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Effect of Staking and Non-staking Systems on Disease Severity, Yield and Quality Attributes of Yams (*Dioscorea alata*)

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Authors' contributions

This work was done in collaboration among all authors. Author PEN designed the study, performed the statistical analysis, wrote the protocol and first draft of manuscript. Author JBAW contributed in analysis and report writing. Authors AES, AM, LS, AGOD, SNF, MTB and MMS contributed in trial establishment, monitoring and data collection. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The aim of this study was to evaluate the effect of staking and non-staking systems on disease severity, yield and quality attributes of yams.
Methodology: High costs and lack of planting materials, labour, staking and inappropriate knowledge on production techniques are major constraints of yam production in Sierra Leone. A total of seven promising hybrid genotypes of yams from International Institute of Tropical Agriculture and one local cultivar, Pulli, were evaluated for yield, reaction to local pest and disease and desirable market traits during 2011 and 2012 in three agro-ecological zones of Sierra Leone. The experiment was laid out in randomized complete block replicated thrice at the experimental

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sites of the Njala Agricultural Research Centre.
Results: Results revealed higher disease pressure in non-staked plots compared to staked plots. Fresh tuber yields were significantly higher in staked plots than the non-staked plots. Five genotypes with yields ranging between 11.8 and 14.7 t.ha^{-1} significantly out-yielded Pulli (9.1 t.ha^{-1}) in the staked plots, while only genotype TDa 02/00012 (11.9 t.ha^{-1}) significantly out-yielded Pulli (7.1 t.ha^{-1}) in the non-staked plots. Farmers' preferences for all genotypes were similar to that of the local cultivar. Staking contributed 30.5% mean yield increase compared to non-staking. Makeni had the highest percent mean yield increase due to staking (38.5%) compared to Njala (29.7%) and Kenema (26.4%).
Conclusion: Staking is beneficial in yam production contributing an average of 28.2% more fresh tuber yields than non-staking. Genotypes in staking system were more tolerant to in-field local diseases, thereby significantly out-yielding those in non-staking system. Genotypes TDa 98/01174, TDa 98/01176, TDa 02/00012, TDa 98/01168 and TDa 00/00194 had stable resistance to in-field diseases in the staking system and desired food quality traits compared to the check variety, Pulli. Findings have good implications for multiple disease resistance breeding for various production systems as the different genes controlling these traits could be pyramided into an ideotype. Similar technique could be used to breed for yield and other desired food quality traits.

Keywords: Yam disease; yield; quality; ecology; staking; non-staking systems.

1. INTRODUCTION

Dioscorea species (yams) are food security crops that sustain many livelihoods in the tropics and subtropics especially in West Africa, where large commercial scale production is practiced [1]. The crop serves as a source of food, medicine and income for many small scale farmers in Africa [2]. Yam is the third most important root and tuber crop in Sierra Leone after cassava and sweet potato. It is highly cherished by Sierra Leoneans both as cash crop and food [3].

Despite its importance, several factors have been identified to influence yam production. Among these factors include inappropriate knowledge on production techniques, cost of planting materials, labour, stakes, staking and lack of healthy and improved planting materials [4,5].

Staking in crop production involves provision of support structures for the elevation of creeping vines above ground level to enhance increased growth and development [6]. Various materials used as stakes include dead or live plant poles, rubber or metal poles, strings of wire or rope, etc. and are usually inserted about 0.2-0.3 m away from yam plant stands prior to sprouting. Staking contributes to increased growth and development of yams. Yam produced under staked system out-grows and out-yields those in non-staked system [7]. Leaves of staked yams have greater interception of sunlight and improved aeration, which promote photosynthetic activity leading to bigger and heavier tuber formation [8]. Staking keeps yam vines and leaves off the soil surface, thereby minimizing or eradicating the burning of young leaves and/or predisposing leaves to microbial attack. It also facilitates easy weeding, earthen-up and other farm operations. It also reduces the infection and spread of soil-borne diseases from one plant to another. Staking is however expensive, laborious and difficult to mechanize [9]. Besides the additional cost of labour and sticks, the inclusion of staking in yam production has been reported to significantly contribute to the yield potential of some genotypes of yam grown especially in the tropics [10]. Dorosh [11] also noted that where soil fertility is maintained, yam remains a profitable crop.

