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Influence of Hydroponics Nutrient Solution on Quality of Selected Varieties of Potato Minitubers

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Abstract: Addressing poor seed quality is pivotal for increased potato yields in Kenya. For this to be realized there is a need for nutrient optimization in the hydroponic system. The objective of this study was to examine the effects of nutrient stock solution concentrations on the quality of minitubers produced under a hydroponic system. Two greenhouse experiments were set up at Egerton University, Kenya in 2022. The treatments included three nutrient solution concentrations: 75% (N75), 100% (N100) and 125% (N125) and four potato varieties (Wanjiku, Unica, Shangi and Nyota) grown in a cocopeat substrate hydroponic system. The results indicated that the application of N125 produced minitubers that had significantly higher specific gravity, dry matter, starch, ash and sugar content. Crude protein and phosphorus did not differ significantly with the application of varying nutrient concentrations. The varieties did not differ significantly in the quality parameters except for total sugars where Unica was significantly different from Nyota and Wanjiku while Shangi did not differ from all varieties. Therefore, it will be advisable to apply 125% of the ADC-Molo recommended nutrient stock formulation which should be considered as an effective method of increasing minitubers quality under a hydroponic system.

Keywords: nutrition composition; quality; seed potato; variety

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1. Introduction

Universally, Potato (*Solanum tuberosum* L.) is ranked as the third most important food crop and its contribution to achieving food security and nutrition in developing countries has increased steadily over the years [1,2]. Potato has been considered a strategic crop to achieve food security and eradicate poverty under the United Nation's Millennium Development Goals [3]. Potato has gained an advantage over other crops due to its nutritional value and its ability to adapt to varying climatic conditions [4]. It is a good alternative to cereals due to its high yield potential and high harvest index of above 75% [5]. It is reported to have a better nutrient balance than other vegetables and is the cheapest carbohydrate source [6,7]. Potato is also an important source of essential nutrients, bioactive elements such as vitamins, proteins, phenolics, minerals and naturally occurring anti-nutrients like glycol-alkaloids and nitrates [8]. It has low levels of cholesterol, sodium, antioxidants and fats, making it most suitable for human consumption [9].

Despite the immense potential, certified seed potato production in Kenya faces a number of challenges including a lack of adequate land to practice crop rotation, increased prevalence of pests and diseases, poor crop nutrition and unfavorable weather conditions [10]. Limited seed potato varieties and a shortage of certified seed potatoes have affected the expansion and profitability of the potato industry in Kenya [11]. Currently, seed potato demand stands at 300,000 metric tonnes against the current production of about 2640 metric tonnes [12]. The informal sector has accelerated the adoption of conventional methods of seed potato production which entails the use of soil as a medium for seed multiplication [13]. Though the soil-based seed potato production method is widely used in Kenya, it has a low multiplication rate in addition to encouraging the build-up of tissue-borne viruses, fungi and bacteria [14,15]. To meet the increasing seed potato demand and reduce the risks associated with conventional production methods, it is important to enhance production efficiency within the informal seed production sector. A hydroponic production system has been introduced to increase minituber quantity and produce high-yielding, disease-free minitubers [2].

Seed potato quality is an important aspect to consider in increasing potato productivity [16]. The genomic potential and other characteristics of the potato can only be realized through the use of good quality seed potatoes [17]. Minitubers must exhibit good physiological and nutritional characteristics including specific density, starch, dry matter contents and nutritional compositions which play a vital role in improving the seedlings' vigor and tuberization capacity of the resultant plants [12]. These tuber qualities are influenced by the amount of nutrient solution applied and the variety used [18,19]. The introduction of a hydroponic production system has been reported to increase minituber production that is free, high yielding and of high quality [2,20]. The composition of nutrient solution for the minituber hydroponic production systems is a key limiting factor in the quality of the minitubers produced [21]. Nutrient management in seed potato production affects the accumulation of dry matter, specific gravity, total protein, sugars, ash content, and starch content [9,22].

Minitubers production is heavily reliant on the supply of nutrients such as potassium, nitrogen, phosphorus, calcium, magnesium and microelements with each nutrient having a specific function for high quality tuber production [23–25]. Potatoes demand substantial amounts of nutrients during the growth period and deficient or excessive nutrient application could have detrimental effects on tuber quality [26]. While nutrient requirements for seed potatoes have extensively been investigated [12,21,27,28], information regarding the use of hydroponic systems to produce minitubers in Kenya remains limited. In addition, there is inadequate information on minitubers quality characteristics of the newly released potato varieties [1]. This knowledge gap necessitates the identification of an optimal nutrient solution application regime in order to maintain tuber quality while minimizing production costs [19]. Hence, to address these challenges the present study aims to investigate the influence of nutrient stock solution concentrations on the minitubers quality under a hydroponic system.

