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Yam Propagation Using 'Aeroponics' Technology

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Authors' contributions

This work was carried out in collaboration between all authors. Authors NM, MB, RA and BA designed the study. Author NM wrote the protocol, performed the statistical analysis and wrote the first draft of the manuscript. Authors PLK and JA were involved in plant health monitoring and pathogen characterization. All authors reviewed the draft and approved the final manuscript.

Short Research Article

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ABSTRACT

Aims: To study yam propagation and seed yam tuber production in aeroponics system.
Study Design: The experiment was conducted in a randomized complete block design and treatments were replicated three times.
Place of Study: This experiment was carried out at the International Institute of Tropical Agriculture Headquarters at Ibadan in Nigeria.
Methodology: The experiment tested fresh vine cuttings of five yam genotypes of two species in an aeroponics system. Three genotypes of *Dioscorea rotundata* (TDr 89/02475, TDr 89/02665 and TDr 95/18544) and two yam genotypes of *D. alata* (TDa 98/01176 and TDa 291) were evaluated.
Results: Vines of both *D. rotundata* and *D. alata* rooted within 2 weeks in aeroponics system. The rooting of vine cuttings varied significantly among genotypes with a maximum of 98% for TDa 98/01176 and a minimum of 68% for TDr 89/02665. Mini-tubers harvested after 4 months of growth in aeroponics weighed between 0.2 and 2.7g. A second harvest 6 months later gave mini-tubers of up to 110g. The analysis of variance showed significant difference ($P<0.05$) among genotypes for rooting at 2 weeks after vine planting, number of plant surviving at 90 days after planting and percentage of plants with bulbils. The best

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genotypes were TDr 95/18544 and TDr 89/02665 for survival at 90 days after vine planting and percentage of plant producing bulbils in the aeroponics system respectively.

Conclusion: This study revealed that yam genotypes performed differently in aeroponics system for vine rooting and production of mini-tubers and bulbils.

Keywords: Yam; Dioscorea spp.; vine propagation; aeroponics; mini-tubers; bulbils.

1. INTRODUCTION

Yam (*Dioscorea* spp.) is traditionally propagated by tuber, the edible part, with very low multiplication rate (less than 1:10 compared to 1:200 in some cereals) [1]. The problem of low multiplication rate is worsened by the long growth cycle and long tuber dormancy period of yam. The low rate of multiplication and the use of the edible tubers for propagation makes seed yam very expensive. Yam production therefore revolves quite repeatedly around the use of mixed genotypes, pre-infected seed yam and farmlands, causing a build-up of an array of fungal, nematode, bacterial and viral diseases and pests [2], leading to 50 to 90% yield reduction. Consequently, there is a significant demand for clean seed in a market driven seed system and 50 - 70% of production costs is spent on purchase of seed yam [3,4,5].

The production of seed yam as an integral part of ware yam production is widely practiced throughout the yam belts of Nigeria and Ghana. Among several practices there are two major methods used by farmers to produce seed yam, namely sorting and milking. At harvest, the tubers are sorted by size; small ones are retained as seed yam, medium as table yam and the very large ones as ceremonial yam. (i.e. presented during ceremonies such as traditional weddings). In the "milking" technique [6,7], tubers are harvested two-thirds into the growing season without destroying the root system, to provide early ware yam for consumption. The parent plant produces new small tubers before senescence which are used as seed yam for the following season. Milking practice represents significant investment by the farmer. First, there is a yield loss by harvesting the main tuber before senescence when maximum yield is attained [8]. Because of the double harvesting labour is increased. These additional costs explain the very high cost of seed yam.

