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Performance of five potato varieties with regards to growth and production of mini-tubers under an aeroponic system in central highlands of Kenya

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There is limited information on the performance of Kenyan potato varieties under aeroponic systems. Experiments were therefore carried out at the Kenya Agricultural Research Institute (KARI), Tigoni, under an aeroponic system in 2012 and 2013 to evaluate the growth and mini-tubers production of five varieties commonly grown in Kenya and differ in vegetative and reproductive characteristics. The experiment was set up in a randomized complete block design (RCBD) replicated three times. Plant growth expressed by plant height differed among the varieties and these differences became more pronounced with plant age. The effect of variety on number of mini-tubers per plant and total weight of mini-tubers per plant was significant. The number of mini-tubers per plant ranged from 62.2 to 19.2 in season 1 and 56.8 and 17.1 in season 2. Correlations between the number of mini-tubers per plant and the total weight of mini-tubers per plant with days to tuberization, days to senescing, days to maturity, plant height measured at 80 days after transplanting and plant vigor, were positive and significant. The correlation between the number of mini-tubers per plant and total weight of mini-tubers per plant was also positive and significant. It is concluded that mini-tubers production under aeroponic system was variety dependent with Tigoni, Asante and Kenya Mpya being the most productive varieties irrespective of the season. Evaluation of a variety's suitability/adaptability to the system is therefore necessary to determine the most adapted varieties before embarking on large scale production as this will ultimately affect production costs, with higher yielding varieties more likely to result in lower mini-tubers production costs.

Key words: Aeroponics, mini-tuber production, vegetative growth.

INTRODUCTION

Potato is an important food security and cash crop in Kenya (Kaguongo et al., 2013). However, scarcity of quality seed is a perennial problem and a major hindrance to improvement of potato production in the country (MoA, 2009; MoALF, 2016). To boost production of seed, various strategies have been put in place including introduction of a mini-tubers production step during the early stages of commercial seed multiplication.

Mini-tubers have the combined advantages of *in vitro* plantlets (disease-free, rapid and year-round production) and tubers (easy storage and transport) and lack some of the disadvantages of *in vitro* tubers (low multiplication rate, small size and poor recovery from environmental stresses). The mini-tubers production phase should ideally generate a large number of mini-tubers so as to contribute not only to quicker bulking of seed and reduced exposure to diseases but also to reduce seed costs.

Methods of mini-tubers production include, high density cultures with non-destructive harvests (Lommen and Struik, 1992), hydroponic systems using different inert substrates, deep water culture systems (Chang et al., 2000; Lommen, 2007), the Nutrient Film Technique (NFT) system (Wheeler et al., 1990; Medeiros et al., 2002) and hydroponic systems with recirculating nutrient solutions in low volume substrates (Struik and Wiersema, 1999). Mini-tubers can also be produced in greenhouses in beds (Wiersema et al., 1987; Tierno et al., 2014) or in containers using different substrate mixtures (Struik and Wiersema, 1999).

Conventional substrate-based methods for pre-basic mini-tuber seed production usually have low productivity with a low average multiplication rates depending on the type of mother plant used and type of production system which contributes to increasing the production costs of a seed potato production program. Substrate based methods also have the inherent risk of infection from soil borne diseases and require sterilization which can be costly. The NFT system can suffer from deficient O_2 concentrations due to consumption by roots and microorganisms (Gislerod and Kempton, 1983), while deep-water culture systems can be prone to inadequate aeration to the root system (Jackson, 1980; Lommen, 2007).

To improve the efficiency of mini-tubers production newer technologies such as aeroponics have been introduced and are currently being promoted as one of the solutions for rapid and efficient production of mini-tubers (Otazu, 2010; Lung'aho et al., 2010; Muthoni et al., 2011; and Mbiyu et al., 2013). The advantages of aeroponics include optimization of root aeration resulting in a high yield of mini-tubers as compared to hydroponics (Soffer and Burger, 1988); limited water use, nutrient recirculation, and good monitoring of nutrients and pH (Otazu, 2010). Multiplication rates in aeroponics systems are reported to be significantly higher than those obtained in conventional systems (Ritter et al., 2001; Farran and Mingo-Castel, 2006; Teirno et al., 2014). The technology has the potential of reducing at least one generation of seed multiplication in the field, with lower costs and maintains high phytosanitary quality (Nichols, 2005). Production of mini-tubers can be increased and production costs lowered using aeroponics (Scherwinski-Pereira et al., 2009). Aeroponic systems have also been reported to have high production efficiency per unit area (> 900 mini-tubers m^{-2}) (Mateus-Rodriguez et al., 2013); (1268 to 1396 mini-tubers s m^{-2}) (Rykaczewska, 2016).

Despite the many advantages of the technology, there is little information on the comparative performance of different varieties under aeroponics production systems in Kenya. This study was therefore, undertaken with the objective of evaluating the performance of growth and production of mini-tubers of five varieties commonly grown in Kenya under an aeroponic production system.

MATERIALS AND METHODS

Study period and location of the experiments

This study was carried out during two growing seasons (season one: March to September, 2012 and season two: October, 2012 to April, 2013) at Kenya Agricultural Research Institute - Tigoni (KARI-Tigoni), located 10°8'S and 36°40'E, at an altitude of 2100 m, 4 km South East of Limuru town in Kiambu County of Kenya.

Preparation of planting materials

In vitro plantlets of 5 varieties (Tigoni, Asante, Dutch Robijn, Desiree and Kenya Mpya) differing in vegetative and reproductive characteristics were used for the experiments (Table 1). The plantlets had been previously initiated through meristem and shoot tip culture from plants that had been certified as disease free. The plantlets were then routinely sub-cultured every 3 to 4 weeks on normal propagation media with agar as the gelling agent (Espinoza et al., 1992) in Kilner jars using nodal cuttings in order to attain sufficient quantities for the experiments. The cultures were then incubated for 3 weeks in a growth room with temperatures of 22 ± 2°C, a 16-h photoperiod and a light intensity of 3,000 lux provided by Philips T12 'cool white' fluorescent tubes. The plantlets were then transplanted to crates containing sand under screen house conditions and regularly fertigated with ½ strength aeroponic nutrient solution (Table 2). When the plantlets were 14 days old, they were carefully transplanted into the aeroponics unit. At this time, the plantlets were approximately 10-15 cm tall with a root length of about 2.5 to 5.0 cm.

