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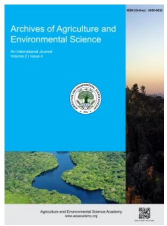

ORIGINAL RESEARCH ARTICLE

Effect of nutrient solution concentrations on the growth and yield of potato (*Solanum tuberosum* L.) varieties grown from apical rooted cutting in a hydroponic system

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ABSTRACT

This study evaluated the effects of nutrient stock solution concentrations on the growth and yield of potato varieties grown from apical rooted cuttings (ARCs). A greenhouse experiment was conducted at the Climate and Water Smart Agriculture Center at Egerton University, Kenya. The experiment was laid out in a split-plot arrangement in randomized complete block design, where the main plot comprised three nutrient concentrations, i.e., 75% (N75), 100% (N100) and 125% (N125) of the ADC-Molo' nutrient formulation. The subplots were allocated to four potato varieties (Shangi, Wanjiku, Nyota and Unica). The results showed that there were no significant ($p \leq 0.05$) interaction effects of the nutrient stock solution concentrations application rates on the growth attributes of ARCs. The main effects of N125 gave the tallest plants (32.29cm) at 60 days after planting (DAP), highest normalised difference vegetation index (NDVI) (0.60) at 75 DAP, plant survival rate (82.15%) at 75 DAP, and fresh weight (79.04g) and dry matter (31.26%) of aboveground biomass (AGB). Nyota variety produced taller plants (26.90cm) at 60 DAP, gave higher NDVI values (0.53) at 75 DAP, and higher fresh weight (64.87g) and dry matter (27.60%) of the AGB. Significant ($p \leq 0.05$) interactions were observed in the yield parameters. The interaction between N125 and Nyota (11.33) and Wanjiku (10.67) gave the highest number of minitubers, the highest yields were obtained between the interaction of N125 and Unica (16.38t/ha). Therefore, to achieve high growth and yields of ARCs under hydroponic system, seed potato producers should use 125% of the ADC Molo nutrient formulation.

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INTRODUCTION

Potato (*Solanum tuberosum* L.) is the third most important food crop in the world after wheat and rice and has contributed to global food and nutritional security (Chebet and Opiyo, 2021). It ranks first among root and tuber crops and by 2050, a global population of 9.7 billion people will demand 70% more food than currently consumed quantities (FAO, 2018). It is an important food crop in Kenya, being second to maize (*Zea mays*) and contributes 23.5% of the total value of horticultural produce (KIA, 2020). There has been a slight increase in potato production and consumption in recent years due to urbanization, population growth and crop diversification in areas with favourable climatic conditions (Waaswa *et al*., 2021). Potato continues to play an important role in food security and increases income of small holder farmers (Harahagazwe *et al*., 2018). More than 60 potato varieties are presently grown in Kenya, but relatively few are widely distributed (Kaguongo *et al*., 2013; MoALF, 2016). The dominance of certain varieties shifts with time due to popularity and preference from region to region. Currently, Shangi is the most popular potato variety in Kenya due to its short maturity period (NPCK, 2019). International Potato Centre has however introduced new improved climate-resilient potato varieties such as Nyota, Wanjiku, Chulu, Lenana and Unica (VanderZaag *et al.*, 2021). While the new varieties are continually being produced, limited information is available on their performance under the hydroponic system.

Potato yields in Kenya are still low (10 t ha^{-1}) due to the use of poor quality, pathogen and pest-infested seed potato (Akoto *et al.*, 2020). Insufficient supply of certified seed potato of preferred varieties in Kenya is a major potato constrain with approximately 2% of the total seed demand being supplied (KEPHIS, 2016; Waaswa *et al.*, 2020). Recently, Molo region of Nakuru county has increased the supply of certified seed potato to 6-8% (Mutinda *et al.*, 2020; Ong'ayo *et al.*, 2020) in response to outreach programmes' efforts to promote the use of certified seed for increased food and nutrition security. The great reliance on informal seed sources (i.e., obtained from previous seasons / positive selection / clean seeds) by up to 98% seed potato demand has been the major cause of potato yields decline from 22 t ha^{-1} to 10 t ha^{-1} over the last decade (KEPHIS, 2016; Waaswa *et al.*, 2021). The shortage of certified seed has consequently led to high cost of seed potato that is estimated to account for 40%-60% of the total potato production cost (Tessema and Dagne, 2018). With the use of these poor quality seeds, pest and disease incidences have increased and low potato productivity is also on the increase (Hussain, 2016). For these reasons there is need to develop a production system that can increase the quantity and quality of certified seed potato.

