabricius | Coleoptera: Nitidulidae |
Some local varieties are said by farmers to be more resistant or tolerant of pests such as nematodes than are others and there is much potential for breeding programmes to produce resistant cultivars, although to date this has been limited. Nonetheless, accessions with apparent resistance to the pathogen causing anthracnose as well as yam mosaic virus have been identified, and some of the genes involved have been mapped using molecular markers (Darkwa et al., 2020). As Darkwa et al. (2020; page 491) have noted, “several inherent biological constraints make yam breeding a very arduous and lengthy endeavor” but nonetheless steady progress is being made on many fronts and cultivars resistant to some pests and diseases may become available in the coming years. Nonetheless, at the time of writing, the most widely used methods for controlling pests and diseases in yam have revolved around the use of pesticide dusts and pesticide dips applied to planting material. Within the yam store, farmers tend to rely on good hygiene (i.e., removing tubers that have become infested) and making sure that tubers receive no physical damage during harvest and transport (Hahn et al., 1987). Some farmers employ an intermittent smoke treatment to help control pests (McNamara & Morse, 2018). Insecticides such as pirimiphos-methyl along with a wide variety of different fungicides have been tested for controlling insect pests and pathogens damaging yams in storage, but their use is not widespread (Aderiye et al., 1989; Nnodu & Nwakiti, 1986; Ogundana, 1972; Ogundana & Dennis, 1981; Olurinola et al., 1992; Plumbley et al., 1985; Sarma, 1984; Ugogi & Uduebo, 1986). Plant extracts (Ano, 2019) and even products such as lime and local gin (Ogali et al., 1991) have also been tried to help control fungal pathogens in yam stores, but with mixed results.

4 | IMPROVING PLANT HEALTH IN YAM PRODUCTION: A BRIEF HISTORY

Given that good quality seed yams can be scarce and expensive in local markets, researchers have sought ways to improve their production and hence availability (McNamara et al., 2012; Morse, 2018, 2021; Morse & McNamara, 2015, 2016, 2018a, 2018b; Morse et al., 2009). These methods have mostly revolved around the cutting of larger tubers (so-called mother yams) into small setts (minisetts), and are based on the fact that the size of a yam tuber produced from a sett is positively related to the size of the sett (Morse, 2018). This is illustrated in Figure 2, where mother yams of around 0.5–1 kg are cut into setts of various sizes. If setts are cut to the right size (minisetts of 10–80 g) then it is possible for them to produce seed yams of around 250 g. However, slightly larger minisetts (80–100 g) can be used to generate a mix of tuber sizes, some of which will be suitable as seed yams while others could be used as ware yams. Very small setts (microsetts) can even be used to grow minitubers that in turn can be planted to generate seed yams. There is much flexibility here, and while much can depend on the time of planting, soil type, plant density, and yam variety, a skilled farmer can generate a variety of tuber size mixtures to suit their needs, and specialist seed yam producers have long employed this approach (Ibana et al., 2012).
to sprout. Given the high financial value of yam tubers, let alone the work involved in land preparation, then the loss of planted setts may represent a significant risk for the farmer (Morse et al., 2009). Researchers have sought ways to minimize the risk to the farmer and this has primarily been achieved through the use of sett treatments such as hot water, plant-based products (e.g., neem; Nwauzor, 2001), and pesticides. These all have their advantages and disadvantages, but to date most attention has been given to the use of pesticides.