Description of the aeroponics system

The design of the aeroponic system was as described by Otazu (2010) but with some modifications. The aeroponic system consisted of an insect proof screen house measuring 9.4 m x 8.4 m and covered with clear sheets and a shade net on stop of the roof to lower the temperatures. The aeroponic boxes measured 6.4 m length x 1.5 m width x 0.95 m depth. The boxes were insulated with styrofoam to prevent developing roots from being affected by temperature variations in the screen house. The boxes had side

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Table 1. [1]Main characteristics of varieties used in the study.

Variety	Pedigree	Genetic gain in pedigree	Plant characteristics	Days to maturity
Tigoni (391391.13)	378493.15 × bk precoz	Andigena	Vigourous upright growing plants, can grow upto 1 m	120
Asante (391391.20)	378493.15 × bk precoz	Andigena	Vigourous plants upright growing plant, can grow upto 1 m	110
Desiree	Urgenta × Despesche	Tuberosum	Relatively short plants.	90
Dutch Robjin	Rode Star × Preferent	Tuberosum	Relatively short plants	100
Kenya Mpya (393371.58)	387170.16 × 387170.9	Andigena	Vigourous plants, can grow up to I metre	130

[1]Under field conditions in Kenya; Source: Onditi et al. (2013); NPCK (2013).

Table 2. Composition of 500-L full strength nutrient solution used in the study for mini-tubers production.

Nutrient	Quantity (g)	
	Half strength	Full strength
KNO3	126	252 g
$Ca(NO3)_2$	59	118 g
KH_2PO_4	34	68 g
$MgSO_4$	123	246 g
Fe(EDTA- Fe 6%)	4.5	9 g
[1]Microsol B	6	12 g

[1]The formulation of Microsol B is: Fe (5.0%), Cu (2.5%), Zn (1.0%), B (2.5%), Mo (0.035%) and Mn (2.5%); [2]Mention of a trade name does not constitute an endorsement or recommendation; [3]pH of the nutrient solution was maintained at 5.7

windows to permit harvesting of mini-tubers and monitoring of the growth of plants and the proper functioning of nebulizers. The inside of the boxes was lined with black plastic to prevent exposure of the root system of the plant to light. The internal bottom (floor) of the boxes was also lined with thick plastic (1 mm) to avoid leakage of nutrients. The external top lining was white plastic, so as to minimize accumulation of heat and also permit greater illumination of the growing plants. The internal lining of the top covers of the boxes was also lined with thin plastic cover. A similar thin black plastic was used to cover the windows of the boxes as double curtains. The internal curtain prevented nebulized nutrient solution from escaping from the boxes, while the external curtain prevented the entry of light into the boxes. The boxes were slanted towards the nutrient tank to allow excess nutrients to return back into the tank by gravity. To facilitate this, the nutrient tank was installed below ground level so that the lower part of each box was above the upper portion of the tanks.

The fertigation system consisted of an underground plastic tank (1000 L) in which the nutrient solution was stored/held for circulation though the closed system. The nutrient solution (Table 1) was pumped into growth chambers (boxes) using a system of pipes and nebulizers. The nebulizers in the boxes were spaced every 60 cm. The fertigation system was controlled by a timer and mists of nutrient solution were sprayed onto the growing roots for 5 min after every 15 min during the day and 5 min after every 45 min at night throughout the experiment This system was powered by electricity, but a generator was used in case of electricity failure. Measurements and corrections of the pH and electrical conductivity (EC) for the nutrient solution were done weekly. The pH was maintained in a range of 5.5 to 6.5 and the EC between 1.5 and 2.0 d Sm^{-1}. Fresh nutrient solution was prepared every month.

The lids of the growth chambers/boxes had small holes (25 mm diameter) through which a plastic pipe (25 mm in dimeter and 70 mm in length) was inserted such that it was flush with the lid of the growth chambers. The plantlets were then placed in the pipes (one plant in each pipe) with the roots hanging inside the box such that nutrients would reach the roots when applied. The upper part of the plantlet (approximately 3-8 cm) was left protruding above the pipe to ensure that the plant was able to photosynthesize. The plantlets were held firmly in an upright position using masking tape. The masking tape also served as a light blocker as it was used to cover each hole thus preventing light from penetrating into the box. The lowest leaf of the plant was cut off every 2 weeks for the next 2 months. This allowed the plants to be pushed deeper down into the growth chamber (equivalent to hilling in conventional potato production) to promote stolon development, this was done once a week for only 4 weeks after transplanting. As the plants grew, they were trained using a nylon trellises and tied with nylon for support.

Experimental design and data collection

The experiment was set up as a randomized complete block design (RCBD) replicated 3 times. Transplants of each of the 5 varieties were placed in an aeroponic box at 17 x 18 cm resulting in a plant density of 32 plants m^{-2}. Each box represented an experimental unit. Data on plant height was taken starting at 30 days after transplanting (DATP) into the aeroponic unit and thereafter at 10-day intervals until the earliest maturing variety started to senesce. A total of 6 measurements were made. Tubers were harvested sequentially starting at 40 days after transplanting, depending on the variety and thereafter every 10 days. The harvest criterion was to remove all tubers which were larger than 15 mm in diameter except during the final harvest when all tubers were removed from the plant regardless of size. During each harvest, the mini-tubers were graded into three sizes: size I (≤5 g), size II (5.1-12 g), and size III (12.1-20 g). The number of tubers in each size group and their weights was then recorded. The average number of mini-tubers s per harvest was computed by dividing the total number of mini-tubers harvested by the number of harvests per variety in a season. Plant vigor was recorded at 60 DATP on a five point scale where, a score of 1 signified a variety least vigorous, 3 signified a variety vigorous and 5 signified a variety very vigorous. Plants were considered to have senesced when 90% of the leaves turned yellow. Standard practices for control of diseases and pests were carried out during the experiment.