Effective exploitation of yams is also constrained by considerable pre-and post-harvest losses [12]. Producers lack post-harvest and quality information to serve as guide in deferring sale during the harvest season when prices are low [12]. The quality of yams arriving at the markets is compromised due to poor harvesting, handling and poor storage conditions [12]. The identification of elite genotypes that are tolerant or resistant to major in-field and in-store diseases and those that possess desired high yields and food quality traits could potentially form the cornerstone of an integrated management strategy for yam.
Yam vines are weak and therefore need support to harness maximum sunlight energy for its good

growth and development [8]. However, there is dearth of knowledge regarding the effect of stake and non-stake systems on disease severity and agronomic performance of yams. A thorough understanding of the effect of in-filed and in-store disease attacks on yield and food quality in stake and non-stake systems is especially imperative to guide producers on economically sound productive system and secondly, identifying genotypes with desired resistance or tolerance to major pests and diseases, possessing high yield and good food quality traits would enhance the efficiency of developing new genotypes and their utilization. The aim of this study was therefore to evaluate the effect of staking and non-staking systems on disease severity, yield and quality attributes of yams.

2. MATERIALS AND METHODS

2.1 Description of Experimental Sites

The study was conducted in three locations including Sarabu, in the eastern region of Kenema, Robusha in the northern region of Makeni and Njala in the southern region of Moyamba, Sierra Leone during 2011 and 2012 cropping seasons. Kenema is in the rainforest zone characterized with sandy loamy soil texture rich in organic matter content. Makeni is in the transition area between farm bush and savannah grassland with sandy clay loam soil texture. Njala consists of secondary bush or transition rain forest vegetation with gravelly clay loam soil texture. Sarabu crop site in Kenema is situated at an elevation of 38 m above sea level on 07º51.086´N latitude and 011º16.551´W longitude. Robusha crop site in Makeni is located at an elevation of 92 m above sea level on 08º46.037´N latitude and 011º59.088´W longitude. Njala crop site in Moyamba is located at an elevation of 73 m above sea level on 08º07.135´N latitude and 012º04.610´W longitude. The total rainfall, mean monthly relative humidity and mean monthly minimum and maximum air temperatures recorded during the experimental periods are presented in Table 1.

2.2 Experimental Design and Cultural Practices

The experiment was established in early May of 2011 and 2012 and harvested in early January of 2012 and 2013, respectively, to assess the effect of staking and non-staking systems on disease severity, yield and quality attributes of yams. A total of eight genotypes including seven improved (TDa 00/00194, TDa 02/00012, TDa 95/00005, TDa 95/00307, TDa 98/01168, TDa 98/01174 and TDa 98/01176) from IITA and one local check, Pulli, were used. In both years, the experimental area was first cleared before mounding. Mounds of about 0.4 m high and 1.0 m apart were constructed. Each plot measured 4 x 10 m (40 m^2) and contained 40 mounds. Setts each weighing 250 g were cut from ware yam of each genotype and used as planting materials. Prior to planting, the setts were locally disinfected with wood ash and allowed to dry under shade for two hours. The setts were then planted into holes 10 cm deep on the crest of mounds spaced 1 x 1 m in a randomized complete block design. No fertilizer or pesticide was applied to test their genetic potentials under natural conditions. Weeds were controlled manually by hand weeding whereas pyramid staking was done prior to sprouting of planted setts by inserting pointed stake supports into the soil about 20 cm away from planted holes or spots.

2.3 Data Collection

A total of fourteen agronomic traits were evaluated. The genotypes were evaluated for their reaction to yam mosaic virus and anthracnose severity using a 1-5 scale; where 1=no visible symptom, 2=very low or mild, 3=low, 4=intermediate and 5=high at 1, 3 and 5 months after planting (MAP) [13]. At harvest (8 MAP), storage tubers were counted and weighed. The genotypes were assessed for their reaction to nematodes, mealy bug, tuber beetles and yam tuber dry rot severity using a 1-5 scale as described above at 1, 2, 3 and 4 months after harvesting (MAH). A 100 g weight of fresh tuber of each genotype was collected and oven-dried for dry matter estimation. Food quality analysis and sensory evaluation were done using semi-trained panelists from the Njala community as described by the yam descriptor [14].

2.4 Data Analysis

Data were subjected to analysis of variance (ANOVA) using the GENSTAT 15th edition statistical programme (Release 15.1, Lawes Agricultural Trust, Rothamsted Experimental Station, Harpenden, UK, 2012).

