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Effect of pre-plant treatments of yam (*Dioscorea rotundata*) setts on the production of healthy seed yam, seed yam storage and consecutive ware tuber production

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Abstract

Numerous pests and diseases of yams are perpetuated from season to season through the use of infected seed material. Developing a system for generating healthy seed material would disrupt this disease cycle and reduce losses in field and storage. The use of various pre-plant treatments was evaluated in field experiments carried out at three sites in Nigeria. Yam tubers of four preferred local cultivars were cut into 100 g setts and treated with pesticide (fungicide + insecticide mixture), neem extract (1 : 5 w/v), hot water (20 min at 53 °C) or wood ash (farmers practice) and compared with untreated setts. Pesticide treated setts sprouted better than all other treatments and generally led to lower pest and disease damage of yam tubers. Pesticide treatment increased tuber yields over most treatments, depending on cultivar, but effectively doubled the production as compared to the control. Pesticide and hot water treated setts produced the healthiest seed yams, which had lower storage losses than tubers from other treatments. These pre-treated seed yams produced higher yields corresponding to 700 % potential gain compared to the farmers usual practice. Treatments had no obvious influence on virus incidence, although virus-symptomatic plants yielded significantly less than non-symptomatic plants. This study demonstrated that pre-plant treatment of setts with pesticide is a simple and effective method that guarantees more, heavier and healthier seed yam tubers.

Keywords: hot water treatment, mancozeb, neem, pesticide dip, seed health, yam tubers

1 Introduction

The development of sustainable seed systems, which can consistently supply seed of high quality that farmers can rely upon and trust, is a necessary foundation for improving yam (*Dioscorea* spp.) productivity. In particular, seed material is commonly infected with viruses and plant-parasitic nematodes, which affect seed viability. This in turn reduces sprouting and plant vigour, leading to missing plants and reduced yields of plants that have sprouted (Degras, 1993).

Pests and pathogens play a major role in yam losses, which are incurred both in the field and during storage. Mealybugs, scale insects and nematodes (*Scutellonema bradys*, *Pratylenchus* spp. and *Meloidogyne* spp.) will also exaggerate fungal (e.g. *Botryodiplodia* spp., *Aspergillus* spp., *Fusarium* spp.) and bacterial (e.g. *Erwinia* spp.) pathogen tuber infection in the field (Amusa *et al.*, 2003; Ogaraku & Usman, 2008). Damage that occurs during storage, leads to reduced quality and quantity of food and planting material (Emehute *et al.*, 1998;

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Bridge *et al.*, 2005). Most losses originate from pre-harvest invasion or infection and/or damage during harvest and transportation (Morse *et al.*, 2000). In Nigeria, storage losses in yams are estimated at ca. 30 % due to nematodes and at ca. 50 % due to fungi, (Wood *et al.*, 1980; Amusa *et al.*, 2003).

Poor quality planting material leads to the perpetuation of disease cycles, returning inoculum from the store back to the field. This adversely affects crop establishment, yield and storability of harvested tubers, ensuring a continued negative impact on quality, especially of highly susceptible cultivars. Yams are usually cultivated mainly for the market as ware yam, while seed yams are produced intentionally as planting material. Ware yams are fairly large tubers traditionally weighing between 2–10 kg while seed yams, used for the production of the ware yams, typically weigh 200 g to 1 kg. Traditional methods by farmers for supplying seed includes reserving smaller tubers or 'milking' their ware yam ahead of plant senescence for seed, by removing most of the ware yam and leaving a small portion behind to produce small sized tubers for seed (Asumugha *et al.*, 2007; Nchinda *et al.*, 2009). However, such smaller sized tubers may be a consequence of inherent disease infection, which has suppressed production and tuber size, while the regrowth of milked tubers is prone to enhanced levels of seed infection borne from a mature mother plant. Seed yam production using the minisett technology was introduced in Ghana and Nigeria, however, the small (25 g) minisett size required special care and the resulting tubers were often too small to plant as seed yams. These proved to be key obstacles to farmers towards adopting the technique (Onyenweaku, 1991; Langyintuo, 1996). The aim of the current study was to identify a suitable and acceptable system that could provide a basis for sustainable production of healthy, affordable, whole seed yam. Simple, pre-plant treatments of cut yam setts of were assessed for their effect on yield and health of seed yams from the field and during storage. The study further assessed the extended impact of the resultant seed through to a second season of ware yam productivity.