Data analysis

Data for each season was analyzed separately. Differences between varieties were determined by analysis of variance (ANOVA) procedures for a randomized complete block design experiment using GenStat 12th edition statistical software (GenStat, 2009) at $p \leq 0.05$. When F values were significant, treatment means were compared using Fischer's protected least significant differences (LSD) test at $p \leq 0.05$. The relationship between mini-tubers yield variables was determined using correlation analysis.

RESULTS

Plant height and vigor

The effect of variety on plant height was significant for all plant heights measured between 30 and 80 DATP in both seasons (Figure 1). At 80 DATP, varieties Tigoni and Asante were significantly taller than the other varieties during both seasons. During the same period, variety Tigoni was almost twice as tall as variety Desiree. Plants tended to be taller in season 2 than in season 1. The difference in plant height between the tallest and the shortest variety became more pronounced with time. For example at 30 DATP, the difference was 6 cm in season 1 and 10.1 in season 2. However, at 70 DATP, the difference was 37 cm in season 1 and 43 cm in season 2. During both seasons, the varieties Tigoni, Asante and Kenya Mpya were rated as very vigorous with high amounts of plant foliage whereas Dutch Robjin and Desiree were rated as vigorous with moderate amounts of foliage.

Days to tuberization, senescing and maturity

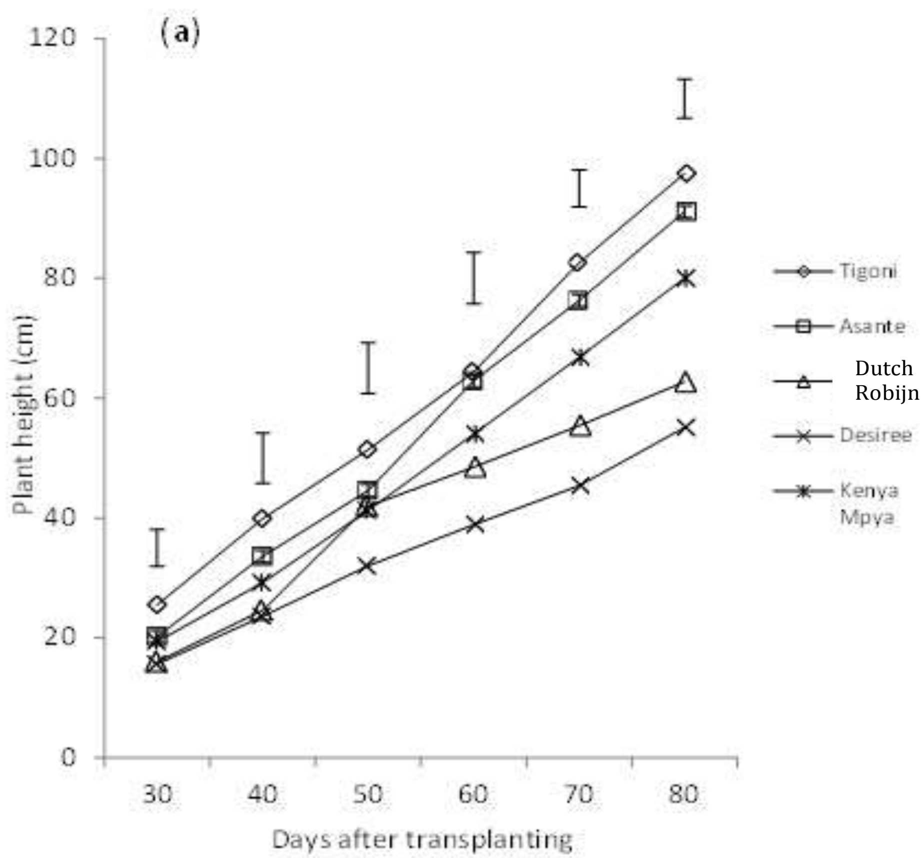
The number of days to tuberization were shorter in season 1 than in season 2 whereas, days to senescing and maturity were longer during season 1 as compared to season 2 (Table 3). The difference in days to tuberization during the first and second season was observed in all the 5 varieties but was more pronounced in varieties Tigoni, Asante and Kenya Mpya which had at least a 9 day difference in days to tuberization between the 2 seasons. Variety Desiree took the least number of days to tuberize by about 1-7 days in season 1, and 3-14 days in season 2 as compared to the other varieties. The varieties senesced in between 102.7-168.0 days after transplanting, in season 1 and in between 94.7 -153.0 days in season 2. On average, all varieties matured about 14 days after they started to senesce. Variety Kenya Mpya showed the longest maturity period of 180.3 days during season 2 and 190.3 days during season 1. In contrast, variety Desiree showed the earliest crop maturity of 109.3 days after transplanting in season 2 and 116.3 days after transplanting in season 1.

Number of mini-tubers harvests per season, mini-tubers per plant and mini-tubers > 5 g per plant

The varieties showed variability in the number of mini-tubers harvests per production season (Figure 2). All the varieties had 2 less harvests during the second season as compared to the first season. In season 1, the number of harvests per variety ranged from 9 to 15, while in season 2, it ranged from 7 to 13. Varieties Desiree and Dutch Robijn had the lowest number of mini-tubers harvests in both seasons. The number of mini-tubers harvested was generally low during the first harvest but increased with each harvest, peaking at the 5-7th harvest depending on the variety and season. Thereafter, the number of mini-tubers harvested gradually declined until the last but one harvest and increased again at the final harvest. For all the varieties, the number of mini-tubers harvested at the final harvest was greater than that harvested in each of the previous harvests and ranged from 3.8 to 10.2 mini-tubers per plant in season 1 and 4.2 and 10.6 mini-tubers s per plant in season 2.

Figure 3 shows that number of mini-tubers per plant was higher in season 1 than season 2 for all varieties with a difference that ranged from 2.1 (Desiree) to 7.4 (Asante) mini-tubers per plant. Varieties Tigoni and Asante had the highest number of mini-tubers per plant, at 62.2 and 51.3, respectively during season 1 and 56.8 and 43.9, respectively, in season 2. Desiree performed poorly with less than 20 mini-tubers per plant in both seasons. The number of mini-tubers per plant of variety Tigoni was more than 3 times that of variety Desiree in both seasons.