Significant progress has been made towards improving the efficiency of the traditional tuber seed yam production technology by developing methods that can increase the multiplication rate. The minisett technology was developed by the National Root Crops Research Institute (NRCRI), Umudike, and the International Institute of Tropical Agriculture (IITA) in the early 1970s to overcome the critical problem of unavailability of good quality seed yam. The process involves cutting of 'mother' seed tubers into small setts of 25-50g each with periderm and some cortex parenchyma [9]. With the technique, the multiplication ratio of white yam has improved from 1:3 to 1:10. The modified minisett technique [10-12], using 25-80g minisett has reduced the production cost of seed yam [7,13] but the rate of adoption is low [10].

Alternatives to seed tubers that are at various stages of development in West Africa by yam researchers include rooting stem (vine) cuttings of the yam plant. Rooted vine cuttings at 20cm long and with 1 to 3-nodes [14-16] produced mini-tubers of 50-600g after 8 months giving a 1:30 propagation ratio. Other high propagation ratio technologies exist but are not being used for yam [17].

The 'aeroponics system' is one of the new technologies implemented for seed yam propagation through the project known as "Yam Improvement for Income and Food Security in West Africa (YIIFSWA)" [18]. Aeroponics is a method of growing plants in a soil-less environment with very little water [19]. The International Union of Soil-less Culture defines aeroponics as "a system where roots are grown continuously or discontinuously in an environment saturated with fine drops (a mist or aerosol) of nutrient solution" [20]. Went [21] named the air-growing process in spray culture as 'aeroponics'.

Techniques for growing plants without soil were first developed in the 1920s by botanists who used primitive aeroponics to study plant root structure [22]. This absence of soil made study much easier: In aeroponics, the plant's roots dangle midair, with only the stems held in place. The way nutrients and water are delivered also demonstrates the efficiency of aeroponics. Atomizing nozzles ensure the most effective delivery of nutrients, since they turn the water into a fine mist. Plants absorb nutrients through their roots by osmosis, a selective absorption of compounds through cell walls. Roots can absorb nutrients more easily as they are delivered via the mist. At the International Potato Centre (CIP) in Peru, yields of over 100 tubers per plant were obtained from potato [23]. Aeroponics technology is being tested in several African countries for the production of potato mini-tubers [24]. The aeroponics technology is well known to be effective for other vegetatively propagated and horticultural crops [25] for high ratio propagation and assurance of high seed quality. However this technique has never been used for yam propagation. In this study, aeroponics technology was used for the propagation of yam using vine cuttings.

2. MATERIALS AND METHODS

The study of yam propagation in aeroponics system was initiated in January 2013 at IITA, Ibadan, Nigeria. The aeroponics system was constructed by EMEC-Engineering Company (Kenya) and the FMS Unit of IITA-Ibadan in an insect proof-screenhouse. It is composed of 14 boxes. Each box has a length of 4.8m and a width of 1.2m at distance of 1m between two consecutive boxes. The tops of the boxes are covered by Styrofoam of 50 mm thickness cut into pieces (tables) of 1.2mx1.2m corresponding to 4 tables per box. Each table was perforated at 20cm x 20cm giving 36 planting holes per table (400cm² per plant). This system was used to conduct two experiments at Ibadan (7°38'N, 3°89'E; forest-savannah transition, 227 masl, annual rainfall 1312mm, annual average temperatures 20.3– 33.8°C; soil type Ferric Luvisols).

The first planting of pre-rooted one-node vines in the aeroponics system was 23-28 February 2013. The one node vine cuttings collected from a seedling nursery were planted in pots in December 2012 for pre-rooting before their transplantation two months later in the newly constructed aeroponics system. Out of the 14 boxes constructed in the aeroponics system, only five and half boxes were covered with the pre-rooted vines. The 6th box partially planted and fully atomized with the nutrient solution, was filled with direct-planted freshly cut two-node vines. To test effectiveness of direct planting of yam vine cuttings in aeroponics, the 7th box was planted the following day with two-node vine cuttings from a 5-month old seedling. For this experiment, the fertilizers used were ammonium nitrate, calcium nitrate, magnesium sulphate, boric acid and Fe (EDTA-Fe6%); two major elements were missing and these were potassium and phosphorous.