2 Materials and methods

2.1 Site and experimental details

Field trials were carried out in Nigeria at three sites located in three ecological zones: the Guinea savanna (Idah, Kogi State), the forest zone (Aramoko, Ekiti State) and the forest transition zone (Ibadan, Oyo State). Seed yams of two locally popular cultivars of *D. rotundata* were sourced from markets at each location: cv. *Imola* and cv. *Akpaji* were planted at Idah, while cv. *Sogbe* and cv. *Ajimokun* were planted at Aramoko and Ibadan. Yam setts were planted in plots of 10×10 m (400 plants per plot) in Idah and 5×10 m (200 plants per plot) in Aramoko and Ibadan, with five replications per treatment at each location. The experiments were laid out in a 5×5 Latin square design in Idah and a randomized complete block design in Ekiti and Ibadan. Plants were spaced at 25 cm within rows and 1 m between rows. The variation in plot size between sites was due to the deterioration of the planting material at Ekiti and Ibadan as a result of poor quality seed.

2.2 Pre-treatment for seed yam production

The five pre-planting seed sett treatments were: pesticide (fungicide + insecticide) dip; hot water (HW) treatment; coating in wood ash (farmer practice); coating in neem leaf slurry; and untreated control. Yam setts were cut from whole tubers (~ 500–1000 g) into ~ 100 g pieces prior to treatment, except for tubers treated with HW, which were cut following treatment. The pesticide treatment was prepared at the rate of 100 g of fungicide (Mancozeb [Maneb®] a.i. concentration 6 mg g^{-1}) and 70 ml of insecticide (Diazinon [Basudin® 600EC] a.i. concentration 600 g L^{-1}) in 10 L of water. The pesticide mix was prepared in a 30 L plastic container into which yam setts were dipped for 5 min then set aside to drain. Neem leaves were collected fresh from trees in Ibadan, air dried in a glasshouse and ground to powder. At planting, a slurry was prepared by mixing 1.0 kg of powdered neem leaves in 5 L of water, which was sufficiently thick to provide a thin coat on the yam setts when dipped. Coated yam setts were spread out to dry. For the hot water (HW) treatment whole tubers were fully submerged in water, heated to 53 °C, for 20 min, then set aside to dry and cool before cutting into setts. Treatment of cut setts with wood ash was undertaken by rolling cut setts in wood ash in a large nylon bag until all setts were covered, this represented the farmers' usual practice. Another farmers' practice of cutting and allowing setts to dry overnight without treatment represented the control. All treatments were undertaken one day ahead of planting.

2.3 Crop growth and damage parameters measured

Percentage germination (sprouting) was assessed at 4 and 8 weeks after planting (WAP) from all plants per plot. Foliar disease assessment was conducted at 8 and 12 WAP per plot and percentage incidence was calculated. Plants exhibiting symptoms of virus were labelled with a tag to be separated at harvest for data collection. At harvest, approx. 7 months after planting, tuber yield and number per plant and plot were recorded.

At harvest, twenty randomly selected tubers per plot were assessed for nematode damage (galls, cracking and flaking), insect damage (termite tunnels, beetle holes, presence of scale insect and mealy bugs) and rots using a rating scale of 1 to 3, where 1 = absence, 2 = mild to moderate and 3 = severe damage. The 20 tubers were then placed in nylon net sacks and stored for four months on raised shelves in a well-ventilated barn after recording fresh weight. Tubers were again scored for damage and weighed at four months after storage and percentage fresh weight loss calculated. These tubers were also assessed for nematode population density. Tubers were peeled using a kitchen peeler, chopped finely and a 5 g sub-sample per tuber removed for nematode extraction over 48 h using a modified Baermann method (Coyne *et al.*, 2007). Nematode suspensions were reduced to 10 ml and nematodes counted from 3×1 ml aliquots of the suspension using a Leica Wild M3C stereomicroscope.