One such approach developed in Nigeria during the late 1970s and strongly promoted by a variety of agencies since the 1980s is called the yam minisett technique (YMT; Morse, 2018). YMT uses mother yams of 500 g to 1 kg to generate minisetts of 25 g. Thus, one mother yam should generate 20 to 40 minisetts of 25 g. The recommendation of 25 g was selected as a compromise between the competing requirements of maximizing the number of setts from a single mother yam (to keep cost and risk down for the farmer) and the need for a reasonable proportion of seed yam-sized tubers in the harvest (George, 1990; Kalu et al., 1989). Minisets sizes greater than 25 g would be advantageous as they would aid survival in the field (George, 1990), but with higher sett sizes the harvest may contain a sizeable proportion (c.30%) of ware yams weighing 1 or more. The originally promoted 25 g recommendation of minisett size in Nigeria was meant to be a compromise between these competing requirements of maximizing the number of setts from a single mother tuber, sett survival in the field, and the need for a reasonable proportion of seed yams in the harvest (Kalu et al., 1989). Once the minisetts had been cut, farmers were encouraged to allow them to dry and harden in a warm but humid location, after which they should be treated with a cocktail of insecticide and fungicide applied as a dust to prevent damage from pests and diseases (Morse, 2020). The sett dressing typically comprised an insecticide (e.g., lindane, aldrin) and fungicide (e.g., thiram), often mixed with wood ash (Morse, 2020), although the effectiveness of woodash in the mixture has been questioned (Onwueme & Charles, 1994).

Once treated, it was recommended that the setts be placed in a nursery comprising a medium free of pests and diseases (e.g., sand that had been boiled in water then dried). The use of a nursery would improve minisett survival, but it is labour intensive—a point often made by farmers (Okoli, 1986). Once the rains had become established, the farmers could transplant sprouted minisetts into the field at a typical depth of 9–12 cm, with a plant spacing of 25 cm (4 stands per m² = 40,000 stands/ha if metre ridges are used). Plant density is an important variable in determining the size of tubers arising from minisetts, with higher plant densities tending to give smaller seed yams (Osiru et al., 1987). As farmers need to wait for the rains to become well-established, planting of minisetts typically takes place later in the season than for the ware yam crop, and this allows farmers to manage their labour. Establishment of sprouted setts in the field can take 4–8 weeks (Okoli, 1986). However, staking is less common when producing seed yams, as foliage growth is not as extensive as it is for ware yams (Danquah et al., 2014), and allowing the vine to cover the soil can help conserve moisture and shade out weeds. Seed yams would be ready for harvest after 6 to 8 months, and under good conditions, minisetts planted at a density of 40,000 stands/ha could yield 13.6 tonnes/ha of seed yams for every tonne of minisett material planted (Okoli, 1986). Between harvest and storage, farmers will typically segregate the tubers into those of seed and ware yam size; the latter would be consumed by the household or sold. Ware yams may be stored for some months and gradually consumed by the household (any excess is sold), while seed yams are all planted early in the growing seasons.

While the YMT was designed to help reduce risks for the farmer, the challenge in promoting it to farmers is that it needs trust. After all, the notion of cutting valuable tubers into small pieces that are then planted to produce, if they survive, seed yams that are not for consumption may not be instinctively appealing, despite the financial regards that could accrue from selling the seed yams or the savings that could be made by the farmer not having to purchase planting material. Most yam farmers concentrate on ware yam production, and indeed may well grow many other crops besides yam, and under subsistence conditions the focus must be the food security of the household. YMT can seem like a diversion of valuable resources, including land and labour, to produce seed yams that have to be planted the following year to generate food. These challenges were well known to researchers, of course, but even so the YMT was strongly promoted throughout West Africa. There have been various reviews of the factors influencing adoption of YMT by farmers (Ilesanmi & Akinmusola, 2016; Morse, 2018). Adoption constraints reported by farmers are typically the high cost of mother yams and the demand for labour, especially given the need to have a nursery stage in the process. Indeed, the way YMT was promoted, especially in Nigeria, as a precise set of recommendations may not have helped with adoption by farmers (Morse, 2018). As a result, there has been some variation on the YMT theme introduced by researchers in more recent years. One of these variants is called the adapted yam minisett technique (AYMT) and was initially developed and promoted during a series of projects funded primarily by the UK Department for International Development (DFID) between 2003 and 2012 (Morse et al., 2020; Table 2). The Bill and Melinda Gates Foundation (BMGF) also became involved in the promotion of AYMT during two large-scale projects managed by international teams of scientists in Nigeria and Ghana between 2012 and 2018 entitled YIIFSWA (Phase I) and CAY-Seed (Table 2; Mignouna et al., 2020).