The second experiment was initiated about four months after the first experiment by direct planting in aeroponics of two-node freshly cut vines of five improved yam genotypes: three *D. rotundata* (TDr 89/02475; TDr 89/02665; TDr 95/18544) and two *D. alata* (TDA 291; TDA

98/01176). The vines were generated in a glasshouse from plants grown in pots using 50g yam minisetts. Eighteen two nodes vine cuttings per genotype were planted in three replications. After two weeks of growth, the fertilizer compositions in the nutrient solution were modified with the objective of increasing the size of mini-tubers to be harvested. The fertilizers used were ammonium nitrate, calcium nitrate, magnesium sulphate, potassium sulphate; triple-super phosphate and micron (micronutrients). Data collected were analyzed using analysis of variance and GGE biplot “GGE biplot (www.ggebiplot.com) is a data visualization tool based on principal component analysis (PCA).

3. RESULTS AND DISCUSSION

The main result of the first experiment was the successful growth of both pre-rooted vines and direct planted vine cuttings in the aeroponics system with development of new roots and shoots (Fig. 1). This is the first report on yam propagation in an aeroponics system [26]. Also literatures on aeroponics for potatoes or horticultural crops were based on transplanted rooted plantlets [23] but not on the use non rooted vines. The vine cuttings directly planted in aeroponics established very good rooting systems within two weeks after planting. Around 95% of yam vine cuttings rooted in aeroponics in comparison with 70% obtained by using carbonized rice husk [15]. Table 1 presents the characteristics of these preliminary results of rooting of yam vine cuttings in aeroponics in comparison with the rooting in carbonized rice husk.

Table 1. Results of vine cuttings rooting in carbonized rice husk and in aeroponics

	Carbonized rice husk*	Aeroponics
% of rooted plants	70%	95%
Time to rooting	12-24 days	10-14 days
Age of mother plant source of vine	70-90 days	Up to 5 months

**Data source: [15]*

The harvest of mini-tubers from the first experiment took place at four months (June 2013) after planting in aeroponics. One to two mini-tubers were harvested per plant. The mini-tubers sizes ranged between 0.2g and 2.g [27]. The harvest was done without destruction of the rooting system to allow the plants to continue their growth in the aeroponics system. Six months after the first harvest of mini-tubers, a second harvest was done on some of the remaining plants of the first experiment. The mini-tubers harvested were of various sizes and one plant produced the highest tuber weight of 110g [28]. From the first experiment initiated in February-March 2013, a few yam plants (from pre-rooted and direct planted vines) continued to grow in the aeroponics system up to 15 months after planting, when last observation was made. Normally yam plants are harvested after 9 to 10 months in the field. Beside the aeroponics system another technology known as Temporary Immersion Bioreactors (TIB) is being implemented by YIIFSWA [29].

The second experiment was initiated in June 2013 with direct vine cuttings planted on the remaining seven boxes in the aeroponics system. Data were collected on rooting of yam vines in aeroponics after the first two and four weeks after vine cutting (WAVC) (Tables 2 and 3). At the end of the first two weeks, the general mean of 83.4% of rooted plantlets was recorded. An average vine rooting of 68.5% was registered for genotype TDr 89/02665 compared to 98.1% recorded for TDa 98/01176. At four weeks after planting of vine cuttings the general mean of plants growing in aeroponics was reduced to 75%.