2.4 Ware production

Seed yams produced from the previous season were used as planting material, following storage, for the production of ware yams in the following year at two sites, Idah and Aramoko. Tubers, which remained viable after storage, were selected from each of the respective treatments for ware production. Whole, uncut tubers without additional treatment were planted in plots of 50 tubers (~ 200 g). The experiment was laid out in a randomized complete block design with five replications (plots) per treatment. One cultivar per site was selected: *Imola* at Idah and *Ajimokun* at Aramoko. Tubers were planted on mounds spaced 1×1 m and harvested seven months after. Data was collected in the same manner as for seed yam above both at harvest and after storage for 4 months.

2.5 Statistical treatment of data

Differences among treatment means were compared with ANOVA using SAS, version 9 (SAS, 2001) and means separated using the Fisher's protected least significant difference test (LSD) at 5 % probability level or standard errors (SE). Nematode population density data was normalized using $\log_{10}(x+1)$ transformation, while percentage data was transformed using arcsine of x prior to analysis.

Table 1: *Percentage incidence of virus-affected plants of four yam cultivars 12 weeks after planting at three field sites in Nigeria, following pre-plant treatments of ~ 100 g setts.*

Treatment†	Idah		Ibadan and Aramoko‡	
	Akpaji	*Imola*	*Ajimokun*	*Sogbe*
Pesticide	79.0 ^{a}	4.0 ^{c}	5.0 ^{bc}	0.0 ^{b}
HW	76.0 ^{ab}	2.0 ^{cd}	7.0 ^{a}	0.0 ^{b}
Neem	65.0 ^{c}	12.0 ^{a}	4.0 ^{c}	0.5 ^{a}
Wood ash	73.0 ^{b}	8.0 ^{b}	6.5 ^{ab}	0.0 ^{b}
Control	67.0 ^{bc}	6.0 ^{bc}	2.0 ^{d}	0.0 ^{b}

Figures with the same letter within a column for each cultivar are not significantly different at ($P \leq 0.05$) using LSD.
† Pesticide = fungicide (mancozeb) + insecticide (diazinon); HW = hot water; control = untreated yam setts.
‡ Data combined for Ibadan and Aramoko sites.

3 Results

3.1 Seed production

Pre-planting waste and discard of planting material was high at both Ibadan and Ekiti as a consequence of rots and nematode damage, resulting in fewer setts planted per plot than at Idah. Data from Ibadan and Aramoko seed yam production in the seed yam trial were combined as the source of seed yam was the same and a similar trend was observed between sites with respect to treatments (F value = 0.14; P value = 0.71).

Virus incidence was relatively higher for *Akpaji* at Idah than for other cultivars, with a similar trend at 8 and 12 WAP (12 WAP data only presented; Table 1). Virus incidence in cv. *Akpaji* -treated pesticide mix was similar to the incidence observed on plants treated with hot water. Significantly lower virus incidence was observed in the untreated plants, neem and wood ash-treated plants. In other cultivars the virus incidence was variable with treatments. Percentage sprouting was higher ($P \leq 0.05$) at 4 and 8 WAP for setts pre-treated with the pesticide mixture, than for all other treatments, no cultivar effect was found (8 WAP data only presented; Tables 2, 3). However, percentage sprouting for control setts, HW, neem and wood ash treated setts varied depending on site and cultivar. Neem and HW treatment appeared to reduce sprouting of some cultivars. Seed yam tuber yield per plot was consistently higher from setts treated with the pesticide than other treatments ($P \leq 0.05$) (Table 3). Seed tuber weight per plant was higher for plants from the pesticide treatment of cv. *Sogbe*, and neem and pesticide treatment for *Ajimokun*, although differences varied considerably by cultivar and site. Tubers from HW treated setts were lower in weight and number per plot for cv. *Akpaji*, as compared to

Table 2: *Effect of pre-plant treatments of yam setts (~ 100 g) on sprouting and tuber yield at harvest of two yam cultivars at a field site in Idah, Nigeria.*