Figure 4 shows that the effect of variety on the number of mini-tubers >5 g was significant in both seasons. The number of mini-tubers >5 g varied between 15.9 and 53.8 mini-tubers per plant in season 1 and between 13.3 and 50.5 mini-tubers per plant in season 2. Varieties Tigoni, Asante and Kenya Mpya significantly out yielded the



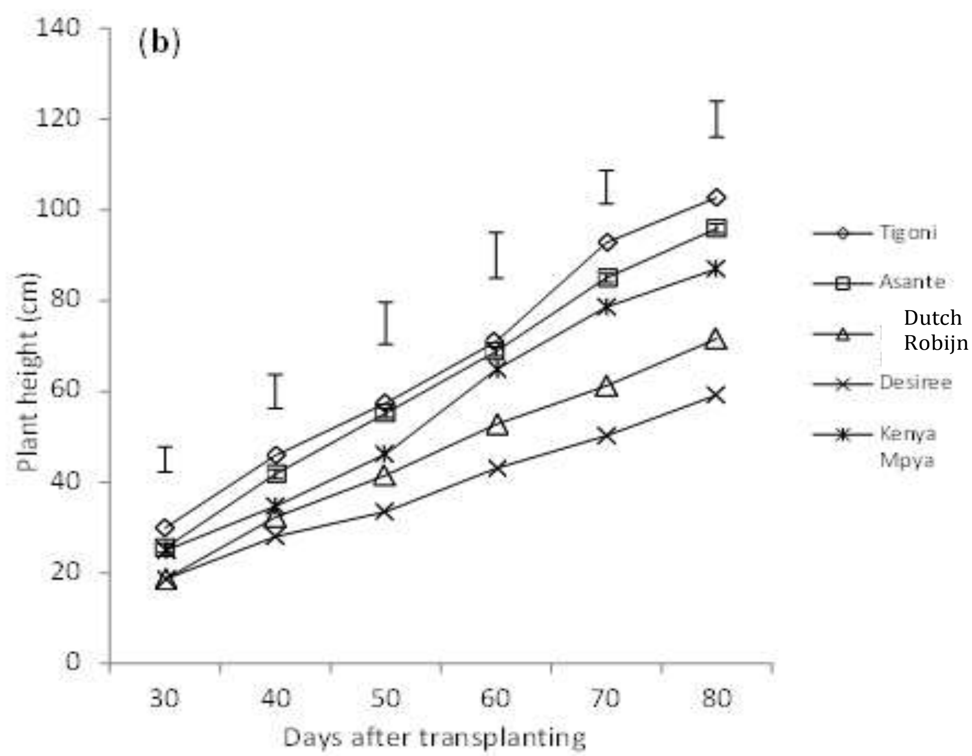
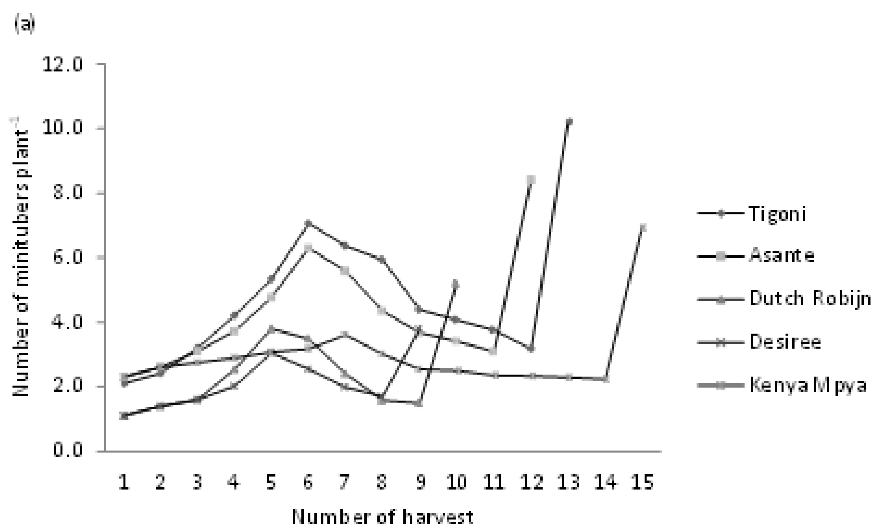


Figure 1. Plant height (cm) during the first 80 DAP of five varieties planted in season 1 (a) and season 2 (b).

Table 3. Effect of variety on days to tuber induction, days to senescing and day to maturity.

Variety	Days to tuberization		Days to senescence		Days to maturity	
	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
Tigoni	43.4	34.4	160.0	151.3	174.7	165.3
Asante	40.6	31.3	140.7	133.3	157.7	150.3
Dutch Robjin	35.1	28.3	113.0	106.0	130.3	120.7
Kenya Mpya	46.4	35.5	168.0	153.0	190.3	180.3
Desiree	32.0	27.5	102.7	94.7	116.3	109.3
Mean	39.5	31.4	136.9	127.7	153.9	145.2
LSD (p=0.05)	2.5	2.4	7.1	5.2	4.6	5.0
CV (%)	3.4	4.0	2.7	2.1	1.6	1.8

[1]Average of 10 plants.



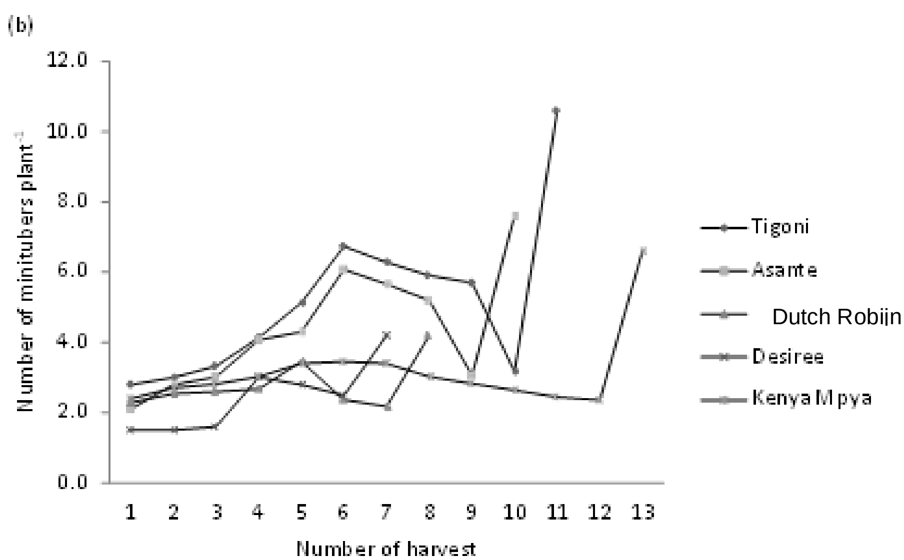


Figure 2. Number and distribution of minitubers during each harvests in season 1 (a) and season 2 (b).