Rapid multiplication techniques (RMTs) such as the use of apical rooted cutting and hydroponic production systems have shortened the multiplication time of certified seed potato (Wambugu *et al.*, 2022). Apical rooted cuttings (ARC) can be used as an effective means of producing basic seed under strict management practices such as hydroponics, with each cuttings producing 8-15 mini tubers, depending on variety (Lemma *et al.*, 2018; Parker, 2017). The productivity of these plantlets is however limited to nutritional factors in the hydroponic system. Therefore, determining the best nutrient solution concentration for growing ARC to produce seed potato will achieve higher production (Tufik *et al.*, 2019). In a hydroponic system, the efficiency and superior crop growth and production displayed is majorly dependent on the continuous nutrients availability (Corrêa *et al.*, 2010). The use of improperly-formulated nutrient solutions in hydroponics often leads to low-yielding crops due to nutrient imbalances which impair plant growth (Lee *et al.*, 2017; Tufik *et al.*, 2019). Similarly, mismatching crop nutrient requirements can lead to reduced plant growth and development in the hydroponic system (Putra *et al.*, 2019). Application of different nutrient levels influence potato growth characteristics i.e., plant survival, height, aboveground biomass and NDVI and yields (Gbollie *et al.*, 2022; Sakamoto and Takahiro, 2020). It is therefore essential to balance nutrient concentrations that will supply the appropriate amounts of required elements based on crop demand, which should accommodate all stages of growth and development of the ARC. Hence this research study aimed to determine the effect of nutrient solution concentrations on the growth and yield of potato varieties grown from apical rooted cuttings in a hydroponic system.

MATERIALS AND METHODS

Experimental site description

A greenhouse experiment was carried out at the Climate and Water Smart Agriculture Centre of Egerton University, Kenya. The site lies between 0°22'11.0"South, 35°55'58.0" East at an altitude of 2267 meters above sea level. The experimental site is in agro-ecological zone III (medium potentials) with an annual rainfall of between 950 and 1500 mm (Jaetzold and Schmidt, 2009). The average maximum and minimum greenhouse temperatures were 30.79°C and 14.38°C, respectively. The experiment was carried out from September to November, 2022.

Description of the potato varieties

Wanjiku variety is a medium tall variety with strong semi- erect stems and dark green medium- sized leaves with pinkish flowers. It takes 90-120 days to maturity (NPCK, 2019). Shangi variety is about 1m high with broad leaves which are light green in colour without anthocyanin pigmentation on the midrib. It has an upright growth and its flowers are abundant and it takes 75-90 days to maturity yielding 30-40 t ha^{-1} (NPCK, 2019). Nyota is a medium tall potato plant with strong semi erect stems and dark green medium size leaves with pink flowers. It takes 90-120 days to maturity yielding >40 t ha^{-1}. Unica variety is a medium tall variety with strong semi- erect stems and dark green medium- sized leaves. It flowers profusely and the flowers are pink. It takes 80-90 days to maturity yielding >45t ha^{-1} (NPCK, 2019).

Experimental treatments and procedures

The experiment was laid out as a split-plot arrangement in a Randomized Complete Block Design (RCBD) with three replications. The subplot consisted of potato apical rooted cuttings (ARCs) varieties (Shangi, Nyota, Wanjiku and Unica) sourced from Agricultural Development Corporation (ADC)-Molo, Kenya. The main plot consisted of the "ADC-Molo" nutrient formulation which was administered in three concentration solutions (i.e., 75% (N75), 100% (N100) (control) and 125% (N125). The control (100%) formulation comprised of: $Ca(NO_3)_2$ (29.5 g), KNO_3 (11.5 g), KH_2PO_4 (34.0g), $MgSO_4$ (61.0g), Microsol-B (3.0g) and Iron (Fe-EDTA) (4.5g). The treatment combinations were as described in Table 1.

The experimental site (greenhouse) measured 800cm by 1500cm. The greenhouse was covered with a 200μm polythene film on the roof and insect-proof nets on both sides of the greenhouse measuring 1500cm by 150cm. Greenhouse modifications were made by placing a black shade net on the rooftop and the inside part of the greenhouse to lower the temperatures. Each experimental plot consisted of troughs which measured 30cm by 700cm.