Treatment †	*Percent sprouting at 8 WAP* ‡	*No. of tubers per plot*	*Tuber weight per plot* (kg)	*Tuber weight per plant* (g)
		cv. Akpaji		
Pesticide	73.6 ^{a}	299.8 ^{a}	29.2 ^{a}	101.3 ^{a}
HW	38.9 ^{d}	146.0 ^{c}	8.8 ^{c}	57.5 ^{b}
Neem	57.0 ^{b}	263.0 ^{ab}	25.0 ^{ab}	118.4 ^{a}
Wood ash	45.2 ^{cd}	189.4 ^{bc}	18.5 ^{b}	99.9 ^{ab}
Control	52.7 ^{bc}	213.0 ^{bc}	20.5 ^{b}	97.9 ^{ab}
		cv. Imola		
Pesticide	75.2 ^{a}	269.6 ^{a}	27.7 ^{ab}	135.7 ^{ab}
HW	58.5 ^{b}	219.8 ^{ab}	24.8 ^{abc}	110.7 ^{b}
Neem	28.3 ^{d}	116.4 ^{c}	18.4 ^{c}	167.4 ^{a}
Wood ash	52.8 ^{bc}	205.6 ^{b}	28.5 ^{a}	94.5 ^{b}
Control	41.1 ^{c}	184.6 ^{b}	20.2 ^{bc}	123.1 ^{ab}

Figures with the same letter within a column for each cultivar are not significantly different at ($P \leq 0.05$) using LSD.
† Pesticide = fungicide (mancozeb) + insecticide (diazinon); HW = hot water; control = untreated yam setts; ‡ WAP = weeks after planting; means separation undertaken on arcsin($\sqrt{x}$) transformed data with non-transformed data presented.

Table 3: *Effect of pre-plant treatments of cut yam setts (~ 100 g) on sprouting and tuber yield of two yam cultivars at two field sites (Ibadan and Aramoko combined) in Nigeria.*

Treatment †	*Percent sprouting at 8 WAP* ‡	*No. of tubers per plot*	*Tuber weight per plot* (kg)	*Tuber weight per plant* § (g)
		cv. Ajimokun		
Pesticide	33.3 ^{a}	63.4 ^{a}	31.9 ^{a}	684.6 ^{ab}
HW	16.9 ^{b}	29.7 ^{b}	12.7 ^{bc}	423.7 ^{b}
Neem	15.7 ^{bc}	37.0 ^{bc}	16.9 ^{b}	1047.7 ^{a}
Wood ash	12.8 ^{bc}	19.5 ^{c}	10.8 ^{c}	514.5 ^{b}
Control	10.4 ^{c}	19.2 ^{c}	9.3 ^{c}	504.5 ^{b}
		cv. Sogbe		
Pesticide	12.8 ^{a}	16.1 ^{a}	9.4 ^{a}	737.2 ^{a}
HW	6.5 ^{b}	14.8 ^{a}	5.5 ^{abc}	474.6 ^{ab}
Neem	4.5 ^{b}	11.4 ^{a}	4.6 ^{bc}	390.7 ^{ab}
Wood ash	5.9 ^{b}	15.5 ^{a}	6.3 ^{ab}	723.2 ^{a}
Control	0.3 ^{c}	0.8 ^{b}	1.5 ^{c}	135.7 ^{b}

Figures with the same letter within a column for each cultivar are not significantly different at ($P \leq 0.05$) using LSD.
† Pesticide = fungicide (mancozeb) + insecticide (diazinon); HW = hot water; control = untreated yam setts; ‡ WAP = weeks after planting; means separation undertaken on arcsin($\sqrt{x}$) transformed data with non-transformed data presented; § Tuber weight per plant = total weight of tubers per plot divided by the total number of tubers per plot.

other treatments. The number of tubers per plot varied by site and cultivar, but was relatively higher in the Idah site, than in Ibadan and Aramoko. At harvest, the number of tubers between non-symptomatic and virus-infected plants differed ($P \leq 0.05$) within treatments, with fewer symptomatic plants in neem and HW treatments (Table 4).

Virus-infected plants, however, consistently produced smaller ($P \leq 0.05$) tubers for all treatments across the experiments (5.0 kg per plot) than non-symptomatic plants (10.3 kg per plot) (Table 4). Percentage rot on seed tubers was high for both *Ajimokun* and *Sogbe* cvs., particularly for the control, which had >65 % increase in rot after 4 months of storage, as compared with 27 %

Table 4: *Yam tuber yield from virus symptomatic and non-symptomatic plants from three field trials in Nigeria, following pre-plant treatments of ~ 100 g cut yam setts*†.

