Research Article

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Yield potential of sandponically produced sweetpotato (*Ipomoea batatas* (L.) Lam) pre-basic seed for selected genotypes

<https://doi.org/10.1515/opag-2020-0025>

received October 30, 2019; accepted April 4, 2020

Abstract: Sufficient sweetpotato (*Ipomoea batatas* (L.) Lam) pre-basic seed at the start of the “seed” value chain is critical and often a bottleneck in the production of sweetpotato in Sub-Saharan Africa. Predominantly, pre-basic seed is multiplied in screenhouse using the conventional soil substrate method which is costly, is untenable, and achieves sub-optimal yields. The sandponics system is a better alternative for sweetpotato pre-basic seed multiplication in the screenhouse attributed to increased yields and cost-effectiveness. This experiment compared sweetpotato yield- and growth-related traits of planting materials sourced from the sandponics system with conventional soil substrate planting materials for four genotypes when grown in the field. A randomized complete block design was used with three replicates. Results showed a significant difference ($p \leq 0.05$) between sources of planting materials and among genotypes for the measured traits. The interaction of source of planting materials and genotype was significant ($p \leq 0.05$) for harvest index. Vine survival, storage root yield, number of storage roots per plant, and vine yield were higher by 4.1%, 24%, 27%, and 24%, respectively, in favor of planting materials sourced from the sandponics system. Sandponically multiplied planting materials showed superior performance for yield and most of the measured growth-related traits to

planting materials multiplied by the conventional soil substrate method.

Keywords: quality sweetpotato vines, sandponics, yield

1 Introduction

Sweetpotato (*Ipomoea batatas* (L.) Lam) has several advantages that give it an important role in combating hunger and malnutrition (Woolfe 1992; Namanda 2012). The crop can produce an acceptable yield with a minimum of inputs including a less fertile soil, where other cereal crops such as maize are difficult to raise (Woolfe 1992; Namanda 2012; Motsa et al. 2015). However, the production of a crop that has a long history as a lifesaver (Lebot 2008; Amajor et al. 2014; Motsa et al. 2015) is constrained by several production factors including pests and diseases, drought, soil infertility, and lack of adequate quality planting materials.

Research has demonstrated that limited access to disease-free quality planting materials and improved genotypes at the start of planting season has been a major hindrance to sweetpotato production, improved varietal dissemination, and ability to control sweetpotato virus disease and weevil pestilence in Sub-Saharan Africa (SSA) countries (Low et al. 2009; Namanda 2012). There have been efforts to build up seed systems steered from research and breeders focusing on varietal trials and release of new improved genotypes to consumers. However, multiplication of adequate quantities of pre-basic seed (also referred to as early generation seed) within a short period of time has been a limitation attributed to slow vine multiplication rate (VMR) and high costs using the conventional soil substrate method (Makokha et al. 2020).

Evidence from research findings show that farmers still experience a challenge of accessing adequate quality seed of improved genotypes during planting season (McEwan et al. 2015). With limited availability of good

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quality planting materials of improved genotypes, farmers opt to source seed from their own fields, neighbors, or friends. This practice contributes to buildup of pests and diseases and accounts for the low storage root yield in SSA countries (McEwan 2016), which is below 10 t ha^{-1} (FAOSTAT 2017). Furthermore, sweetpotato breeding programs have developed improved sweetpotato genotypes that are consumer-preferred; however, these genotypes are not reaching smallholder resource-poor farmers and consumers due to the lack of effective seed multiplication and dissemination systems.

Sweetpotato pre-basic seed multiplication in the screenhouses is predominantly done using the conventional soil substrate method. The conventional soil substrate media is composed of forest top soil, cow manure, and gravel in the ratio of 5:2:1, which is sterilized in a steam boiler for 30 min at 82°C using diesel as the source of energy. However, Makokha et al. (2020) have shown that multiplication of pre-basic seed using this method is costly, is unsustainable, and does not achieve optimal yields.