Table 1. Treatment combinations of nutrient solution concentrations and apical rooted cuttings potato varieties.

Nutrient stock solution concentrations	Varieties	Combinations
N75	V1	N75V1
N75	V2	N75V2
N75	V3	N75V3
N75	V4	N75V4
N100	V1	N100V1
N100	V2	N100V2
N100	V3	N100V3
N100	V4	N100V4
N125	V1	N125V1
N125	V2	N125V2
N125	V3	N125V3
N125	V4	N125V4

N75 (75% nutrient solution concentration), N100 (100%) and N125 (125%), V1: Shangi, V2: Nyota V3: Wanjiku, V4: Unica.

The troughs were slanted towards the outlet tank to allow excess nutrients to flow using gravity. About 80kg of cocopeat media was used per trough considering that one plant requires 2 kg of air dried cocopeat (Gbollie *et al*., 2022). The ARCs were hardened in the greenhouse for 7 days before transplanting into the planting troughs. The four potato varieties were planted per trough at a spacing of 15cm by 15cm with each variety occupying 150cm.The fertigation system consisted of two tanks per nutrient stock solution concentration (NSSC) with one being an inlet and the other being the outlet. The inlet tanks were raised at an elevation of 150cm and the outlet tanks were placed underground at the end of the troughs to collect the excess nutrient solutions. The nutrient solutions were pumped back to the inlet tank using electric pumps (PKm60, Davis and Shirtliff, manufactured by Pedrollo, San Bonifacio, Italy). The electrical conductivity (EC) and pH of the NSSC were measured using EC meter (pHep®4 pH-HI98127) and pH meter (pHep®4 pH-HI98127) made by HANNA company, Woonsocket, USA. The pH and EC were maintained at 5.5-6.5 and 1mS cm^{-1}, respectively using sodium hydroxide and phosphoric acid, in all the tanks after every circulation. All plots were irrigated at equal time intervals depending on environmental conditions using drip lines that supply 1.6 L h^{-1} per dripper and each dripper was spaced at 15cm between two plantlets.

Data collection

Growth measurements

Plant survival was determined at 15 DAP and 75 DAP by manually counting the number of surviving plants per plot. The percentage plant survival was calculated according to USEPA (2018) formula given below:

$$\text{Plant survival (\%)} = \frac{\text{Surviving plants after 15 days}}{\text{Number of plants planted}} \text{x100}$$

Data on plant height, normalised difference vegetation index (NDVI) and aboveground biomass weight and dry matter was collected from five randomly selected tagged plants. Plant height was taken using a ruler (cm) from the surface of the media to the highest point of the plant (i.e., leaf tip) at 15, 30, 45 and 60 days after planting (DAP). The NDVI was taken at 15 days intervals till the 75 DAP using the GreenSeeker sensor (HCS-100 GreenSeeker, Trimble, Califonia, USA). The sensor height of observation was maintained at about 60cm above the top of the potato plant (Zaeen *et al*., 2020). Aboveground biomass was determined from the fresh weight of individual plants taken during dehaulming (75 DAP) using an electric weighing balance (1708-374 Precisa 310M made by Precisa Gravimetrics, Switzerland). The top biomass was then dried for 72 hours at 60°C and weighed. The dry matter (DM) percentage was calculated according to Agle and Woodbury (1968).

$$\text{Abovegroud biomass dry metter (\%)} = \frac{\text{Weight of the sample after drying (g)}}{\text{Initial weight of the sample}} \text{ x 100}$$

Yield determination

Minitubers were harvested after three months and the numbers per plant were determined by counting manually from the five tagged plants per plot. Minitubers weight classes were graded according to Gbollie *et al*. (2022); C1 (class 1, <8g), C2 (Class 2, 8.01-15.99g), C3 (Class 3, 16-18.00g) and C4 (Class 4, >18g). Tuber weight (g) of individual plants was measured using an electronic weighing balance after harvest as described by Gikundi *et al*. (2021) and used to calculate total yield per hectare using the formula below:

$$\text{Minitubers yield (t ha}^{-1}\text{)} = \frac{\text{Yield (kg) x 1000 m}^2}{\text{Number of plants harvested x planting distance}}$$

Data analyses

Before analysis, data collected were subjected to Shapiro-Wilk test for normality at $p \leq 0.05$. For any abnormally distributed data, data transformation was done based on the most suitable method using SAS statistical software version 9.4. The General Linear Models (GLM) procedure of SAS was used for the analysis of variance (ANOVA). Treatment means for the main effects of nutrient solution concentrations and potato varieties were separated using Tukey's Honest Significant Difference test at a probability level of $p \leq 0.05$ level of significance.