Treatment ‡	*No. of tubers from non-symptomatic plants per plot*	*No. of tubers from symptomatic plants per plot*	*SE*	*Tuber weight from non-symptomatic plants per plot* (kg)	*Tuber weight from symptomatic plants per plot* (kg)	*SE*	*Tuber weight per non-symptomatic plant* (g)	*Tuber weight per symptomatic plant* (g)	*SE*
Pesticide	58.8	61.6	1.4	15.6	7.7	4.0	265.3	125.0	70.9
HW	43.8	34.4	4.7	9.6	3.5	3.1	219.2	101.7	59.3
Neem	42.3	35.3	3.5	10.2	3.4	3.4	241.1	96.3	73.1
Wood ash	31.5	35.3	1.9	8.5	4.5	2.0	269.8	127.5	71.9
Control	43.7	52.9	4.6	7.8	5.9	1.0	178.5	111.5	33.8
Mean	44.0	43.9		10.3	5		234.8	112.4	
SE	4.4	5.7		1.4	0.8		17.0	6.3	

† Data are means from three locations each with two cultivars; ‡ Pesticide = fungicide (mancozeb) + insecticide (diazinon); HW = hot water; control = untreated control; SE = Standard error ($P \leq 0.05$).

rot increase for the cv. *Ajimokun* on pesticide-treated setts (Fig. 1). Tubers from pesticide and HW treated plants stored better than other treatments in Aramoko and Ibadan. Storage rot in Idah was relatively low in comparison to the other storage sites.

Nematodes found in tubers after four months storage were mostly *S. bradys* (data not shown). The initial number of nematodes (Pi) at planting was 122 taken from sampled tubers. Tubers from HW and neem treatments were least ($P \leq 0.05$) infected, with 14 and 91 nematodes per 5 g of tuber cortex respectively, while tubers from wood ash-treated setts showed highest ($P \leq 0.05$) densities (186 per 5 g). *Meloidogyne* spp. were observed only in tubers from the wood ash treatment, but at barely detectable levels of 4 nematodes per 5 g of cortex. Dry rot damage was generally low (data not shown). Only the cv. *Akpaji*, showed that up to 5 % of the untreated control tubers were dry rot damaged ($P \leq 0.05$), while for cv. *Imola* just 1 % of wood ash treated tubers were affected. Tubers from HW and pesticide-treated setts had, in general, the lowest dry rot damage after storage ($P \leq 0.05$). Although present at harvest, yam beetle damage (3 % in Idah only) and termite infestation (41.5 % across locations and cultivars) did not progress during storage (data not shown). There was no evidence of the yam scale insect (*Aspidiella hartii*) infestation from either the field or storage. Mealybug infestation increased during storage, especially in Idah on cv. *Imola*; pesticide and HW pre-treated plants were least affected ($P \leq 0.05$) (Fig. 2). Generally the HW and pesticide treatment tubers hosted fewer insect pests.

Following four months storage, percentage weight loss of seed yam tubers was higher ($P \leq 0.05$) for cultivars *Ajimokun* and *Sogbe* than for *Imola* and *Akpaji* (Fig. 3). Differences between treatments occurred across cultivars with greatest differences observed for the cvs. *Ajimokun* and *Sogbe*. Less ($P \leq 0.05$) tuber weight loss occurred in the pesticide and HW treatments (9.5 % and 10.2 %, respectively), than for the control (e.g. 86.6 % and 62.8 % for cvs. *Sogbe* and *Ajimokun*, respectively). Total combined loss per treatment, as a result of poor sprouting in the previous season and storage weight loss was also lower for the pesticide and HW treatments, which reduced availability of planting material for the most affected treatments for the following ware yam production.

3.2 Ware production

More tubers were lost during storage from plots with previously untreated tubers and wood ash pre-treated tubers compared to tubers pre-treated with the pesticide mix, HW and neem slurry. Although plants pre-treated with neem had more losses compared to the either pesticide or HW treated plants (Table 5). Ware yam produced from seed that originated from the control treatments in the previous seed yam trial, yielded less than seed arising from pesticide treated setts ($P \leq 0.05$) for cv. *Ajimokun*, while *Imola* cv. tubers from the HW treatment also yielded better than the control ($P \leq 0.05$) (Table 5). This occurred even though seed material used for production of ware yam was selected only from the viable material that remained following storage, which was of relatively even quality and size (~ 200 g) for all treatments. Taking into account the difference in production of seed material between control and pesticide treatments in the previous season, combined with tuber losses during storage, and further to the difference in production of the ware yam from the remaining seed material (in the seed yam production season), the pesticide pre-plant treatment of setts (best treatment) led to an overall 214 % greater yield for *Imola* and 700 % for *Ajimokun* compared to the control (Table 5). This equates to an increase in ware yield from 7.4 to