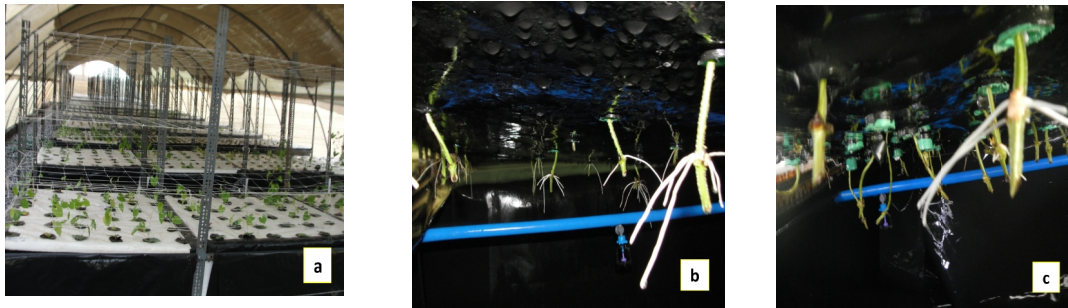


Fig. 1a. Yam plants with shoots in aeroponics system; (b): Vine of *D. rotundata* rooting in aeroponics and (c): Vine of *D. alata* rooting in aeroponics

Analysis of variance of the number of plants at two and four WAVC showed significant differences ($P < 0.05$) among genotypes indicating variation in genotypic responses to vine rooting in aeroponics. For some genotypes such as TDa 98/01176 and TDr 89/02475, the aeroponics system should be considered as a very good medium for vine rooting.

Table 2. Average number of plants growing at 2 and 4 weeks after direct planting of 2 nodes vine cuttings in aeroponics

Genotype	Number of plants two weeks after vine cuttings	Number of plants four weeks after vine cuttings
TDa 98/01176	17.7 ^a	17.0 ^a
TDr 89/02475	16.7 ^{ab}	14.0 ^{ab}
TDr 95/18544	14.7 ^{abc}	14.0 ^{ab}
TDa 291	13.7 ^{bc}	12.7 ^{bc}
TDr 89/02665	12.3 ^c	9.7 ^c
Mean	15.0	13.5
CV%	13.5	16.7

Means in same column followed by same letters are not significantly different at $p < 0.05$

Table 3. Average % plants growing in aeroponics at 2 and 4 weeks after vine cutting

Genotype	Plants in aeroponics two weeks after vine cuttings (%)	Plants in aeroponics four weeks after vine cuttings (%)
TDa 98/01176	98. ^a	94.4 ^a
TDr 89/02475	92.6 ^{ab}	77.8 ^a
TDr 95/18544	81.5 ^{abc}	77.8 ^a
TDa 291	75.9 ^{bc}	70.4 ^b
TDr 89/02665	68.5 ^c	53.7 ^b
Mean	83.3	74.9
CV%	13.5	16.7

Means in same column followed by same letters are not significantly different at $p < 0.05$

In the biplot analysis, the PC1 (96.7%) and PC2 (3.3%) together explained 100% of the total variability attributed to genotypes and growth period (2 WAVC and 4 WAVC) under two different nutrient solutions. A polygon view of the biplot (Fig. 2) showed the performance of

genotypes for number of plants. The best genotype when combining the two periods of two and four weeks is TDa 98/01176 followed closely by TDr 89/02475.

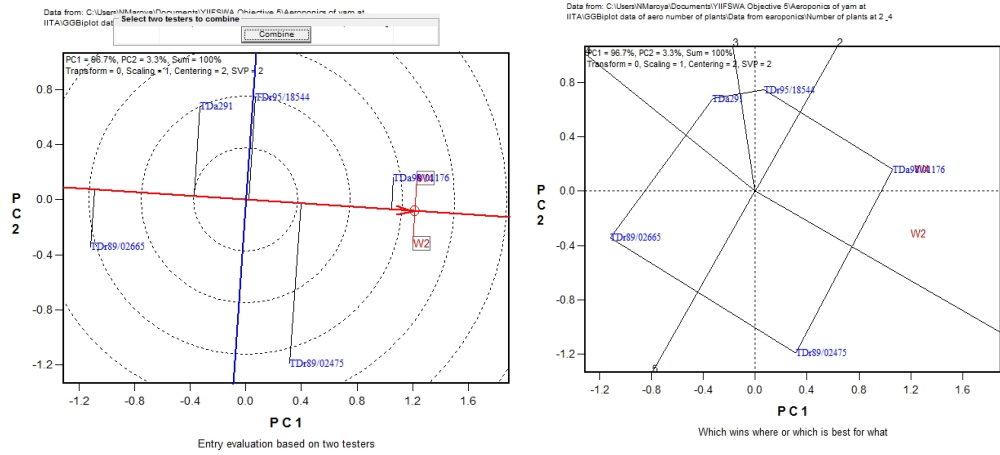


Fig. 2. Graphic representations of the number of plants at 2 and 4 weeks after vine cuttings and relative performance of genotypes