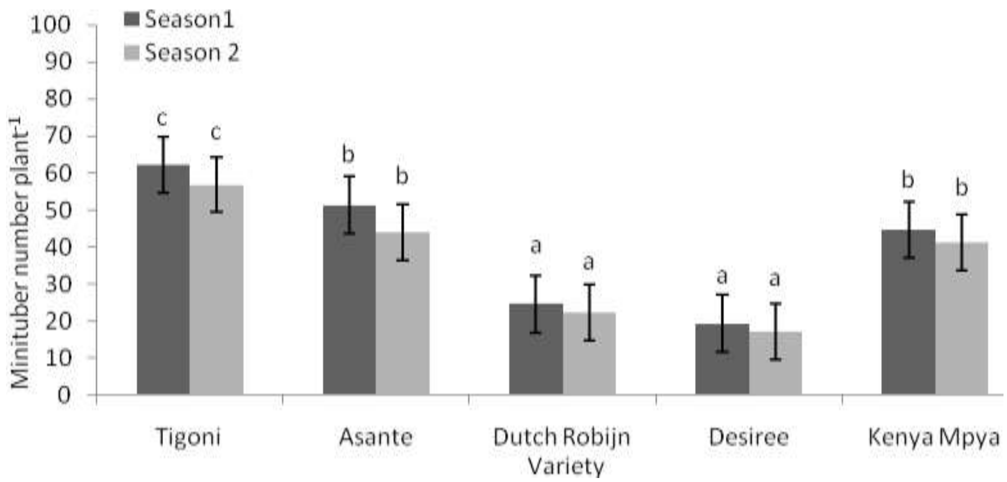


Figure 3. Effect of variety on minituber production. Error bars show LSD values.

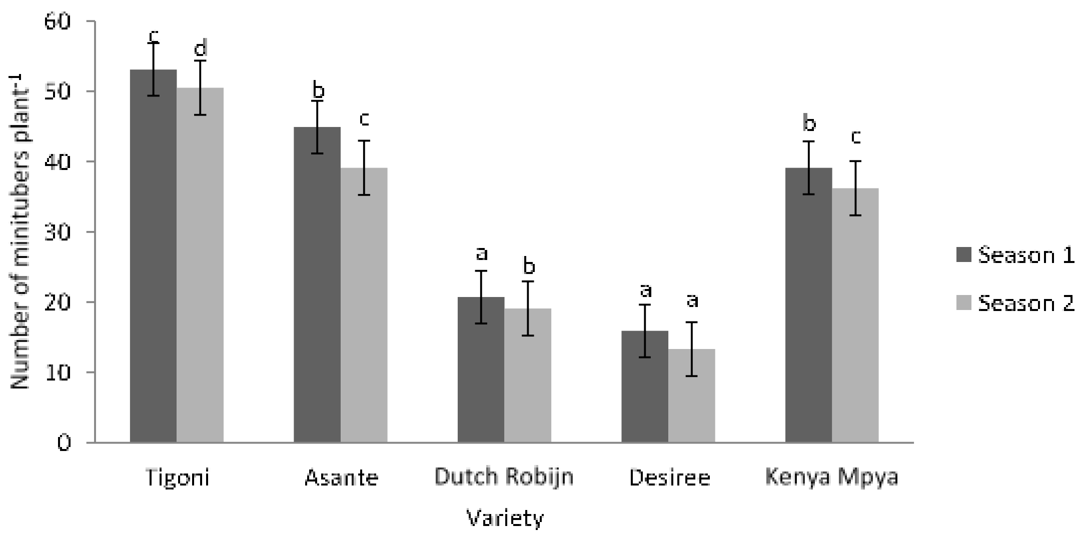


Figure 4. Effect of variety on number of minitubers >5 g. Error bars show LSD values.

other varieties during both seasons. The effect of varieties on the proportion of number of mini-tubers >5 g relative to the total number of mini-tubers produced by a variety was however, not significant in both seasons and varied from 83.7 to 88.1% in season 1 and from 78.0 to 89.4% in season 2.

Average number of mini-tubers s per harvest, weight of total yields and graded yields and average mini-tubers tuber weight

Varieties Tigoni and Asante had the highest number of mini-tubers per harvest in both seasons (Table 4). Variety Tigoni had an average of 4.8 mini-tubers per harvest and 5.2 mini-tubers per harvest in seasons 1 and 2, respectively while Asante had an average of 4.3 mini-tubers per harvest in season 1 and 4.4 mini-tubers per harvest in season 2.

Figure 5 shows that the average mini-tubers weight was significant among the varieties in season 1 but not season 2 and ranged between 7.8 and 9.9 g in season 1 and from 7.4 and 8.8 g in season 2. Total weight of mini-tubers per plant varied across the varieties (Figure 6). The highest yielders were varieties Tigoni and Asante with total mini-tubers yields of 537.7 and 396.7 g per plant, respectively in season 1 and 492.9 and 345.6 g per plant, respectively in season two. Between 83.8 and 88.3% of the mini-tubers yield in season 1 was greater than 5 g, while in season 2, the range was 78.0 and 89.4% (Figure 7). For all the varieties, the largest graded weight of the mini-tubers was size II (5-12 g). The

Table 4. Number and distribution of mini-tubers during each harvest in five cultivars grown during seasons 1 and 2.