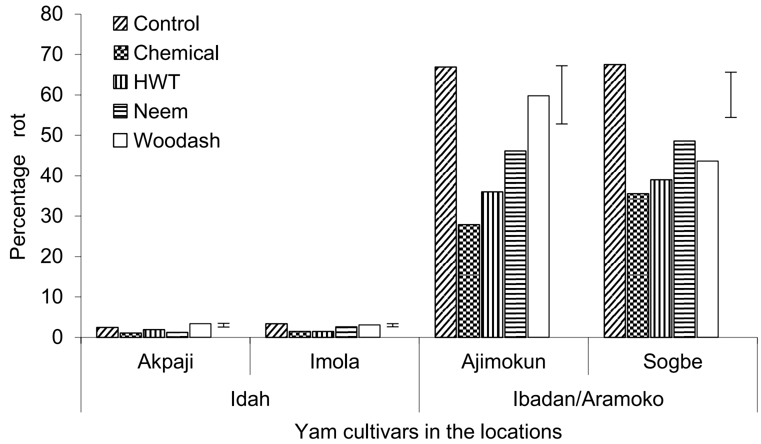

Fig. 1: *Percentage increase in tuber rot incidence of yam tubers following pre-plant treatments, between harvest and storage for four months in Nigeria. Error bars = Standard errors; means separation undertaken on* $\arcsin(\sqrt{x})$ *transformed data with back-transformed data presented. N = 100 per cultivar.*

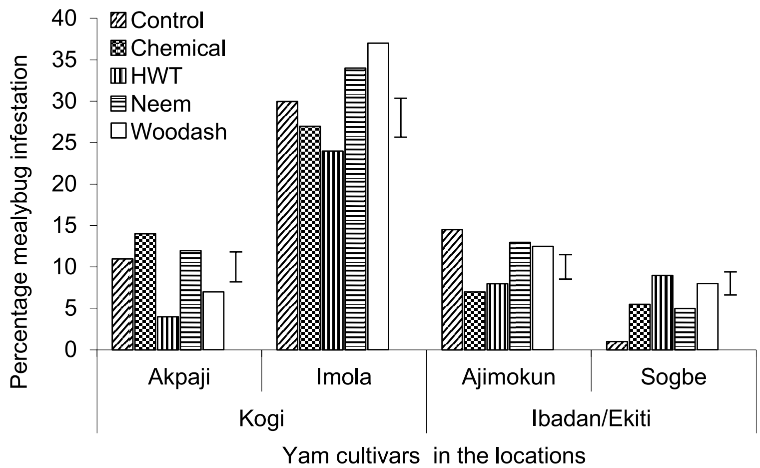

Fig. 2: *Percentage increase in mealybug infestation incidence of yam tubers following pre-plant treatments, between harvest and storage for four months in Nigeria. Error bars = Standard errors; means separation undertaken on* $\arcsin(\sqrt{x})$ *transformed data with back-transformed data presented. N = 100 per cultivar.*

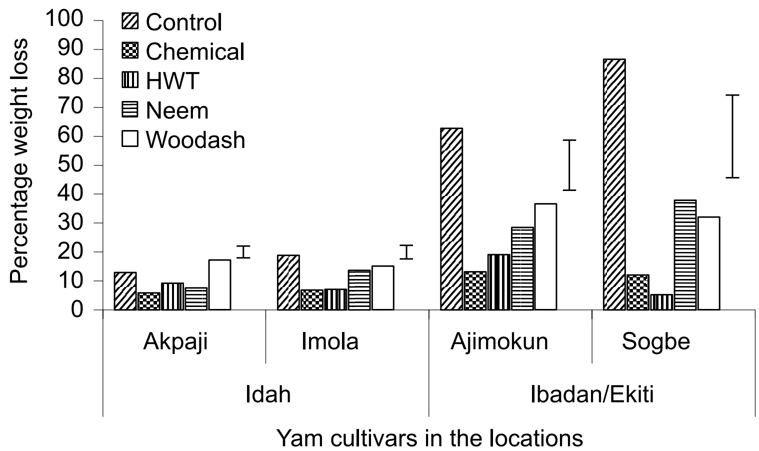

Fig. 3: *Weight loss of harvested yam tubers following pre-plant treatments, during storage for four months in Nigeria. Error bars = Standard errors; means separation undertaken on* $\arcsin(\sqrt{x})$ *transformed data with back-transformed data presented. N = 100 per cultivar.*