From 45 to 60 days after direct planting of vine cuttings in aeroponics it was observed that many genotypes of both *D. rotundata* and *D. alata* started producing multiple shoots and bulbils. The number of plants with bulbils at 90 days after planting of vine cuttings (DAVC) was recorded for each genotype. It was observed that all the bulbils produced by all the plants of *D. rotundata* were growing with development of new shoots and roots from the bulbils (Fig. 3); the situation was similar for some of the bulbils of *D. alata*. Some bulbils with new shoots harvested from *D. rotundata* and planted in plastic bags, sprouted and grew normally.

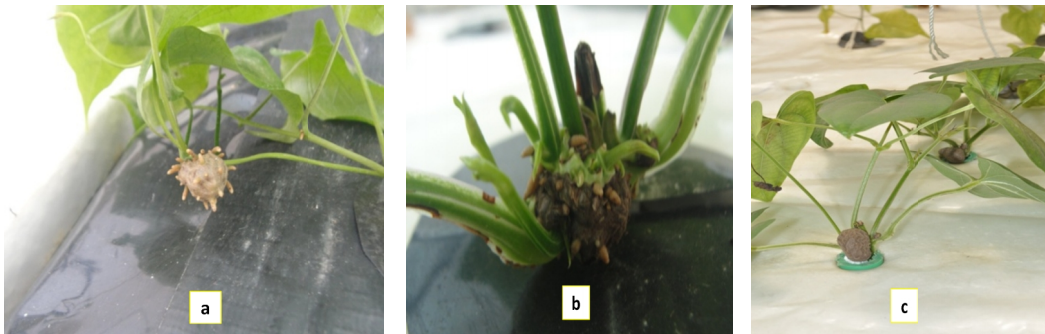


Fig. 3a. Bulbils on *D. rotundata* plant with shoot and roots in aeroponics; (b): Bulbils on *D. alata* plant showing shoots and roots and (c): Bulbils on *D. alata* plant with no shoot and no root in aeroponics

At 90 DVC the average number of plant per genotype was reduced to 8 out of 18 vines planted. This was due to the heat (up to 36°C inside the screen house) stress on the plants resulting from lack of environmental control in the screen house used for the aeroponics system. High temperature (43°C outside the screen house) also affected the nutrient solution (29°C) and ice blocks were added to reduce the temperature. The analysis of variance of the

number of plants at 90 DVC showed significant difference ($P < 0.05$) among genotypes. The genotype TDr 89/02665 was the most affected with an average of 5 plants. The genotype TDr 95/18544 was relatively less affected by heat and maintained up to 13 plants on average. In addition to the heat, a sample of plants collected and analysed revealed infestation (19 to 29%) by *Colletotrichum sp.* (both leaves and stem), *Sphaerosporium sp.* (stems) and *Fusarium sp.* (stems).

For the number of plants with bulbils (NbPB) the best genotypes were TDr 89/02665 and TDr 89/02475 which were significantly different from the three other genotypes. For percentage of plants with bulbils (%PB) three different classes of genotypes were observed. The first class made up of TDr 89/02665 with 90.5% was the best genotype and almost each plant had bulbils. The second group was formed by TDr 89/02475 and the third was composed of the other three genotypes (Table 4).