Table 1. Total rainfall, mean monthly relative humidity, minimum temperature and maximum temperature of experimental sites from 2011 to 2012

Year	Total rainfall (mm)		
	Location		
	Kenema	Makeni	Njala
2011	2745.4	2539.2	2604.4
2012	2788.5	2627.7	2662.1
	Mean monthly relative humidity (%)		
2011	74.6	72.4	69.9
2012	77.0	76.9	72.3
	Mean monthly min. temperature (°C)		
2011	20.7	19.9	21.5
2012	20.5	19.6	21.7
	Mean monthly max. temperature (°C)		
2011	31.6	31.1	31.2
2012	31.4	31.0	29.9

The two-way ANOVA in randomized blocks was engaged in GENSTAT. Mean separation was done using the Least Significance Difference (LSD). The residuals of data for the parameters used were first checked for normality and homogeneity using the Shapiro-Wilk test and Bartlett's test to ensure that data were normally distributed [15].

3. RESULTS AND DISCUSSION

3.1 In-field and In-storage pest and Disease Assessment

Generally, mean disease severity increased with time in both staking and non-staking systems and disease infection was higher in non-stake compared to stake plots. At three months after planting (MAP), yam mosaic virus (YMV) and anthracnose severity scores were mild in both stake and non-stake plots (Table 2). Mean severity scores was higher for both diseases in 2011 compared to 2012. At 5 MAP, genotypes TDa 98/01174 and TDa 00/00194 exhibited mild infection of YMV, while Pulli had intermediate attack. Five genotypes with severity ranging between 4.0 and 4.6 had intermediate infection of anthracnose in the non-stake plots, while only Pulli and TDa 95/00005 had intermediate attack of the disease in stake plots.

Findings were partly consistent with Green et al. [16] who noted marked differences between agro-ecological zones and between species, with *D. alata* showing high susceptibility to fungal disease compared to *D. rotundata*, which showed moderate to high levels of resistance. However, earlier report revealed moderate resistance in some genotypes of *D. alata* [17]. The observed large variance of anthracnose severity among genotypes in staking and non-staking systems compared to virus disease infection agrees with Egesi et al. [13], indicating that ranking of genotypes for anthracnose is more likely to change when tested in multi-locations. Van Loon [18] noted severe reduction of photosynthesis due to many mosaic or yellowing disease symptoms when calculated on chlorophyll basis. The variance may be due partly to the genotypes and environmental conditions under which they were grown. The decreased fresh tuber yields in highly infected genotypes were possibly due to their decreased photosynthetic leaf area and shoot dry weight. The elite introduced genotypes with stable resistance can be used to develop elite genotypes and as resource for further genetic studies.

Storage time, mean in-door and out-door temperature and mean in-door and out-door relative humidity recorded during in-store pest and disease assessment are presented in Table 3.

Results of ten fresh tubers randomly selected and sampled during a four month period at the yam barn indicated that disease and pest attacks were generally mild during the first 60 days after harvest (DAH) (Tables 4 and 5). Although the severity pressure increased with time in all genotypes, TDa 00/00194 exhibited mild damage of all storage pests and diseases sampled up to 120 DAH. The remaining genotypes had low damage of nematode and mealy bug, while the

local check, Pulli, had low damage of nematode, intermediate damage of mealy bug and low damage of tuber dry rot at 90, 120 and 120 DAH, respectively.

Findings partly agree with Morse et al. [19] who noted that most of the yam rot induced by insect attacks are mainly due to storage beetles (Coleoptera), mealy bug (*Planococcus citri*) and scale insect (*Aspidiella hartii*) during storage. Ikotun [20] also reported that about 25% of post-harvest losses of yam in storage are due to disease infection. The implication of this study is that small tubers harvested from infected plants as planting materials could serve as sources of infection, which may affect percent sprout, days to sprouting, vigour, survival and consequently the yield of yams. However, avoidance of use of infected planting materials and soils could ameliorate the menace. Genotypes with good tolerance to local in-store pests and diseases also serve as a source of good income, since they appreciate good selling price in the market at a time when prices would have at least doubled compared to the peak harvest season.

3.2 Fresh Tuber Yield

Fresh tuber yields were significantly higher in stake plots than the non-stake plots (Tables 6 and 7). Five genotypes with yield ranging between 11.8 and 14.7 $t.ha^{-1}$ significantly out-yielded the local check, Pulli (9.1 $t.ha^{-1}$), in the stake plots. However, only genotype TDa 02/00012 (11.9 $t.ha^{-1}$) significantly exhibited higher yield than the local check (7.1 $t.ha^{-1}$) in the non-stake plots. Generally, staking contributed 30.5% mean yield increase compared to non-staking. The low yields in the non-stake plots were partly due to the higher disease infection and inherent genotypic variation.