Findings from research have shown that the sandponics system is a better alternative to the conventional soil substrate method for pre-basic seed multiplication in the screenhouses. This method involves the use of sterilized sand media with a fertigation system to multiply sweetpotato planting materials. Further, multiplication of sweetpotato planting materials using the sandponics system is cost-effective and increased VMR. However, while there is evidence for increased VMR and cost-effectiveness of multiplying planting materials using the sandponics system, there is limited knowledge about the field establishment and agronomic performance of sweetpotato genotypes with planting materials sourced from a sandponics system. Given that the sandponics system is an emerging innovation for multiplication of sweetpotato pre-basic seed in the screenhouses, it would be important to understand the quality of planting materials produced using this technology when grown in the field considering sweetpotato growth-related attributes and yield. Therefore, this study was designed to investigate the effect of methods of multiplying planting materials (sandponics system and conventional soil substrate method) and genotype on sweetpotato yield and growth-related traits when grown in the field.

2 Materials and methods

The trial was conducted between September 2018 and December 2018 at the Kenya Agricultural and Livestock

Table 1: Meteorological data for KALRO, Kiboko, research station during September–December 2018

2018	Total rainfall (mm)	Mean temperature ($^\circ\text{C}$)	Relative humidity (%)
September	7.0	23.0	79.5
October	45.0	23.9	82.6
November	171.0	24.7	82.5
December	323.5	24.0	85.2

Research Organization (KALRO), Kiboko, Kenya, located at latitude $010^\circ 15' \text{ S}$, longitude $360^\circ 44' \text{ E}$, and an altitude of 975 masl with a mean annual rainfall of 587 mm. Table 1 shows the meteorological data during the trial season. KALRO-Kiboko research station is situated in one of the locations representing the major sweetpotato-growing areas in Kenya as described by Jaetzold and Schmidt (1983). A soil sample was collected from the site and taken to Crop Nutrition Laboratories, Kenya, for analysis to determine the nutrient composition of the field. Some soil chemical and physical properties of the soil profile are given in Table 2.

The experiment was conducted with four sweetpotato genotypes: Irene, Kabode, Ejumula, and Gweri, which were selected based on their growth morphology as described by Tumwegamire et al. (2014) as erect, semi-erect, spreading, and extremely spreading, respectively. The experimental design consisted of a replicated ($n = 3$) randomized complete block design with two sources of planting materials (sandponics system and conventional soil substrate method) in two blocks. Ridges of 1 m width and 60 cm height were prepared. Vine cuttings of about 20–30 cm length harvested in the sandponics system and the conventional soil substrate method growing in a screenhouse under the same roof were used. The cuttings were from the first harvest crop aged 1.5 months. During planting, cuttings were spaced at 0.3 m (within row) and 1 m (between rows) in two-row plots each row planted with 12 plants in plots of $3.3 \times 1 \text{ m}$ giving a total of 33,333 plants ha^{-1} . Two-thirds of the vine was buried in the soil at planting. Weeding was done manually until the crop had enough ground foliage cover to smother the weeds. Earthing up was done during weeding to cover any soil cracks through which roots could be exposed and susceptible to weevil damage. The crop was irrigated three to four times per week using a $12 \times 12 \text{ m}$ grid overhead sprinkler system with three main sprinkler lines until 4 weeks after planting. At approximate full ground cover, the irrigation was reduced to one to two times per week for a period of 4 months until harvest. The crop was sprayed

Table 2: Chemical and physical soil properties for the experimental farm of KALRO-Kiboko research station

Sampling depth (m)	pH	Organic C (%)	C.E.C (Meq/100q)	EC (salts) ($\mu\text{S}/\text{cm}$)	Total N (%)	C/N ratio	Available P Olsen (ppm)	Exchangeable cations (ppm)			Sulfur (ppm)	Boron (ppm)	Iron (ppm)	Copper (ppm)	Manganese (ppm)	Zinc (ppm)
								Ca	Mg	K						
0.3	7.9	2.9	16.0	237	0.15	11.1	41.9	1920	449	450	106	1.39	57.7	2.44	154	23.3
Description	High	Low	Optimum	Optimum	Low	Optimum	Optimum	Optimum	High	Optimum	Optimum	Optimum	Optimum	Optimum	Optimum	High

Soil analysis results and descriptions based on Crop Nutrition Laboratories, Nairobi, Kenya.

with alternating insecticides at 2-week intervals to control sweetpotato virus vectors until harvesting time.