AYMT introduced a number of changes to the YMT recommendation package. First, AYMT uses larger sett sizes (typically 40–80 g) than the YMT and, critically, no single size is recommended in the way that 25 g was promoted as a “one size fits all” for YMT. Instead, farmers are encouraged to experiment with sett size to generate the range of tuber sizes that suit their needs under their conditions. The advantage of using a larger sett size is that it does away with the need for a nursery (farmers can plant the setts directly in the field) and also the mix of tuber sizes means that farmers can have some ware yam tubers for consumption and sale as well as seed yams. Using a range of minisett sizes, rather than promoting a single size, means that farmers can adapt
the size that suits their local growing conditions and choice of variety. This move away from a “one size fits all” approach in terms of sett size is what is meant by “adaptive” in AYMT. The emphasis is more upon presenting the notion that sett size influences tuber size, and this can be adapted to suit needs. Secondly, while the setts could still be treated in the same way as in YMT (i.e., by using pesticide dust with or without woodash), the researchers developed new ways of treating the setts using a pesticide dip prior to drying the sett. The use of a dip provides a number of advantages, including better penetration of the pesticide into the sett, thereby reducing pests and diseases inside the sett rather than only on the surface. This also means that less persistent insecticides can be used.

AYMT is much more recent than the YMT and to date has not received anything like the same degree of promotion by extension services and other agencies in West Africa. So far it has only received a limited degree of promotion within projects such as YIIFSWA Phase I (2012 to 2016) and CAY-Seed (2014 to 2018) funded by the Bill and Melinda Gates Foundation in Nigeria and Ghana (Table 2). Anecdotal evidence suggest it is far more amenable to farmers than YMT, although there are still significant issues about the availability of pesticide that can be used in the dip.

5 | PESTICIDE TREATMENT OF YAM MINISETTS: BOON AND BANE

The literature on the agronomic and economic performance of both YMT and AYMT has grown significantly since the 1980s and has explored the impacts of variables such as sett treatment, yam

| Project title | Funder | Period; country | Project aims |
|---------------|--------|----------------|-------------|
| Evaluation and promotion of crop protection practices for “clean” seed yam production systems in Central Nigeria | Department for International Development (DFID), UK | 2003 to 2005; Nigeria | Development of a new approach to producing seed yams that are relatively pest and disease “free”. The research resulted in the development of the Adaptive Yam Minisett Technique (AYMT). |
| Up-scaling sustainable “clean” seed yam production systems for small-scale growers in Nigeria. | DFID | 2005 to 2006; Nigeria | Promotion of AYMT via demonstrations. |
| DFID-RIR funded “best bets” project on healthy seed yam production | DFID | 2010 to 2012; Nigeria | Followed on from the two previous DFID-funded projects on seed yam production using AYMT with an emphasis on promotion of entrepreneurship (i.e., clean seed yam producers) and associated business plan training. |
| Yam Improvement for Incomes and Security in West Africa (YIISWA Phase I) | Bill and Melinda Gates Foundation (BMGF) | 2012 to 2016; Nigeria/Ghana | A large project designed to address many gaps in knowledge about yams. One aspect of the project focused on the promotion of AYMT to farmers in Nigeria and Ghana. |
| Community action in improving farmer-saved seed yam (CAY-Seed) | BMGF | 2014 to 2018; Nigeria/Ghana | Designed to be complementary to YIIFSWA Phase I by focusing on training and testing of positive selection, selecting only the healthy yam plants for planting material. The project included further promotion of AYMT. |
| Yam Improvement for Incomes and Security in West Africa (YIISWA Phase II) | BMGF | 2015 to 2021; Nigeria/Ghana | Builds on work undertaken in YIIFSWA Phase I and seeks to develop and establish a functional, commercial seed yam seed system in Nigeria and Ghana to benefit smallholder farmers through timely and affordable access to high quality seed yam tubers of improved varieties. YIIFSWA Phase II focused more on the use of an aeroponic-based system for clean seed yam production. |