RESULTS AND DISCUSSION

Main effects of nutrient stock solution concentrations on the growth of potato varieties grown from apical rooted cuttings

No significant interactions were observed between nutrient stock solution concentrations (NSSC) and varieties on the growth parameters i.e., plant survival, height, normalised vegetation difference index (NDVI), and fresh weight and dry matter percentage of the aboveground biomass.

Plant survival

The apical rooted cuttings survival at 15 days after planting (DAP) showed no significant difference both under nutrient stock solution concentrations and varieties (Table 2). The survival rate was greater than 85% in all nutrient stock solution concentrations. The high survival may be more likely to be a factor of acclimatization of the ARCs grown in a greenhouse Tsoka *et al.* (2012) than to the effect of varying nutrient stock solution concentrations. The ARCs survival rates conformed to those reported by Aarakit *et al.* (2021) where ARCs that had undergone hardening 30 days before to transplanting were observed to survive in new environmental conditions at early growth stages. However, at 75 DAP, plant survival varied with the application NSSC; N125 (82.15%) had significantly higher plant survival than N75 (47.51%). Craine and Dybzinski (2013) opined that inadequate nutrient in the crop (at later stages of growth) induced nutrient stress which led to competition for limited resources leading to the ultimate death of a majority of plants grown in soils. There were no significant effects ($p<0.05$) of varieties on the plant survival rate at 15 DAP and at 75 DAP. At 75 DAP; Unica gave 64.80% survival followed by Nyota (64.23%), and Wanjiku and Shangi which had (56.75%) as showed in Table 2. Similar results were observed by Tsoka *et al.* (2012) where all potato varieties did not differ in percentage survival when administered with different nutrient concentrations in early and later stages of growth.

Plant height

Plants supplied with N125 were significantly ($p<0.05$) taller (32.29cm) than plants supplied with N100 (22.41cm) and N75 (19.15cm) at 60 days after planting (DAP). Iraboneye *et al.* (2020) attributed increased potato heights to increasing phosphorus (P) and nitrogen (N) levels which increased root development, improved nutrient uptake, enhanced vegetative growth and canopy cover. According to Putra *et al.* (2019), application of adequate nutrients increased the metabolic processes such as photosynthesis, cell enlargement and division which led to the overall increase in plant growth. Plant height differed among varieties (Table 2); at 60 DAP, Nyota (26.90cm) and Wanjiku (26.02cm) were observed to be significantly taller than Shangi (22.80cm) and Unica (22.77cm). The difference in variety performance could be attributed to the different genotype adaptation (Chiota *et al.*, 2015).

Table 2. The effects of three nutrient stock solution concentrations and four potato varieties on the apical rooted cuttings heights, survival, above ground biomass fresh weight and dry matter percentage, and normalized difference vegetation index.