The PC1 and PC2 explained together 98.1% of the total variation attributed to genotypes and the genotypes interaction with number of plants or percentage of plants with bulbils (Fig. 4). A polygon view of the GGE biplot (Fig. 3) showed relative performance of genotypes in environments represented by variables under study. Considering NbPB and %PB, the genotype TDr 89/02665 was the best because it is closest to the point of intersection of the two variables. The vertex genotypes were TDr 89/02665, TDr 95/18544 and TDa 291. The other genotypes were located within the polygon and were found less responsive. The mega-environment made up of NbPB and %PB fell in the niche where genotype TDr 89/02665 is the best performer. The second mega-environment represented by NbPB, falls in the sector where genotype TDr 95/18544 was the best (Fig. 4).

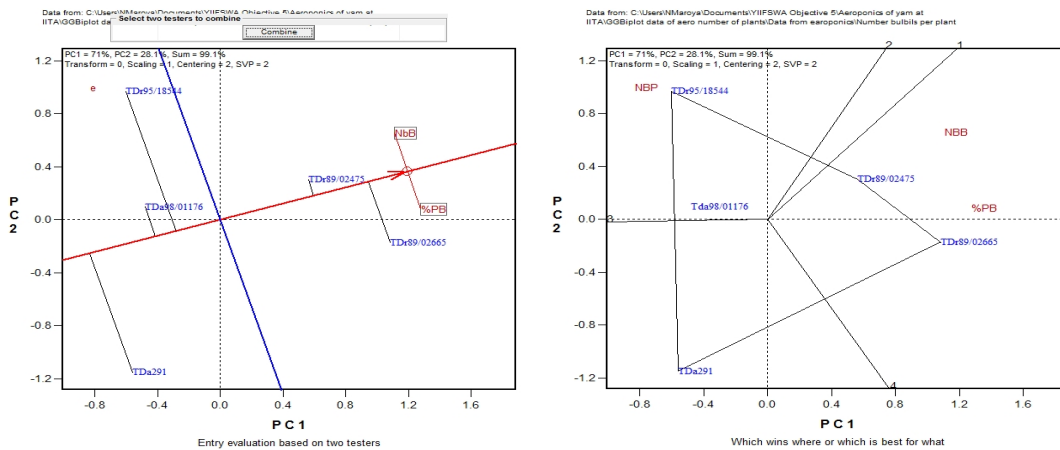


Fig. 4. Graphic representations of the number of bulbils per genotype and percentage of plants with bulbils per genotype

Table 4. Number of plants, number of plants with bulbils and percentage of plants with bulbils in aeroponics system at 90 DAVC

Genotype	Number of plants	Number of plants with bulbils	Plants with bulbils (%)
TDr 95/18544	12.7 ^a	2.7 ^{ab}	21.1 ^c
TDa 98/01176	9.7 ^b	2.0 ^{ab}	23.3 ^c
TDr 89/02475	7.3 ^{bc}	4.3 ^a	59.4 ^b
TDa 291	6.0 ^c	0.7 ^b	15.0 ^c
TDr 89/02665	5.0 ^c	4.3 ^a	90.5 ^a
Mean	8.1	2.8	41.9
CV%	15.9	48.4	31.4

Means in same column followed by same letters are not significantly different at $p < 0.05$

4. CONCLUSIONS

The aeroponics technology should be considered as an effective yam propagation method. Genotypes of both *D. rotundata* and *D. alata* were successfully propagated in it using both pre-rooted and fresh vine cuttings. Results of these studies revealed that vines cutting from five months old plants rooted successfully (95%) within 14 days in aeroponics. An average of 83% (range of 68% - 98%) rooting of vine cutting was registered for the five genotypes used. Genotypes performed differently in aeroponics technology for mini-tuber production. Yam mini-tubers harvested from aeroponics varied from 0.2g to 110g depending on the genotype, the age of harvest and the composition of the nutrient solution. Various sizes of mini-tubers and bulbils of yam can be generated using aeroponics. However, this system is sensitive to excessive heat and care must be taken to regulate the temperature.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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