3 Data collection and analysis

Pre-harvest and harvest data were collected on various growth- and yield-related parameters as described by Grüneberg *et al.* (2010) and later adapted by Agili (2012) as follows: number of plants planted per plot (NOPS) and number of plants established (NOPE) per plot were determined 3 weeks after planting and data were used to compute vine survival (SHI) using the formula $\text{SHI} = \text{NOPE} / \text{NOPS}$. For each plot during harvesting, inner plants (excluding end plants) for the two rows formed the net plot area; the weight of commercial storage roots (CRW) per net plot was calculated as $\text{CRW} \times 10 / \text{net plot area m}^2$; the weight of non-commercial storage roots (NCRW) was calculated as $\text{NCRW} \times 10 / \text{net plot area m}^2$; the yield of total storage roots per hectare (RYTha) was calculated as $\text{RYTha} = (\text{CRW} + \text{NCRW}) \times 10 / \text{net plot area m}^2$; the vine yield in tonnes per hectare (VYLDha) was computed as $\text{VYLDha} = \text{VYLD} \times 10 / \text{net plot area m}^2$; the harvest index (HI) was calculated using the formula $\text{CRW} + \text{NCRW} / \text{CRW} + \text{NCRW} + \text{VW}$, i.e. (total storage root weight/total storage root weight + vine weight), and dry matter content where ten storage root samples per net plot were used in the determination of dry matter content. The middle portions of the fresh roots were cut into chips, and samples weighing 250 g placed in Mafuco paper bags and dried in an oven at 70°C until a constant dry weight was achieved. This weight was then recorded, and from it, the percent dry matter content was determined using the formula $\text{DMC} = (\text{DMF} / \text{DMD}) \times 100$, where DMC = dry matter content, DMF = dry matter fresh, and DMD = dry matter dry. Preparation of samples for DMC determination was done within 24 hours of harvesting storage roots.

Parametric statistics were used to analyze the measured agronomic traits using general linear model procedures in the Statistical Analysis Software, version 9.4 (SAS Institute Inc., 2013). The mean values of treatments were compared using least significant differences (LSD) at $p \leq 0.05$ probability confidence.

4 Results

The analysis of variance (Table 3) showed that the system used to multiply planting materials (seed source)

significantly affected vine survival, storage root yield, number of storage roots per plant, vine yield, and dry matter content. Consequently, the mean vine survival, storage root yield, number of roots per plant, and vine yield were higher by 4.1%, 24%, 27%, and 24%, respectively, when the planting materials were sourced from the sandponics system (Table 4). However, the dry matter content was higher by 0.5% in favor of planting materials sourced from the conventional soil substrate method.

Also, the results showed significant ($p \leq 0.05$) variations for storage root yield, non-commercial storage root yield, vine yield, HI, and dry matter content among genotypes. Our data further showed that genotypes Kabode and Ejumula had the highest storage root yield (36.2 t ha^{-1} and 32.2 t ha^{-1} , respectively) and HI (76.8% and 74.5%, respectively), while genotype Gweri had the lowest storage root yield and HI of 22.6 t ha^{-1} and 53.7%, respectively (Table 5). Therefore, among the four genotypes, Kabode possesses the highest source potential, while genotype Gweri has the least source potential.

These results further showed a higher storage root yield and vine yield for genotype Irene which had a nonsignificant difference in vine yield ($p > 0.05$) of 18.2 t ha^{-1} compared to 19.3 t ha^{-1} for genotype Gweri, but still recorded a significantly ($p \leq 0.05$) higher storage root yield (28.2 t ha^{-1}) than Gweri (22.6 t ha^{-1}). In brief, the storage root yield for genotype Irene was not significantly ($p > 0.05$) different from genotype Ejumula ($32.2 \text{ t ha}^{-1}/36.2 \text{ t ha}^{-1}$, respectively). However, regardless of the high vine yield by genotype Irene, which was not significantly different ($p > 0.05$) to genotype Gweri, Irene recorded a significantly ($p \leq 0.05$) higher HI (60.9%) than genotype Gweri (53.7%), which is also reflected in the significant reduction in non-commercial storage roots for genotype Irene (5.7 t ha^{-1}) compared to Gweri (10.0 t ha^{-1}).