NSSC	Apical rooted cuttings heights (cm)				Apical rooted cuttings survival (%)		Fresh above ground biomass (g)	Above ground biomass dry matter (%)	Normalized Difference Vegetation Index				
Days after planting	15	30	45	60	15	75	75	75	15	30	45	60	75
N75 (75%)	5.27^{b}	8.32^{b}	14.83^{b}	19.15^{b}	87.96^{a}	47.51^{b}	43.31^{b}	21.44^{b}	0.30^{ab}	0.41^{a}	0.41^{b}	0.42^{c}	0.40^{b}
N100 (100%)	7.89^{a}	9.53^{b}	16.39^{b}	22.41^{b}	92.13^{a}	53.65^{ab}	47.20^{b}	23.43^{b}	0.29^{b}	0.42^{a}	0.45^{b}	0.46^{b}	0.44^{b}
N125 (125%)	8.37^{a}	14.62^{a}	23.75^{a}	32.29^{a}	93.74^{a}	82.15^{a}	79.04^{a}	31.26^{a}	0.32^{a}	0.46^{a}	0.58^{a}	0.62^{a}	0.60^{a}
MSD	1.56	2.69	4.28	4.36	16.31	39.63	7.38	1.77	0.02	0.15	0.14	0.09	0.14
p value	***	***	***	***	**	**	***	***	**	***	***	***	***
Varieties	15	30	45	60	15	75	75	75	15	30	45	60	75
Shangi	6.79^{ab}	9.75^{b}	16.27^{b}	22.80^{b}	86.71^{a}	56.75^{a}	53.63^{b}	24.14^{b}	0.30^{b}	0.40^{b}	0.47^{b}	0.47^{b}	0.49^{a}
Nyota	7.81^{a}	12.12^{a}	20.73^{a}	26.90^{a}	93.83^{a}	64.23^{a}	64.87^{a}	27.60^{a}	0.32^{a}	0.47^{a}	0.53^{a}	0.52^{a}	0.53^{a}
Wanjiku	7.45^{ab}	11.76^{a}	20.19^{a}	26.02^{a}	94.44^{a}	56.75^{a}	55.91^{b}	25.77^{ab}	0.31^{ab}	0.42^{b}	0.49^{ab}	0.50^{ab}	0.48^{a}
Unica	6.67^{b}	9.67^{b}	16.10^{b}	22.77^{b}	90.12^{a}	64.80^{a}	52.15^{b}	24.00^{b}	0.30^{b}	0.43^{ab}	0.47^{b}	0.47^{b}	0.48^{a}
MSD	1.09	1.91	1.9	1.82	10.15	17.54	4.64	2.87	0.02	0.04	0.04	0.04	0.07
p value	***	***	***	***	**	**	***	***	**	***	***	***	***
CV (%)	11.43	13.25	7.78	5.57	8.34	2.15	6.16	8.49	4.38	6.59	6.77	6.55	10.99

MSD: Minimum significant difference. NSSC: Nutrient stock solution concentrations. Similar letters indicate that means do not differ significantly according to Tukey Honest Significant Difference at (α=0.05). When the *p* value is *** it indicates significance at $p<0.001$ and ** significance at $p<0.05$.

Normalized Difference Vegetation Index

The NDVI values increased with maturity up to a maximum on the 60th DAP and declined afterwards up to the dehaulming stage (75 DAP). This was similarly reported by Gómez *et al.* (2019) who noted that NDVI values in potato production were highest at 75 DAP and declined with the onset of senescence for late maturing varieties. Increase in NSSC significantly (p<0.05) increased NDVI values with N75, N100 and N125 giving a mean of 0.42, 0.46 and 0.62 at 60 DAP, respectively. This may be due to inadequate nutrient concentrations administered that consequently led to quick exhaustion of any nutrients in the rhizosphere leading to low vegetation growth (Maboko *et al.*, 2017). On the other hand, crops supplied with N100 and N125 NSSC resulted in better growth and healthier crop. Farias *et al.* (2023) noted that the more the leaf canopy the higher the leaf area index which led to higher near-infrared reflectance, resulting in higher NDVI values. Similarly Gbollie *et al.* (2022) postulated that increasing the N content through $Ca(NO_3)_2$ application increased the vegetative growth which increased the NDVI values. The potato varieties showed a significant difference (p<0.05) in the NDVI values. At 60 DAP; Nyota (0.52) gave significantly higher NDVI values as compared to Shangi (0.47) and Unica (0.47). Wanjiku (0.50) did not differ significantly from all varieties. At 75 DAP, no significant differences were reported among the varieties. Nyota reported 0.53, Shangi 0.49, Wanjiku and Unica both reported 0.48.