Table 2. Mean disease severity scores[+] of eight yam genotypes assessed at 3 and 5 MAP in three locations for two years in Sierra Leone

Genotype	Anthracnose severity				Yam mosaic virus severity			
	3 MAP		5 MAP		3 MAP		5 MAP	
	Non-stake	Stake	Non-stake	Stake	Non-stake	Stake	Non-stake	Stake
Pulli	1.7	1.4	4.3	3.5	2.0	1.4	3.8	3.3
TDa 00/00194	1.7	1.4	3.8	3.0	1.4	1.4	3.1	2.6
TDa 02/00012	1.6	1.4	3.9	3.3	1.9	1.3	3.4	2.8
TDa 95/00005	1.7	1.5	4.1	3.5	2.0	1.4	3.8	2.8
TDa 95/00307	2.0	1.7	4.3	3.5	2.0	1.6	4.1	3.5
TDa 98/01168	2.0	1.3	3.8	3.0	1.7	1.3	3.1	2.8
TDa 98/01174	1.5	1.4	3.6	2.9	2.1	1.3	3.4	2.1
TDa 98/01176	1.8	1.7	3.7	3.5	1.7	1.7	3.0	2.7
Mean	1.7	1.4	3.9	3.2	1.8	1.4	3.5	2.7
$LSD_{(5\%)gen}$	0.21^{***}		0.27^{***}		0.07^{**}		0.32^{***}	
$LSD_{(5\%)sup}$	0.09^{***}		0.12^{***}		0.03^{***}		0.14^{***}	
$LSD_{(5\%)gen\ x\ sup}$	0.29^{ns}		0.39^{ns}		0.10^{***}		0.45^{**}	
CV(%)	2.7		0.9		2.8		0.6	

[+]*Severity score: 1=no visible symptom, 5=high, plants were also predominantly healthy with no visible symptom expression of diseases assessed at 1 MAP; MAP=months after planting; TDa=tropical Dioscorea alata; gen=genotype, sup=support; ^{ns}, **, and ***=non significant, significant at p<0.01 and p<0.001, respectively*

Table 3. Storage time, mean in-door and out-door temperature and relative humidity of eight yam genotypes sampled for four months at Njala

Storage time (days)	Mean indoor temp (°C)	Mean outdoor temp (°C)	Mean indoor RH (%)	Mean outdoor RH (%)
30	30.7	31.1	62.0	58.0
60	30.8	31.1	64.0	58.4
90	31.1	31.6	64.7	60.0
120	27.8	28.1	77.3	74.0

Table 4. Mean mealy bug and nematodes severity scores[+] of eight yam genotypes assessed at 1-4 MAH at Njala

Genotype	Mealy bug				Nematode			
	Storage time (DAH)				Storage time (DAH)			
	30	60	90	120	30	60	90	120
Pulli	1.5	2.0	2.5	4.0	1.5	2.2	3.0	3.3
TDa 00/00194	1.6	1.7	2.0	2.3	1.7	2.0	2.3	2.3
TDa 02/00012	1.5	2.0	2.1	1.9	1.3	1.6	1.7	3.1
TDa 95/00005	1.5	1.6	2.4	4.2	1.8	1.9	2.1	3.0
TDa 95/00307	1.8	2.0	2.5	3.5	1.7	2.0	2.2	3.9
TDa 98/01168	1.5	1.9	2.3	2.7	1.3	1.5	1.7	2.9
TDa 98/01174	1.7	2.0	2.2	2.9	1.3	1.6	2.1	2.0
TDa 98/01176	1.3	1.3	2.0	2.9	1.9	1.9	2.0	2.8
Mean	1.6	1.8	2.3	3.2	1.6	1.8	2.1	2.9
$LSD_{(0.05)gen}$	0.08***				0.07***			
$LSD_{(0.05)st}$	0.06***				0.05***			
$LSD_{(0.05)gen\ x\ st}$	0.16***				0.14***			
CV(%)	4.5				4.1			

[+]*Severity score: 1=no visible symptom, 5=high; DAH=days after harvesting; TDa=tropical Dioscorea alata; gen=genotype, st=storage time; ***= significant at p<0.001*

Table 5. Mean tuber rot and tuber beetle severity scores[+] of eight yam genotypes assessed at 1-4 MAH at Njala