Note: Table has been adapted from Morse et al. (2020).
variety, and planting date, to name but three. Some example studies for the AYMT can be found in Morse and McNamara (2015, 2016, 2018a, 2018b). There have also been studies on the agronomic impact of using seed yams produced from AYMT on subsequent ware yam production (Morse & McNamara, 2017) as well as the technical efficiency of both ware and seed yam production under farmer-managed conditions in Nigeria (Morse, 2021). An example of one of the studies of clean seed yam production designed to explore the agronomic impact of pesticide dip applied to minisetts in AYMT is provided by Morse (2020). The work reported in this study was based on a series of demonstrations of AYMT in the middle-belt region (Benue and Kogi States) of Nigeria and was part of the YIIFSWA Phase I project listed in Table 2. The project, which ended in 2016, worked with yam growers in many parts of Nigeria and indeed Ghana, and the middle-belt region of Nigeria is one of the major yam-producing areas of the country, especially as it encompasses the flood plains of the two great rivers—Benue and the Niger—and the nutrient-rich soils are ideal for yam cultivation (Morse & McNamara, 2015, 2016, 2018a, 2018b). Each of the demonstration plots was divided into two parts, with one part planted to untreated while the other was planted to treated setts. The demonstrations took place over four growing seasons (2013 to 2016) and were entirely farmer-managed except for the application of the pesticide dip comprising a mix of chlorpyrifos (insecticide) and mancozeb (fungicide). Data covering a series of agronomic (sprouting rate, average tuber weight, number of tubers harvested, weight of tubers harvested) and economic (cost, revenue, gross margin) variables were collected and used to explore differences between untreated and treated setts in terms of seed yam production. In the original paper the data were aggregated over the growing seasons, but Figure 3 presents the results of a re-analysis of the data to illustrate change in pesticide dip efficacy over the four growing seasons. The variables in Figure 3 are sprouting rate of planted minisetts (%), average tuber weight (kg), number of tubers harvested per hectare, and weight (kg) of tubers harvested per hectare. The variables were compared within each growing season and Figure 3 includes the results of a Welch’s analysis of variance. There are two patterns that emerge. First is the positive impact of sett treatment, especially in terms of sprouting rate and yield. The impact on number of tubers is less marked, but the increased yield does generate an increase in average tuber weight. The other pattern in Figure 3 but not discussed in Morse (2020) is the decline in all the variables over time for the untreated setts, although even here the yields for the worst years were nearly 5 tonnes of tuber per hectare. A similar pattern was observed for the treated setts, although not as marked. Based on anecdotal evidence gleaned from the farmers and extension agents.

![Graph A](image1.png)  
**Figure 3** The results of some agronomic variables (a, sprouting rate; b, average tuber weight; c, number of tubers harvested; d, weight of tubers harvested) on the use of pesticide treatment of minisetts in the adapted yam minisett technique (AYMT) in Nigeria. The figures are the means and 95% confidence intervals of the variables across four growing seasons (2013 to 2016) in the middle-belt of Nigeria. Also shown are a summary of the results of a Welch’s analysis of variance (ns, not significant at $p < 0.05$; **$p < 0.01$; ***$p < 0.001$) applied to test the statistical significance between untreated and treated setts within each season. The graph and analysis are based on a reworking of data employed in Morse (2020), and details regarding methodology are available in that publication.
involved in the project, there could be a number of reasons for this pattern, including rainfall patterns in the locations chosen for the demonstrations. Clearly there are other factors in play in seed yam production besides crop protection.