Table 5: *Potential ware yam yield for two cultivars produced from seed yams arising from different pre-plant treatment of 100 g seed setts.*

Treatment	*No. of tubers available for planting* †	*Yield of ware yam per plot* (kg)	*Yield increase of ware yams* (%) ‡	*Actual yield* ($t\,ha^{-1}$) §	*Potential yield per plot* (kg) ¶	*Percentage increase in potential yield* ‖	*Potential yield increase* ($t\,ha^{-1}$) **
				cv. Imola			
Control	82.3 (55.4)	26.2	0	5.2	43.1	0.0	0.0
Chemical	182.7 (32.2)	37.1	41.6	7.4	135.6	214.4	15.9
HW	133.9 (36.9)	33.8	29	6.8	90.5	109.9	7.5
Neem	63.6 (45.4)	24.6	−6.1	4.9	31.3	−27.5	−1.3
Wood ash	96.8 (52.9)	31.4	19.8	6.3	60.8	41.0	2.6
Mean	111.9	30.6	16.9	6.1	72.3	67.5	4.9
SE	21.2	2.3	8.9	0.5	18.8	43.5	3.1
				cv. Ajimokun			
Control	7.4 (61.5)	10.5	0	2.1	1.5	0.0	0.0
Chemical	41.4 (31.7)	15	17.3	3.0	12.4	700.9	21.0
HW	22.2 (36.1)	12.3	7.2	2.5	5.5	252.3	6.3
Neem	15.3 (48.4)	13.5	11.6	2.7	4.1	167.1	4.5
Wood ash	8.7 (55.4)	13.5	11.5	2.7	2.4	52.0	1.4
Mean	19.0	13.0	9.5	2.6	5.2	234.5	6.7
SE	6.2	0.8	2.9	0.6	1.9	125.0	3.8

† Number of tubers remaining for planting after the storage period (number at harvest - number lost in storage) with percentage number lost in parenthesis); ‡ Ware yield difference of treatments over untreated control; § Yield of ware yams from pre-treated seed yams calculated per ha; ¶ Yield of ware yams provided all available tubers per treatment were planted; ‖ Percentage increase of treatments over control provided all available tubers were planted; ** Increase in potential yield (provided all tubers were planted) of other treatments over control.

23.3 $t\,ha^{-1}$ for *Imola* and 3.0 to 24 $t\,ha^{-1}$ for *Ajimokun*. The potential increase in ware yam yield from HW treated seed was also significantly higher ($P \leq 0.05$) than from other treatments (neem and wood ash) for *Imola*.

4 Discussion

The poor state of yam planting material in Nigeria was emphasized during the current study, with large proportions of the planting material purchased for the study in Ekiti State becoming unusable and discarded before planting. Production of seed yam from the remaining suitable material then resulted in poor quality and quantity of seed from untreated setts, with low germination rates, high incidence of tuber diseases and ultimately high levels of loss during storage, culminating in marked low yam production potential over two seasons. The traditional practice of using wood ash before planting reduced tuber losses during storage to a small extent but in comparison to the pesticide treatment, yields remained low while losses during storage were high. Consequently, the current study provided a clear insight of the general state and quality of seed yam material available for farmers in Nigeria, reaffirming earlier reports (Asiabaka *et al.*, 2001). The dual combination of pesticides used on pre-plant setts led to greater production of seed yam and, along with HW, yielded healthier seed tubers than traditional practices. HW treatment is therefore effective at producing healthy material, as previously reported (Meerman & Speijer, 2001), but showed serious shortcomings on its initial effect on sett viability and sprouting. The success rate of the HW treatment is cultivar dependent, possibly due to the number of eye buds and cortex thickness (Coyne *et al.*, 2010). It is also of limited attraction due to its burdensome application, reducing its adoption by individual farmers (Asiabaka, 1994; Agbaje & Oyegbami, 2005). Although neem is well recognized for its pest and disease control properties (Onalo *et al.*, 2001; Okigbo, 2004; Okigbo *et al.*, 2009), its effect was not consistent in the current study. The neem treatment may have proved better using seed extracts or commercial products, for more consistent concentration of the active ingredient azadirachtin (Schmutterer, 1990). The systemic nature of azadirachtin has been reported to lead to phytotoxicity in crops, particularly by stressed plants or those with limited root mass (Oetting *et al.*, 1990; Schmutterer, 1990). This may have contributed to the poor sprouting of neem-treated setts of some cultivars, particularly as yam setts produce roots only a few weeks after planting (Orkwor & Ekanayake, 1998).