Genotype	Tuber rot				Tuber beetle			
	Storage time (DAH)				Storage time (DAH)			
	30	60	90	120	30	60	90	120
Pulli	1.4	1.6	2.2	3.0	1.4	1.5	1.8	2.6
TDa 00/00194	1.3	1.5	1.5	1.8	1.3	1.9	2.0	2.5
TDa 02/00012	1.2	1.4	1.4	2.3	2.0	2.5	2.7	2.7
TDa 95/00005	1.2	1.3	1.5	2.2	1.8	2.0	2.2	2.4
TDa 95/00307	1.2	1.3	1.7	1.7	1.7	1.9	1.9	2.6
TDa 98/01168	1.3	1.4	1.5	1.6	1.4	1.6	2.1	2.6
TDa 98/01174	1.4	1.6	1.7	2.2	2.0	2.0	2.2	2.5
TDa 98/01176	1.0	1.4	1.6	1.7	1.6	1.9	1.9	2.0
Mean	1.3	1.4	1.6	2.1	1.7	1.9	2.1	2.5
$LSD_{(0.05)gen}$	0.07***				0.09***			
$LSD_{(0.05)st}$	0.05***				0.06***			
$LSD_{(0.05)gen\ x\ st}$	0.15***				0.18***			
CV(%)	5.6				5.4			

[+]*Severity score: 1=no visible symptom, 5=high; DAH=days after harvesting; TDa=tropical Dioscorea alata; gen=genotype, st=storage time; ***= significant at p<0.001*

A yield increase of 50 to 60% was observed in stake plots compared to non-stake plots in Cameroon [21]. In the present study, the five outstanding elite genotypes including TDa 00/00194, TDa 02/00012, TDa 98/01168, TDa 98/01174 and TDa 98/01176 produced 37, 19, 33, 45 and 45% more yield, respectively, in stake plots compared to non-stake plots. Similarly, a significant percent mean yield increase due to staking was observed across three agro-ecologies of Sierra Leone. The savannah grassland region (Makeni) had the highest percent mean yield increase due to staking (38.5%) compared to the forest transition, Njala (29.7%) and the rainforest, Kenema (26.4%) regions. The difference may be due partly to higher exposure of plant leaves that enhanced increased photosynthesis and lower disease infection in staking plots compared to non-staking system. Some genotypes grown on fertile soil may establish and compete well for nutrients in both stake and non-stake plots thereby reducing the yield gap. In regions where stakes are scarce and expensive, the yield gain in stake

plots may not buffer the extra cost of production. However, staking becomes more useful where many large-size tubers appreciate in price compared to many small tubers obtained in non-stake plots.

3.3 Storage Tuber Quality Traits

Peel loss, cooking time and dry matter content varied significantly ($p<0.001$) among genotypes (Table 8). The percent peel loss was highest in TDa 95/00005 (38.7%) and lowest in TDa 98/01176 (20.4). Peel loss is possibly affected by the extent of damage by nematodes and root rot attack in the field and storage and the shape and size of genotypes.

All the genotypes were cooked under 20 minutes (Table 8). Five improved genotypes, which cooked from 9 to 15 minutes, had similar cooking time as the check.

All genotypes exhibited acceptable cooked tuber taste and color. High dry matter content and low percent peel loss are important processing parameters for secondary products [22,23]. A total of six genotypes including five improved and one local check had high dry matter content within the range of 27 to 35% [24].

3.4 Economic Analysis of Staking and Non-staking Production Systems

The estimated variable cost of yam production under staking system was higher than the non-staking system in all agro-ecologies (Table 9). The mean gross margin return of yam production was estimated at Le 22,800,000. The breakeven yield to recover costs of production at Kenema, Makeni and Njala were estimated at 5.7, 5.8 and 5.7 $t.ha^{-1}$, respectively. Mean yield difference between staking and non-staking systems in Kenema was 3.4 $t.ha^{-1}$, whereas those at Makeni and Njala were 3.6 and 3.0 $t.ha^{-1}$, respectively. The amount allocated to staking system was less than 1 $t.ha^{-1}$ fresh tuber yield equivalence of Le 4,000,000, which implied that staking operation is economically beneficial in enhancing increased yield and quality in yam production. The extent of benefit however, depends, in part, on the genotype and the growing agro-ecology. The cost of planting material ranked the highest variable input followed by weeding and staking (i.e. cost of sticks, transportation and labour), while planting and harvesting are among the lowest variable inputs.

Of the eight genotypes assessed, six genotypes including TDa 00/00194, TDa 02/00012, TDa 98/01168, TDa 98/01174, TDa 98/01176 and Pulli had consistently higher gross margin returns in staking than the non-staking system in all agro-ecologies studied. The results are partly consistent with those obtained by Dorosh [11] who noted that despite the high production cost of yam under forest and savanna ecological zones of Nigeria, yam production in fertile soils is highly profitable. Ezeh et al. [25] also reported the significant impact of rainfall intensity and distribution on the yield and profitability of yams.