Considering vine yield, genotypes Gweri and Irene recorded the highest yield of 19.3 t ha^{-1} and 18.2 t ha^{-1} , respectively. Additionally, genotypes Gweri and Ejumula had the highest non-commercial storage root yield (10.0% and 7.6%, respectively) and dry matter content (30.3% and 29.9%, respectively), while genotype Kabode had the lowest dry matter content (22.9%). These results further demonstrated that growth morphology of genotypes as erect, semi-erect, spreading, or extremely spreading influences storage root yield, non-commercial storage root yield, vine yield, HI, and dry matter content (Table 5). Genotype Gweri recorded the highest dry matter content attributed to its bushy growth morphology with high leaf area.

The interaction of the effect of method used to multiply planting materials with genotype was significant

Table 3: Mean squares for sweetpotato traits with planting materials sourced from sandponics system and conventional soil substrate method

Source of variation	DF	Vine survival (%)	Total storage root yield (t ha^{-1})	Commercial storage roots (%)	Non-commercial storage roots (%)	No. of storage roots/plant	Vine yield (t ha^{-1})	Harvest index (%)	Dry matter content (%)
Seed source (SS)	1	207.9**	605.6**	171.8 ^{ns}	0.6 ^{ns}	6.7**	151.2*	0.4 ^{ns}	3.4*
Genotype (GEN)	3	31.0 ^{ns}	403.6**	95.4 ^{ns}	61.9**	0.6 ^{ns}	234.0**	1464.9**	157.2**
SS × GEN	3	22.2 ^{ns}	113.2 ^{ns}	56.9 ^{ns}	11.8 ^{ns}	0.2	36.0 ^{ns}	67.5**	1.7 ^{ns}
Error	40	20.8	63.0	89.8	12.9	0.2	21.8	13.5	0.7

^{ns}Non significant, *significant at $p \leq 0.05$, **significant at $p \leq 0.01$.

Table 4: Mean values for vine survival, storage root yield, number of storage roots per plant, vine yield, and dry matter content as affected by source of planting materials

Source of planting materials	Vine survival (%)	Storage root yield (t ha ⁻¹)	No. of storage roots/plant	Vine yield (t ha ⁻¹)	Dry matter content (%)
Sandponics system	98.4 ^a	33.4 ^a	3.4 ^a	16.8 ^a	26.8 ^b
Conventional soil substrate	94.3 ^b	26.3 ^b	2.6 ^b	13.2 ^b	27.3 ^a
<i>p</i> value	0.003	0.004	<0.0001	0.01	0.03
LSD (5%)	2.7	4.6	0.3	2.7	0.5

In each category and trait, mean values with different letters in the same column are significantly different at $p \leq 0.05$.

Table 5: Mean comparison for measured sweetpotato traits for the genotypes

Genotypes	Storage root yield (t ha ⁻¹)	Non-commercial storage root yield (%)	Vine yield (t ha ⁻¹)	Harvest index (%)	Dry matter content (%)
Irene	28.2 ^{bc}	5.7 ^b	18.2 ^a	60.9 ^b	25.1 ^b
Kabode	36.2 ^a	4.9 ^b	11.1 ^b	76.8 ^a	22.9 ^c
Ejumula	32.2 ^{ba}	7.6 ^{ba}	11.3 ^b	74.5 ^a	29.9 ^a
Gweri	22.6 ^c	10.0 ^a	19.3 ^a	53.7 ^c	30.3 ^a
<i>p</i> value	0.001	0.006	<0.0001	<0.0001	<0.0001
LSD (5%)	6.5	7.8	3.8	3.0	0.7

For each trait, mean values with different letters in the same column are significantly different at $p \leq 0.05$.

for HI. This implies that the HI of genotypes is affected differently by the method of multiplying planting materials. Comparison of genotype performance with planting materials sourced from the two seed multiplication methods using the *t*-test procedure indicated that only genotype Gweri had a significant difference for HI (Table 6), while other measured growth parameters were not significant ($p > 0.05$).

5 Discussion

The superior field performance of planting materials sourced from the sandponics system compared to the conventional soil substrate planting materials considering

vine survival, total storage root yield, number of storage roots per plant, and vine yield could be attributed to the higher residual nutrients in planting materials multiplied by the sandponics system as reported by Makokha *et al.* (2020). This indicates that field establishment and growth of plants benefit from the residual effects of the system used for the multiplication of planting materials. This could have an implication in the pricing and business model for commercializing pre-basic seed produced by the sandponics system.