Harvesting period (at 10-day intervals) DATP	Season 1					Season 2				
	Tigoni	Asante	Dutch Robjin	Desiree	Kenya Mpya	Tigoni	Asante	Dutch Robjin	Desiree	Kenya Mpya
40		73.5	35.2	35.2					48.0	
50	67.2	83.6	44.8	44.8	73.6		67.2	73.2	48.0	
60	77.2	99.2	51.2	51.2	83.6	89.6	89.6	81.2	51.2	76.8
70	102.4	119.4	81.2	64.6	88.1	96	96.6	83.2	96.4	86.6
80	134.6	152.4	121.6	97.6	92.5	106.4	130.4	85.6	89.6	90.2
90	170.6	201.5	111.5	81.4	98.4	132.5	137.6	110.6	79.6	96.8
100	225.8	178.4	76.8	63.4	101.6	164.3	194.5	75.8	134.4	108.8
110	203.6	139.2	50.6	54.6	115.4	215.6	181.2	69.6		110.6
120	189.6	117.6	47.9	121.6	96.3	201	166.4	134.4		108.8
130	140.5	109.2	166.4		81.4	189.2	98.1			96.8
140	130.4	98.8			80	182.4	243.2			90.6
150	120.4	268.8			75.4	101.4				84.4
160	101.7				74.6	339.2				78.2
170	326.4				73.3					75.4
180					71.4					211.2
190					221.6					

[1]Shaded area indicates that no harvesting was done for a particular variety; [2]Harvesting of mini-tubers was done at 10-day intervals; [3]Number of mini-tubers harvested per m^2; [4]average of 3 replications.

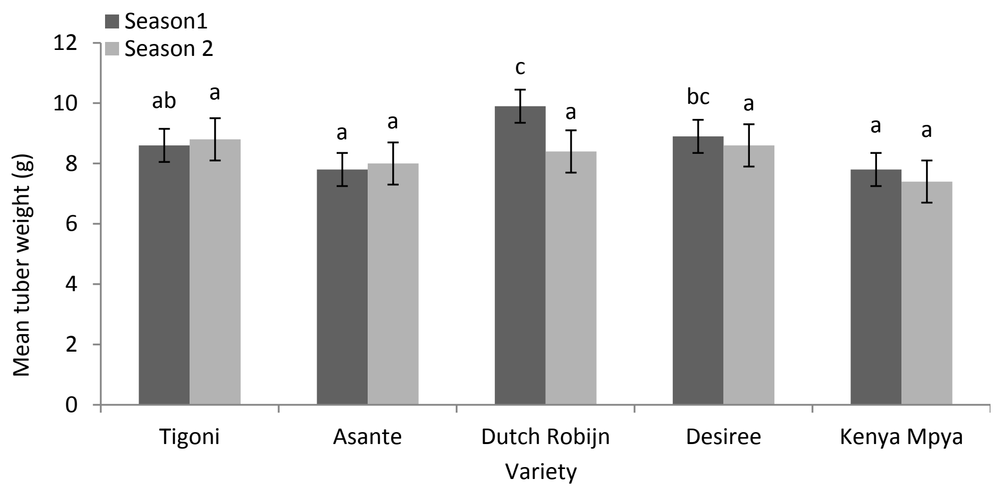


Figure 5. Effect of variety on mean tuber weight (g). Error bars show LSD values.

differences among the varieties were not significant in season 1. In season 2, variety Kenya Mpya had the highest proportion of size II tubers (83.0%) and significantly out-yielded variety Tigoni and Desiree.

Correlations

The number of mini-tubers s per plant and the total weight of mini-tubers s per plant correlations with days to tuberization, days to senescing, days to maturity, plant height measured at 80 days after transplanting, plant vigor and number of the number of mini-tubers > 5 g were positive and significant (Table 5). The correlation between the number of mini-tubers s per plant and total weight of mini-tubers s per plant was also positive in both seasons (r^2= 0.967 in season 1 and r^2= 0.969 in season 2). The average mini-tubers weight was negatively correlated with plant vigor and the total number of mini-tubers per plant, although the relationship was not

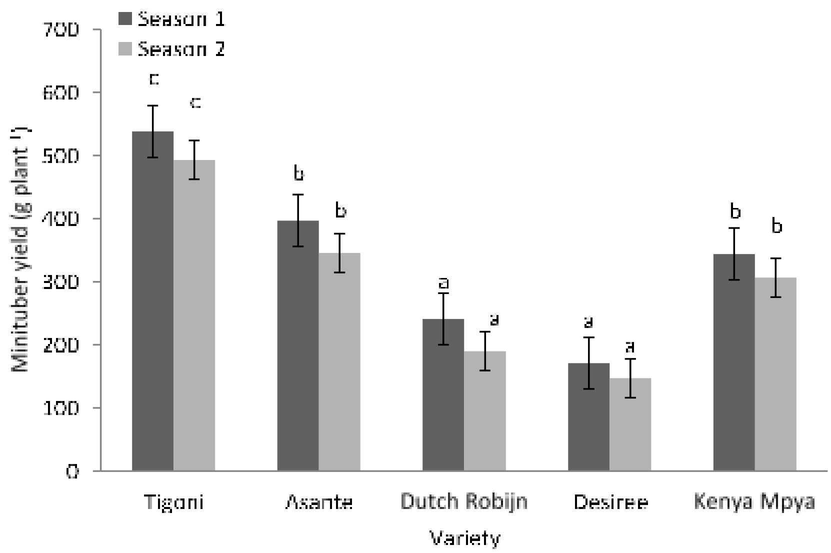


Figure 6. Effect of variety on tuber yield (g plant^{-1}). Error bars show LSD values.