Table 6. Mean fresh tuber yield ($t.ha^{-1}$) of eight yam genotypes evaluated at three locations for two years in Sierra Leone

Genotype	Location					
	Kenema		Makeni		Njala	
	Non-stake	Stake	Non-stake	Stake	Non-stake	Stake
Pulli	9.7	10.6	4.8	7.7	6.5	9.2
TDa 00/00194	10.8	18.2	5.2	9.2	7.7	10.4
TDa 02/00012	13.4	15.5	10.8	13.9	11.5	14.6
TDa 95/00005	6.6	8.3	5.0	5.6	5.3	6.0
TDa 95/00307	7.9	8.0	4.8	6.6	4.7	5.0
TDa 98/01168	10.1	14.3	5.8	11.0	7.9	10.2
TDa 98/01174	9.3	13.9	5.9	12.4	6.1	13.0
TDa 98/01176	8.3	14.7	4.2	9.2	7.3	12.7
Mean	9.5	12.9	5.8	9.4	7.1	10.1
$LSD_{(5\%)gen}$	1.23^{***}		1.36^{***}		1.64^{***}	
$LSD_{(5\%)sup}$	0.62^{***}		0.68^{***}		0.82^{***}	
$LSD_{(5\%)gen\ x\ sup}$	1.74^{***}		1.93^{***}		2.32^{***}	
CV(%)	6.1		14.1		6.9	

Gen=genotype, sup=support; TDa=tropical Dioscorea alata; ***= significant at $p<0.001$, respectively

Table 7. Percent yield increment of eight yam genotypes evaluated at three locations for two years in stake and non-stake production systems

Genotype	Location			Support			
	Kenema	Makeni	Njala	Non-stake	Stake	Mean	% yield increase
Pulli	10.2	6.2	8.0	7.1	9.1	8.1	22.0
TDa 00/00194	14.5	7.2	9.0	7.9	12.6	10.3	37.3
TDa 02/00012	14.5	12.3	13.1	11.9	14.7	13.3	19.1
TDa 95/00005	7.5	5.3	5.6	5.6	6.6	6.1	15.1
TDa 95/00307	8.0	5.7	4.7	5.9	6.4	6.2	7.8
TDa 98/01168	12.2	8.4	9.1	7.9	11.8	9.8	33.0
TDa 98/01174	11.6	9.1	9.5	7.1	13.1	10.1	45.8
TDa 98/01176	11.5	6.7	10.0	6.6	12.2	9.4	45.9
Mean	11.2	7.6	8.6	7.5	10.8	9.2	28.2
$LSD_{(5\%)gen}$	1.24***			1.15***			
$LSD_{(5\%)loc}$	0.75***			0.57***			
$LSD_{(5\%)gen\ x\ loc}$	2.14**			1.62***			
CV(%)	8.3			8.3			

*Gen=genotype, loc=location, sup=support; TDa=tropical Dioscorea alata; ** and *** = significant at p<0.01 and p<0.001, respectively*

Table 8. Food quality traits of eight yam genotypes sampled at harvest

Genotype	Tuber shape	Peel loss (%)	Color of raw tuber	Color of cooked tuber	Cook time (min)	Taste of cooked tuber	Dry matter content (%)
Pulli	Oblong	27.7	Cream	Deep cream	14	Bland	31.5
TDa 00/00194	Oblong	23.5	Light purple	Light purple	19	Bland	36.3
TDa 02/00012	Oblong	36.8	White	Off-white	18	Bland	26.0
TDa 95/00005	Cylindrical	38.7	White	Cream	11	Sweet	33.1
TDa 95/00307	Cylindrical	20.8	White	Light purple	10	Sweet	19.2
TDa 98/01168	Palmitate	23.1	Purple	Cream	18	Very sweet	29.2
TDa 98/01174	Oblong	33.5	White	White	19	Sweet	27.0
TDa 98/01176	Oblong	20.4	White	White	10	Sweet	33.0
Mean	-	27.0	-	-	15.7	-	30.8
$LSD_{(0.05)}$	-	1.7***	-	-	1.6***	-	2.3***
CV(%)	-	8.4	-	-	5.8	-	9.8

*TDa=tropical Dioscorea alata; ***=significant at p<0.001*

Table 9. Estimated partial costs and gross margins analyses of one hectare ware yam production under stake and non-stake systems in three agro-ecologies of Sierra Leone