When assessing the relative performance of seed sett treatment over the two cycles of seed-through-ware yam production, the pesticide treatment consistently provided heavier seed tubers, which were healthier and stored better than other treatments. Following storage, this seed produced heavier and healthier ware yam, compared with other treatments. It is important to note, however, that ware yam was produced only from the seed tubers surviving the storage period, which were inevitably healthier and less infected than those from other treatments and subject to lower losses. Taking these losses into account therefore vastly exaggerates the overall potential yield difference between the pesticide treatment and traditional treatment, emphasizing the negative "knock-on" effect of using poor seed yam. For the two cultivars, *Imola* and Ajimokum a sufficient quantity of tubers remained after storage in order to potentially increase ware yam production by a staggering 212 and 700 %, respectively. This difference in potential yield could be achieved through the use of a simple pesticide dip on seed yam setts in the previous season, as compared to the no-treatment control, a regular farmer practice. Some of the treatments assessed in the current study are recognized and have previously been studied (Bridge *et al.*, 2005); pesticide and HW for example are not "new" or innovative (Meerman & Speijer, 2001). They have both proved effective treatments, with remarkable rates of return for the pesticide treatment. The current study provides information that further supports previous studies, but builds on this further through following the assessment over two crop cycles and the intervening storage period. Our study underscores the necessity for the development of a sustainable healthy seed yam system, but furthermore highlights the colossal differences that such simple techniques can provide. The benefits of a healthy seed yam system are not under question, but rather how to systematically develop, implement and sustain it.

The use of pesticides can be contentious where availability of good, unadulterated products is often limited or inconsistent (Neuenschwander, 2004; Ngowi *et al.*, 2007). However, the products used in this study were selected based on suitable sized packages for small scale farmers, ease of availability, affordability and were in their original (sealed) packages. The method of application by dipping could be applied with relative simplicity by farmers. The sett dipping application helps to prevent adverse effect on non-target organisms and general environmental contamination. A further consideration to promoting the use of pesticides for seed yam production, is that their use is targeted as a pre-treatment of seed yam, which can then be used without any further treatment for ware yam production. The application of pesticide at least two seasons prior to consumption thus limits residue contamination to the consumer. Additionally, diazinon is a contact, non-systemic compound, apparent from the increased incidence of mealybugs during storage. The combined fungicide and insecticide sett treatment improved yields substantially (62 %), more so than the wood ash treatment, resulting in healthier seed yam tubers, with improved storability and thus improved quality and health for ware production in the following season.

The cost of seed yam equates to approximately 50 % of the total cost of yam production (Nweke *et al.*, 1991; Aighewi *et al.*, 2003). An effective and simple treatment of setts, that guarantees more, heavier and healthier seed yam tubers, that preserve longer and store better than the farmers' usual practices, implies substantial benefits to yam productivity. The higher quality of tubers additionally attracts premium prices. Planting healthy, superior quality seed tubers for ware yam production ensures fewer empty mounds, reducing labour wastage and leads to better ware yam yields. Healthy and sustainable seed systems remain the platform upon which to improve crop productivity. The technique is referred to as the adapted yam minisett technique (AYMT) and has been demonstrated in farmer managed trials (Morse & McNamara, 2017). The simple, cost effective method demonstrated here is ideal for small and large-scale yam farmers alike in West Africa, providing that good quality products are used and that safe and proper pesticide practices are employed and observed.

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