Fresh weight and dry matter (%) of the above ground biomass

The main effects of NSSC and varieties significantly influenced fresh weights and dry matter (%) of the above ground biomass (Table 2). Increasing NSSC from N75 to N125 increased the fresh AGB from 43.31g to 79.04g and the AGB dry matter (%) from 21.44% to 31.26%. According to Petropoulos *et al.* (2020) and Sakamoto and Takahiro (2020), potato biomass weight and dry matter (%) is influenced by nutrition. Similarly, Maboko *et al.* (2017) reported that increasing nutrient concentrations increases plant fresh weight and biomass dry matter accumulation in a tomato hydroponic system. Aarakit *et al.* (2021) attributed the increase in potato biomass weight to the adequate application of phosphorus alongside recommended nitrogen levels which influenced total leaf area that increased crop light interception which contributed to biomass accumulation. The results are in agreement with Misgina (2016) who reported an increase in phosphorus rates by 33% of the recommended boosted plant metabolic activity during the early growth stages of potato that encouraged stem elongation increasing biomass yields. Increasing nitrogen fertilizer rates in potato was also reported to increase biomass since it is one of the most crucial macronutrients for plant growth and biomass development (Iraboneye *et al.*, 2020). Low biomass accumulation in N75 was attributed to nutrient deficiency in biomass and plant which affects productivity. Therefore biomass production and tuber production can be maximized by controlling the optimum levels of nutrients available in the media (Chatzistathis and Therios, 2013).

The application of NSSC significantly influenced fresh and dry matter (%) production of the above ground biomass among potato varieties (Table 2). Significant differences were observed between the varieties in both the fresh weight and dry matter (%) of the AGB (p<0.05). Nyota variety (64.87g) gave a higher AGB fresh weight which differed significantly from Wanjiku (55.91g), Shangi (53.63g) and Unica (52.15g). Nyota (27.60%) gave the highest AGB dry matter (%) which was significantly different from Shangi (24.14%) and Unica (24.00%) but not significantly different from Wanjiku (25.77%). The difference between varieties may be attributed to the genetic makeup that supports vegetative canopy development and shoots biomass accumulation (Lee *et al.*, 2021).

Interaction effects of nutrient stock solution concentrations on the yields of potato apical rooted cutting varieties

The results in Table 3 indicate that interaction between nutrient stock solution concentrations (NSSC) and potato varieties significantly influenced the number of mini tubers per plant and yield (t/ha).

Number of mini tubers per plant

Mini tubers number is an important variable in reporting potato production in greenhouse production (Awati *et al.*, 2019). The interaction between N125 and Nyota (11.33) and Wanjiku (10.67) gave a significantly higher number of mini tubers per plant as compared to Shangi (8.67) and Unica (6.67). The increase in the number of mini tubers plant^{-1} with increase in nutrient concentrations may be due to the adequate nutrient concentrations and balance in the cocopeat which influences apical rooted cuttings yield (Gbollie *et al.*, 2022). Additionally, El-Hadidi *et al.* (2017) attributed the increase in minitubers number to increase in nitrogen levels which increase stolon numbers through its effect on gibberellins biosynthesis in the potato plant and potassium. The increase in minitubers per plant was also reported to increase with increasing nitrogen, phosphorus and potassium levels (Misgina, 2016).

Yields (t/ha)

In the yields, N125*Unica (16.38t ha^{-1}) gave significantly higher yields than N125*Shangi interaction (9.90t ha^{-1}). Nyota (13.43 t ha^{-1}) and Wanjiku (12.63 t ha^{-1}) were not significantly different from Unica and Shangi. Low yield in N75*variety interaction could be due to nutrient deficiency which leads to low photosynthetic area that affects potato tuber formation. According to Petropoulos *et al.* (2020) application of adequate nutrient concentration levels influences the allocation of assimilates in the tubers accumulation. In a study by Bekele *et al.* (2020), increasing N, P and K levels by 150% of the recommended levels increased tuber yield by 114% due to their roles in assimilation, transportation and storage of photosynthesis which leads to an increase in yields. The interactions of nutrient stock solution concentrations and Unica gave the highest yield per hectare despite having low top biomass. This was also observed by Tsoka *et al.* (2012) and Zimba *et al.* (2014) where high yield was observed in potato plants that had low biomass due to less competition between tubers and leaves in terms of sucrose loading (compensatory growth).

Table 3. Interaction effects of nutrient stock solution concentration and potato varieties on yield (t ha^{-1}), minitubers number and classes per plant.