Item	Location								
	Kenema			Makeni			Njala		
	Unit cost(Le)	Quantity	Value (Le)	Unit cost(Le)	Quantity	Value (Le)	Unit cost(Le)	Quantity	Value (Le)
Exchange rate							$1 = Le 4,300		
*Yield to breakeven (t.ha^{-1})			5.7			5.8			5.7
Mean yield stake (t.ha^{-1})			12.9			9.4			10.1
Mean yield non-stake (t.ha^{-1})			9.5			5.8			7.1
Variable inputs:									
Land (lease cost/1 ha/yr)	50,000	1	50,000	50,000	1	50,000	50,000	1	50,000
Planting material^{+}	4,000	2500	10,000,000	4,000	2500	10,000,000	4,000	2500	10,000,000
Farm guard (1 man/8mon)	200,000	8 months	1,600,000	200,000	8	1,600,000	200,000	8	1,600,000
Brushing (man-days/ha)	12,000	100	1,200,000	10,000	50	500,000	10,000	50	500,000
Clearing (man-days/ha)	12,000	100	1,200,000	10,000	50	500,000	10,000	50	500,000
Mounding (man-days/ha)	12,000	100	1,200,000	10,000	100	1,000,000	10,000	100	1,000,000
Planting (man-days/ha)	10,000	25	250,000	10,000	25	250,000	10,000	25	250,000
Sticks	4,000	834 doz.	3,336,000	4,000	834 doz.	3,336,000	4,000	834 doz.	3,336,000
Transportation of sticks	4,500	10 L fuel	45,000	4,500	20 L	90,000	4,500	10 L	45,000
Staking (man-days/ha)	10,000	50	500,000	10,000	50	500,000	10,000	50	500,000
Weeding (man-days/ha)	10,000	100 x 3	3,000,000	10,000	100 x 4	4,000,000	10,000	100 x 4	4,000,000
Harvesting (man-days/ha)	10,000	25	250,000	10,000	25	250,000	10,000	25	250,000
Transportation of tubers	4,500	20 L fuel	90,000	4,500	20 L	90,000	4,500	20 L	90,000
TPC Stake system			22,721,000			22,571,000			22,121,000
TPC Non-stake system			18,840,000			18.240,000			18.240,000
Gross margin return			22,800,000			23,200,000			22,800,000

**Yield to breakeven; $^{+}$1 kg ware yam costs Le 4000; TPC=total production cost*

4. CONCLUSION

Staking is beneficial in yam production contributing an average of 28.2% more fresh tuber yields than non-staking. Genotypes in staking system were more tolerant to in-field local diseases, thereby significantly out-yielding those in non-staking system. Genotypes TDa 98/01174, TDa 98/01176, TDa 02/00012, TDa 98/01168 and TDa 00/00194 exhibited stable resistance to in-field diseases in the staking system with mean yield ranging between 11.8 and 14.7 $t.ha^{-1}$ and desired food quality traits compared to the check variety, Pulli. The mean breakeven yield was estimated at 5.7 $t.ha^{-1}$ and the corresponding breakeven cost of production was Le 22,933,000. The same genotypes that exhibited mild resistance to anthracnose were also resistant to yam mosaic virus with little variation. These have good implications for multiple disease resistance breeding as the different genes controlling these traits could be pyramided into an ideotype. Similar technique could be used to breed for high yield and desired food quality traits.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Mwiringi PN, Kahangi EM, Ngende AB, Mamati EG. Morphological variability within the Kenyan yam (*Dioscorea* spp.). Journal of Applied Biosciences. 2009;16:894-901.
2. Norman PE, Tongoona P, Shanahan PE. Diversity of the morphological traits of yam (*Dioscorea* spp.) genotypes from Sierra Leone, Journal of Applied Biosciences. 2011;45:3045-3058.
3. Ministry of Agriculture, Forestry and Food Security (MAFFS)/National Agricultural Research Coordinating Council (NARCC). Crop Production guidelines for Sierra Leone. 2005;104.
4. Maina M. Yam (*Dioscorea* spp.). How will this crop be revived to enhance food security in East Africa? In: Agricultural Biosciences. Proceedings of the 1st International e-Conference on Agricultural Biosciences. 2008;I. Accessed 8 April 2009. Available: www.e-conference.elewa.org/agriculture.
5. Sesay L, Norman PE, Massaquoi A, Kobba F, Allieu AP, Gboku ML, Fomba SN. Assessment of farmers' indigenous knowledge and selection criteria of yam in Sierra Leone. Sky Journal of Agricultural Research. 2013;2:1-6.
6. National Agricultural Research Institute (NARI). Wet-Lowlands Mainland Programme Sir Alkan Tololo Research Centre, P. O. Box 1639, Lae 411, Morobe Province, Papua New Guinea. 2006;5. Accessed April 2006. Available: www.nari.org.pg/sites/default/files/.../BUB010(E)_Yam_staking.pdf
7. Tsado EK. Substituting wooden sticks with plastic stakes in yam production in Niger State, Nigeria. Journal of Natural Sciences Research. 2012;2:88-96.
8. Orkwor GC, Asiedu R, Ekanayake IJ, editors. Food Yams: Advances in Research, IITA, Ibadan and NRCRI, Umudike, Nigeria. 2000;249.
9. Onwueme IC. Strategies for progress in yam research in Africa. In: Proceedings: First Triennial Symposium of the International Society of Tropical Root Crops–Africa Branch, IDRC, Ottawa, Canada. 1981;173-178.
10. International Institute of Tropical Agriculture (IITA). First Global Conference on Yam 'to harness research innovations to unleash the potential of yam' 3-6 October 2013, Alisa Hotel, Accra, Ghana, Symposium organized by International Institute of Tropical Agriculture. 2013;146.
11. Dorosh P. The economics of root and tuber crops in Africa. RCMP Research Monograph No. 1, Resource and Crop Management Program, IITA, Ibadan, Nigeria. 1988;31-48.
12. Rees D, Bancroft R, editors. Development of integrated protocols to safeguard the quality of fresh yams (R 7582 (ZB 0234). Final Technical Report, Natural Resources Institute, University of Greenwich, United Kingdom 1 February 2000–31 March. 2003;113.
13. Egesi CN, Onyeka TJ, Asiedu R. Severity of anthracnose and virus diseases of water yam (*Dioscorea alata* L.) in Nigeria I: Effect of yam genotype and date of planting. Crop Protection. 2007;26:1259-1265.
14. International Plant Genetic Resources Institute (IPGRI/IITA). Descriptors for yam (*Dioscorea* spp.) IPGRI, Rome, Italy: International Plant Genetic Resources