While the use of a pesticide dip does provide significant benefits as shown in Figure 3, there are nonetheless some important issues related to this. There may be challenges with the availability of pesticides of the appropriate quality and price, as well as issues over farmer safety and environmental impact. Pesticides suitable for treating setts with dips may not be available or may have a high price in markets. Indeed, there are many issues of fake pesticides on sale in countries such as Nigeria, so even if products are available at a price the farmer could afford there may be issues of efficacy (Oruonye & Okrikata, 2010). Pesticide costs are in themselves a relatively minor aspect of seed yam production, as illustrated in Figure 4, which has also been based on the data employed in Morse (2020). The major costs in seed yam production are labour and planting material, which together account for some 95% of the total costs. Pesticide costs are just 2% of the total, and this may seem to be rather insignificant. However, it needs to be noted that the labour costs in Figure 4 are largely imputed (i.e., estimated) given that most labour is supplied by the household and is not paid for by the farmer; hence it would appear to the farmer to be free. Plant material costs have also been imputed based upon what the farmers would pay in their local market for mother yam tubers, but in practice most farmers would use their own material saved from the harvest of the previous year. While the farmer may not pay cash for the labour and planting material inputs in Figure 4, these do represent opportunity costs; the farmer is using labour and yam tubers for seed yam production that could be used for something else. Hence, while the pesticide costs in Figure 4 are relatively low in proportional terms, they would require purchase with cash, and for the farmer this may be a significant outlay.

**FIGURE 4** The main contributors to the cost of producing seed yam in Nigeria using the adapted yam minisett technique (AYMT). The graph is based on data presented in Morse (2020)
one other cultivated plant that arguably comes close to this is the oil palm (*Elaeis guineensis*). But from the perspective of the farmer, yam is a challenging crop to produce, transport, and store, and there are significant risks involved, especially given the potential for losses to pests and diseases. Yam demands a lot of natural and human resources, and these can come at a significant financial cost to the farmer, and if the crop fails then the impact on household food security, let alone income, could be serious. It is perhaps understandable that asking farmers to cut valuable yam tubers into setts before planting them may generate a sense of incredulity and resistance. Indeed, given the demands of growing yam it is perhaps not unsurprising that many farmers have switched to growing a less demanding, although not as nutritious let alone socially or economically valued crop, such as cassava (Korieh, 2007).

While the YMT and AYMT interventions were designed to help address the issue of making good quality (i.e., as free as possible of pests and diseases) plant material available to farmers at a price they could afford, there are important limitations that need to be considered. The use of pesticide to treat the minisetts may help with limiting the pest and disease burden of the seed yams produced in YMT/AYMT but it does not control diseases caused by viruses, and these can find their way into the seed yams and subsequent ware yam crops. Farmers could, of course, be encouraged to adopt a positive selection process and only use tubers from plants showing no virus symptoms for the source of their planting material, and this was the intervention at the heart of the CAY-Seed project funded by BMGF, which ran from 2014 to 2018 (Table 2). The CAY-Seed project involved training of farmers so they could spot disease symptoms, including those generated by viruses, and the benefits of using planting material that had been positively selected was also demonstrated to them. However, it has to be acknowledged that farmers with limited resources are often faced with a strong temptation to use all the material that they can. There is also potential for virus testing kits to be made available at low cost to support plant breeders and seed certification schemes (Silva et al., 2018). But there are other factors at play besides pests and diseases that impact on the sustainability of yam production in West Africa, such as flooding and damage from migratory herdsman, which are arguably growing in intensity with climate change and increasing population density in countries such as Nigeria. Yam production has typically been focused on the wetter regions such as the southern and middle-belt areas of Nigeria where rainfall is usually plentiful, although droughts are not uncommon. Given its relatively high nutritional and economic value, yam production has been moving north in West Africa towards areas that are drier but where rainfall patterns to sustain the crop also seem to be changing, although here the risk of drought is greater than in the south. The result is a complex geographical pattern of yam production based on interacting and evolving compromises of value (nutritional, economic, and cultural), resource availability, population density, and technology availability and adoption to address plant health issues. Growers, traders, processors, and consumers have all adapted to these changes and indeed driven some of them. But the driving forces of climate change, globalization, urbanization, pandemics, and increasing population density could severely limit the room for manoeuvre and it is here that researchers, especially in plant health, have such an important role to play in the sustainability of yam.

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**CONFLICT OF INTEREST**

The author has no conflict of interest.

**DATA AVAILABILITY STATEMENT**

Data sharing is not applicable to this article as no new data were created or analysed in this study.

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