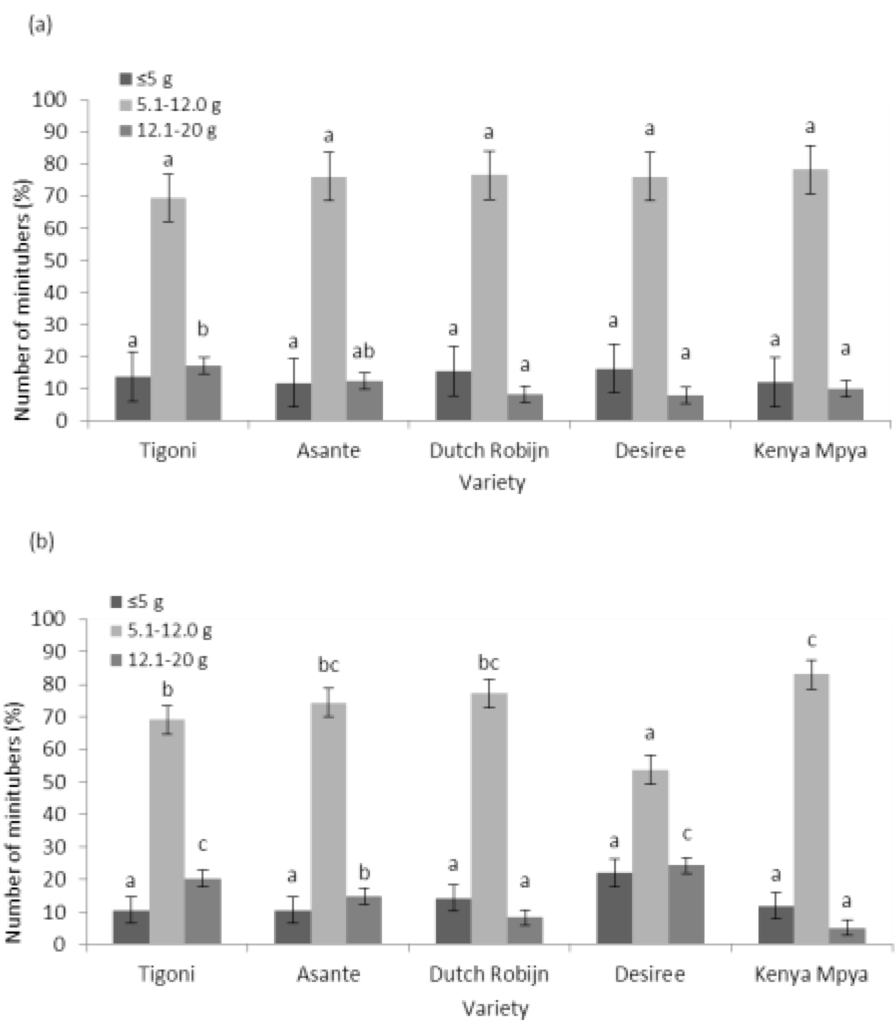


Figure 7. Minituber size distribution expressed as a percentage of total minitubers produced per plant in season 1 (a) and season 2 (b). Error bars show LSD bars

Table 5. Correlation coefficients describing the relationships among mini-tubers yield variables.

	Season 1								Season 2							
	Average mini-tubers weight (g)	Days to maturity	Days to senescing	Days to tuberization	Plant height (80 DATP)	Plant vigour	Number of mini-tubers > 5g	Number of mini-tubers s/plant	Average mini-tubers weight (g)	Days to maturity	Days to senescing	Days to tuberization	Plant height (80 DATP)	Plant vigour	Number of mini-tubers > 5 g	Number of mini-tubers/plant
Average mini-tubers weight (g)	-								-							
Days to maturity	0.576*	-							-0.389 ns	-						
Days to senescing	-0.533*	0.991**	-						-0.308 ns	0.978**	-					
Days to tuberization	-0.491ns	0.951**	0.959**	-					-0.316 ns	0.905**	0.854**	-				
Plant height (80 DATP)	-0.501ns	0.779**	0.810**	0.757**	-				-0.042 ns	0.803**	0.866**	0.720**	-			
Plant vigour	-0.695ns	0.907**	0.991**	0.951**	0.911**	-			-0.302ns	0.920**	0.940**	0.789**	0.900**	-		
Number of mini-tubers > 5 g	-0.494ns	0.803**	0.831**	0.762**	0.976**	0.920**	-		-0.118 ns	0.843**	0.911**	0.762**	0.958**	0.903**	-	
Number of mini-tubers/plant	-0.544*	0.789**	0.810**	0.738**	0.966**	0.904**	0.984**	-	-0.154 ns	0.838**	0.897**	0.785**	0.938**	0.917**	0.994**	-
Total weight of mini-tubers/plant	-0.327ns	0.727**	0.763**	0.692**	0.944**	0.823**	0.968**	0.967**	0.084 ns	0.756**	0.837**	0.709**	0.941**	0.839**	0.975**	0.969**

*Indicates significance at $p \leq 0.05$; ** indicates significance at $p \leq 0.01$; ns indicates non-significance at $p \leq 0.05$. DATP- Days after transplanting.

significant for plant vigor in both seasons (r^2=-0.695 for season 1 and r^2=-0.302 for season 2) and for total number of mini-tubers per plant in season 1 and 2 (r^2=-0.544 for season 1 and r^2=-0.154 in season 2).

DISCUSSION

The pattern of mini-tubers production among the varieties was similar across the 2 seasons. In general, production of mini-tubers for all the varieties increased up to a peak then declined up to the second last but one harvest, then increased again. The initial increase of the number of mini-tubers produced by a variety may be attributed to the combined influences of: (i) the removal of the most dominant tubers during each harvest, resulting in more potential tuber sites that were not subjected to the dominance of rapidly growing tubers, and (ii) pushing of the stem downwards into the aeroponic box after every two weeks (up to 50 days after transplanting) which resulted in more nodes being exposed to stolon inducing conditions. Similar observations were made by Lommen and Struik (1992) who observed increased production of mini-tubers with repeated harvesting followed by deeper re-planting after each harvest. After peak production, the number of tubers at each harvest started to decline.

According to Lommen and Struik (1992), this may probably be due to (a) a limited number of possible tuber sites, (b) the dominant effect of the tubers that remain in the plant after a harvest (because they have not reached the desired size) before new tubers are initiated, (c) resorption of newly initiated tubers. Increase in the number of tubers harvested at the final harvest as compared to the last but one harvest was because during the last harvest, all the mini-tubers on a plant regardless of their size was harvested.