Institute (IPGRI)/International Institute of Tropical Agriculture (IITA), Ibadan Nigeria. 1997;61.
15. David Garson G. Testing statistical assumptions. Statistical Associates Publishing, Blue Book Series, 2012 Edition, 274 Glenn Drive, Ashebero, NC 27205 USA. 2012;52.
16. Green KR, Sangoyomi AT, Amusa NA. The importance of Rhizoctonia solani as a pathogen of yam (*Dioscorea* spp.) in Nigeria. In: Proceedings of the 6th Symposium of the International Society for Root and Tuber Crops African Branch. 1995;412-418.
17. Nwankiti AO, Arene OB. Diseases of yam in Nigeria. Pest Articles and News Summaries. 1978;24:486-494. Orkwor GC, Asiedu R, Ekanayake IJ, (eds.). Food Yams. Advances in Research, IITA and NRCRI, Nigeria. 2000;249.
18. Van Loon LC. Disease induction by plant viruses. Advances in Virus Research. 1987;33:205-225.
19. Morse S, Acholo M, McNamara N, Oliver R. Control of storage insects as a means of limiting yam tuber fungal rots. J. Stored Products Res. 2000;36:37-45.
20. Ikotun T. Diseases of yam tubers. International Journal of Tropical Plant Diseases (India). 1989;7:1-21.
21. Ministry of Agriculture and Rural Development (MARD)/National Programme for Roots and Tubers Development (NPRTD). Technical guide for the production and conservation of yams (*Dioscorea* spp.). NB Thomas, M Andre and N Dominic (eds.). 2007;31. Accessed 15 October 2014. Available: www.gs2i.fr/fineprint/pdffa.
22. Okaka JC, Okaka ANC. Food: Consumption, spoilage, shelf-life extension. OCJANKO Academic Publishers, Enugu, Nigeria. 2001;225-232.
23. Ukpabi UJ, Omodamiro RM, Ikeorgu JG, Asiedu R. Screening of new improved water yam (*Dioscorea alata*) genotypes for the preparation of amala in Nigeria. In: Root and tuber crops for poverty alleviation through science and technology for sustainable development, NM Mahungu (ed.). Proceedings of the 10th Symposium of ISTRC-AB held from 8-12 October, 2007 in Maputo, Mozambique. 2010;258-264.
24. Degras L. The yam: A tropical root crop. Macmillan Press, London. 1993;31-38.
25. Ezeh NOA, Aniedu OC, Oduakwe SO, Ubbor AO. The effects of weather variables on root and tuber crop yields in Umudike, Imo State, Nigeria. Nigeria Agricultural Journal. 1991;25:9-21.

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