Nutrient stock solution	Potato varieties	Number of mini tubers plant^{-1}	Yield (t/ha)	Mini tubers weight classes per plant			
Concentrations				C1	C2	C3	C4
N75	Shangi	3.33^{f}	1.06^{f}	2.47	1.00^{cd}	0.00^{e}	0.00^{e}
(75%)	Nyota	4.33^{ef}	2.31^{ef}	3.07	1.00^{cd}	0.00^{e}	0.00^{e}
	Wanjiku	4.00^{ef}	2.41^{ef}	2.93	0.87^{d}	0.00^{e}	0.00^{e}
	Unica	4.33^{ef}	3.14^{ef}	2.00	1.60^{bcd}	0.67^{de}	0.00^{e}
N100	Shangi	6.33^{cd}	3.29^{ef}	2.67	2.67^{ab}	1.00^{cde}	0.00^{e}
(100%)	Nyota	7.33^{bc}	6.08^{cde}	2.67	3.00^{a}	1.67^{bcd}	0.00^{e}
	Wanjiku	7.33^{bc}	5.51^{de}	2.40	2.33^{abc}	1.67^{bcd}	0.00^{e}
	Unica	5.00^{de}	8.05^{cde}	0.87	0.67^{d}	2.33^{abc}	1.00^{d}
N125	Shangi	8.67^{b}	9.90^{bc}	1.33	2.33^{abc}	2.67^{ab}	2.33^{c}
(125%)	Nyota	11.33^{a}	13.43^{ab}	1.67	3.00^{a}	3.33^{a}	3.33^{b}
	Wanjiku	10.67^{a}	12.63^{ab}	1.67	3.33^{a}	2.67^{ab}	3.00^{b}
	Unica	6.67^{c}	16.38^{a}	0.00	0.33^{d}	2.00^{abcd}	4.33^{a}
p value		***	***	ns	***	***	***
Mean		6.66	7.01	1.98	1.84	1.50	1.16
CV		8.73	20.78	25.00	24.63	19.51	14.29

The means followed by the same letter (s) in the same column are not significantly different using Tukey HSD test at a 5%. When the *p* value is *** it indicates significance at $p<0.001$ and ns: not significant at 5% level of significance.

Minitubers classes

There was significant interaction ($p<0.05$) between the NSSC and the potato varieties in minitubers class 2 (C2), class 3 (C3) and class 4 (C4) (Table 3). Under C2, N125*Wanjiku (3.33), Nyota (3.00) and Shangi (2.33) produced significantly higher number of minitubers as compared to N125*Unica (0.33). The interactions under N100 were similar to those reported under the N125*variety interaction while under N75*variety no significant difference was observed in the number of minitubers produced. Under class 3, no significant difference was observed in the number of minitubers under N125 and variety interaction. Similar observations were observed under the N100 and N75 interactions. In Class 4, under N125 and variety interaction, Unica (4.33) produced significantly higher number of minitubers as compared to Nyota (3.33) and Wanjiku (3.33) and Shangi (2.33). Under N100*variety interaction, Unica (1.00) differed significantly from all the other varieties. Under N75* variety interaction, no minitubers were produced under Class 4. Heavier (C4) tubers produced from N125 interaction may be due to the adequate application of amounts of nitrogen and phosphorus in the N125 plots which increased tuber sizes due to their function in allocating assimilates in tubers and tuber bulking (Koch *et al.*, 2020; Petropoulos *et al.*, 2020). Additionally, Bekele *et al.* (2020) attributed big tuber sizes to increasing potassium levels which has a stimulating effect on photosynthesis, phloem loading and translocation, and the synthesis of large molecular weight substances within storage organs that may contribute to the rapid bulking of the tubers. Application of low nutrient concentrations (75%) led to the production of small-sized minitubers per plant (2.62) (C1). With respect to tuber size, class 4 (>18g) is the most demanded by seed potato farmers in Kenya Gbollie *et al.*, (2022) and would therefore recommend the use of N125 for heavier seed production.

Conclusion

In this study, the application of nutrient stock solution concentrations (NSSC) significantly affected growth and yield of ARCs. Increasing NSSC from 75% to 125% increased growth and yield parameters of the apical rooted cuttings. Potato varieties responded differently in growth and yields under the hydroponic system. Nyota and Wanjiku varieties gave higher growth rates and produced higher numbers of minitubers while Unica gave the highest yields (t/ha). This study therefore recommends that the application of 125% of the "ADC-Molo nutrient formulation" for optimum growth and yield of potato varieties grown from apical rooted cuttings under a hydroponic system maybe the appropriate rate. Further studies on the effects of individual nutrient elements on the growth and yield of potato apical rooted cuttings are recommended.

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Competing interests

The authors declared that there is no competing interest.

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