Research has shown that vine survival as a trait is particularly important in drought-prone areas as genotypes with this trait will “maintain” themselves and spread easily among farmers (Agili 2012; McEwan 2016). Apparently, the increased vine survival in sandponics-sourced vines translated to optimal planting density

Table 6: Mean comparison of HI due to the effect of interaction between seed source and genotype

Sweetpotato trait	Genotype	Seed source		<i>t</i>	<i>P</i>
		Sandponics system	Conventional soil substrate		
HI	Irene	58.7 ± 6.3	63.3 ± 1.6	−1.4	0.2
	Kabode	77.1 ± 1.7	76.4 ± 1.0	0.7	0.5
	Ejumula	73.7 ± 2.2	75.6 ± 1.9	−1.2	0.3
	Gweri	56.7 ± 1.9	50.6 ± 4.6	2.5	0.05

which statistically increased the total storage root yield and vine yield per hectare agreeing with the findings of Oswald et al. (1994).

The higher mean storage root yield and HI for genotypes Kabode and Irene could be strongly based on the positive relationship between the potential of leaves to export photosynthates and photosynthetic efficiency of leaves also referred to as “source potential” and the sink capacity. Moreover, dry matter partitioning to storage roots and other parts of the plant is said to be simulated basically on the concept of the source potential and the sink capacity (Ravi et al. 2009; Mbah and Eke-Okoro 2015). The reduced partitioning of food reserves to the storage roots is reflected in the increased percentage of non-commercial storage roots (10%) for genotype Gweri. Furthermore, other studies on sweetpotato physiology showed that an excessive shoot growth consumes a greater amount of photoassimilates and does not favor storage root growth (Ravi and Saravanan 2012).

The higher storage root yield and vine yield for genotype Irene show that there is a positive correlation between vine yield and storage root yield, although varietal dependent, confirming the findings of Mukhopadhyay et al. (1992) in their study on the effect of potassium on growth and yield of sweetpotato.

The significant variations in dry matter content among genotypes could be due to differences in genetic formation which influenced the strength of their biomass production and the partitioning of photosynthates. Similar results were echoed by Mbah and Eke-Okoro (2015) in their studies on the relationship between some growth parameters, dry matter content, and yield of some sweetpotato genotypes grown under rainfed weathered Ultisols in the humid tropics. These findings further concur with those of Rukundo et al. (2013) who reported that significant differences in dry matter content of sweetpotato genotypes could be attributed strongly to marked differences in genetic makeup and potentials of the individual genotypes. Agili (2012) and later McEwan (2016) reported that genotypes with high leaf area possess high dry matter content.

The differences in the HI could have been as a result of the varying growth habits (Tumwegamire et al. 2014) exhibited by the four genotypes and their response to the method of multiplying planting materials.

These results conclude that the combination of enhancing both the total biological yield and the commercial yield of sweetpotato genotypes, the sandponics system allots pre-basic seed production a higher value. This study also demonstrated that there is no loss in quality of planting materials multiplied by the sandponics system;

however, it would be important to know the VMR of basic seed in the protected structures and open field relied upon by commercial vine multipliers as well as VMR of certified seed when planting materials are sourced from the sandponics system. In summary, planting materials multiplied by the sandponics system have higher yield potential than planting materials multiplied by the conventional soil substrate method when grown in the field. Therefore, sandponics system is a technically viable alternative for pre-basic seed generation.

Conflict of interest: The authors declare no conflict of interest.

Acknowledgements: This study was undertaken as part of the CGIAR Research Program on Roots, Tubers and Bananas (RTB) funded by the Sweetpotato Action for Security and Health in Africa (SASHA) phase II project implemented by the International Potato Center (CIP). The authors thank Kenya Plant Health Inspectorate Service – Plant Quarantine and Biosecurity Station (KEPHIS-PQBS), Muguga, Kenya, and Kenya Agricultural and Livestock Research Organization (KALRO), Kiboko, Kenya, for providing infrastructure facilities for this research.

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