Differences in yield performance with regards to the yield variables, total tuber weight and number of mini-tubers per plant among the varieties evaluated were attributed to genetic differences between the varieties. Previous studies have reported large variations in mini-tubers yield among varieties (Tierno et al., 2014). The difference in performance of the varieties across seasons was attributed to differences in growing environment during the two growing seasons. This observation is consistent with Mateus-Rodriguez et al. (2014) who reported strong environmental effects on plant development and mini-tubers production of a diverse group of potato genotypes grown under an aeroponic system. The yields per plant obtained in this study are in agreement with previously reported work (Mateus-Rodriguez et al., 2014) and are attributed to the increased availability of nutrients (Balamani et al., 1986) and sequential harvesting which eliminates the dominant tubers allowing the development of existing tubers and stimulating the production of new tubers (Lommen, 1992). Tsoka et al. (2008) and Tierno et al. (2014) also obtained higher yields by aeroponics than using conventional technologies for the production of seed tubers.

The slight increase in plant height and delayed tuberization observed during the second season are probably due to temperatures effects. High temperatures are known to induce tall plants by causing greater translocation of photosynthates towards the vegetative organs (stems and leaves) (Wolf et al., 1990). Our results are in agreement with that of Mateus-Rodriguez et al. (2014) who observed considerable increases in the length of the vegetative cycle and plant height in genotypes grown in warmer environments. Long days, high night temperatures and high nitrogen fertilization inhibit or delay tuberization whereas, short days and cool night temperatures promote tuberization (Menzel, 1980, Sattelmacher and Marschner, 1978). Low temperatures are known to stimulate tuberization (Ewing, 1981) and such conditions may probably have occurred at the time of tuberization during the first season.

The increase observed in the vegetative cycle for all the varieties as compared to their known maturity period when grown under field conditions is consistent with results obtained by Tierno et al. (2014) who reported an extended vegetative cycle of between 12 and 36% (17 and 50 days) in plants grown under an aeroponic system as compared to the plants cultivated in greenhouse beds. Otazú (2010) reported similar extensions of the vegetative periods (1 to 2 months when plants are grownunder aeroponic conditions). Kang et al. (1996) also reported an increase in the vegetative period of potato plants when grown in an aeroponics system and attributed his effect to the high availability of nutrients, especially nitrogen.

The positive correlations between number of mini-tubers per plant and the total weight of mini-tubers per plant with the traits days to tuberization, days to senescing, days to maturity, plant height measured at 80 days after transplanting, plant vigor and number of mini-tubers > 5 g indicates that these traits exert considerable influence in the number of mini-tubers and total weight of mini-tubers produced by a variety. The fact that these traits were also correlated positively with each other, also suggests that their interrelationship could act in combination to influence both the number and weight of mini-tubers produced by a variety.

Mini-tubers are a valuable and expensive category of early generation seed and it is necessary to maximize their production and utilization. In addition, using varieties best adapted to the technology, optimum production season and a high multiplication rate, the size of the mini-tubers produced in aeroponics systems is very important because of its effect on storage and subsequent field performance. Tubers weighing at least 5 g usually constitute the size that can be used for further bulking in the field in the Kenyan potato program. Smaller sized mini-tubers are more difficult to store as they show larger losses during storage than larger mini-tubers (Lommen, 1993) The size of the mini-tubers affects the duration of the dormancy, the vigor of the seed tuber, the number of stems that can be successfully produced, the rate of emergence, the number of surviving plants and stems, and the vigor of the individual stem. Smaller seed tubers usually emerge later, have single stems, and are more susceptible to pests, diseases and environmental stresses. Their overall performance and yielding ability is poor (Lommen and Struik, 1994, 1995; Karafyllidis et al., 1997). Thus, an increase in tuber number per plant in an aeroponic system should be accompanied by a simultaneous increase in the proportion of tubers > 5 g.

The proportion of mini-tubers <5 g relative to the total number of mini-tubers produced by a variety observed in this study (a range of 11.7 and 16.2% in season 1; and 10.6 to 22.0% in season 2) suggests that the system used in this study could be further improved to optimize the production of larger sized mini-tubers possibly by modifying the nutrient media during the growth cycle according to changing plant demand, instead of maintaining the same concentrations throughout growth or prolonging the harvest intervals. Small mini-tubers can, however, be planted under protected screen houses to produce larger sized mini-tubers using a variety of methods including sand hydroponics or as a source of mother for aeroponic mini-tubers production (Otazu, 2010; Rykaczewska, 2016).

The higher mini-tubers yields of varieties Tigoni, Asante and Kenya Mpya may be due to their abundant vegetative growth and longer productive time. In contrast, the relatively poor performance of varieties Desiree and Dutch Robijn may be due to their poor adaptation to the aeroponics system in the study area and lower production of stolons. In crops grown from seed tubers, the number of tubers produced per plant is determined by the number of tubers per stolon, the number of stolons per stem and the number of stems per plant (Haverkort et al., 1990). Furthermore, the abundant vegetative growth observed for varieties Tigoni, Asante and Kenya Mpya can be exploited to harvest stem cuttings from such vigorous varieties during aeroponic mini-tubers production so that the cuttings can be used directly for further mini-tubers production (Bryan, 1981; Lung'aho et al., 1997) in beds or pots or they can be used for aeroponics mini-tubers production (Otazu, 2010). The use of such an integrated approach can result in a many fold increase in mini-tubers production.

Conclusion

It was observed that mini-tubers production under the aeroponic system used in this study was variety dependent with Tigoni, Asante and Kenya Mpya being the most productive varieties irrespective of the season. Evaluation of a variety's suitability/adaptability to the system is therefore necessary to determine the most adapted varieties before venturing into large scale production as this will ultimately affect production costs, with higher yielding varieties more likely to result in lower mini-tubers production costs. Because of their positive association with the number of mini-tubers and total weight of mini-tubers per plant produced by a variety, the traits: days to tuberization, days to senescing, days to maturity, plant height measured at 80 days after transplanting, plant vigour and number of mini-tubers > 5 g could be used as predictors for the yield of mini-tubers produced by a variety.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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