2. Material and Methods

2.1. Experimental Location and Layout

The study was carried out in a polyfilm greenhouse at the Climate and Water Smart Agriculture Center at Egerton University, Njoro, Kenya from September to November 2022. The experiment was laid out in a split plot design in a randomized complete block design (RCBD) arrangement with three replications. The main plot treatments were the Agricultural Development Corporation (ADC)-Molo nutrient formulation which was applied at 75%, 100% and 125% (N75, N100 and N125, respectively) of the recommended concentrations (Table 1) while the subplot treatments entailed four potato varieties (Wanjiku, Nyota, Shangi and Unica) (Table 2).

Table 1. Nutrient concentrations compositions.

Nutrient Compositions	KH_2PO_4	$MgSO_4$	Microsol-B	Iron (Fe-EDTA)	KNO_3	$Ca(NO_3)_2$
75%	25.500 g	45.750 g	2.250 g	3.375 g	8.625 g	22.125 g
100%	34.000 g	61.000 g	3.000 g	4.500 g	11.500 g	29.500 g
125%	42.500 g	76.250 g	3.750 g	5.625 g	14.375 g	36.875 g

Table 2. Description of the potato varieties used [29].

Variety	Days to Maturity	Yield (t ha^{-1})	Flesh Color	Dry Matter	Use	Dormancy (Months)
Shangi	≤90	30–40 t	Cream skin	21.4%	Chips, table	<1
Nyota	90–120	>40 t	White-cream skin	20%	Table, crisp, chips	2–3
Wanjiku	90–120	>40 t	White-cream skin	21%	Table, crisp	>3
Unica	75–100	>45 t	Red skin	21%	Chips, table	2.5–3.5

The experimental area measured 750 cm by 800 cm and each planting trough/plot measured 30 cm by 700 cm. Cocopeat was used as the planting media and was prepared as described by Gbollie et al. [30]. Each planting trough consisted of the four potato varieties, with each variety occupying 150 cm which were planted at a spacing of 15 cm by 15 cm giving a plant population of 20 plantlets per variety. The drip irrigation system with drip emitters spaced at 20 cm intervals and an emitter flow rate of 6 L h^{-1} was placed at the surface of the cocopeat to supply nutrient solutions in each block. The fertigation system consisted of three 1500 L inlet tanks and three 250 L outlet tanks placed underground to collect excess nutrient solutions through gravity flow. Since the hydroponic system was closed, electric pumps were used to pump the nutrient solutions back to the inlet tanks. The nutrient solutions were monitored daily by measuring the electrical conductivity (EC) using an EC meter (pHep®4 pH-HI98127, Woonsocket, RI, USA) and pH using a pH meter (pHep®4 pH-HI98127, Woonsocket, RI, USA). Sodium hydroxide and phosphoric acid were used to maintain the pH between 5.5–6.5 and EC at 1 mS/cm. Harvesting was conducted 90 days after planting. Crop management practices including pest and disease control were carried out throughout the growing season. The harvested minitubers were cleaned to eliminate any cocopeat using a dry towel before they were taken to the laboratory.

2.2. Data Collection

At harvest, data was collected on minitubers dry matter (TDM), specific gravity (SG), starch content, phosphorus content, total sugars, crude protein (CP) and ash content from randomly selected samples per plot.

Minitubers dry matter was determined by sampling five minitubers from five plants at random from each plot and variety. They were cut into smaller pieces, mixed thoroughly and 200 g per sample were weighed and oven dried at 60 °C for 72 h until a constant weight was achieved. The dry matter weight was recorded and the dry matter percentage was determined using the following equation [31]:

$$\text{Minitubers dry matter } (\%) = \frac{\text{weight of sample after drying (g)}}{\text{initial weight of the sample}} \times 100$$

Specific gravity was evaluated using the weight in air and weight in water method as described by Islam et al. [5] where 5 kg of minitubers were selected from each plot and variety and cleaned with running water then weighed in air and then in water. The specific gravity of the minitubers was calculated using the following equation:

$$\text{Specific gravity} = \frac{\text{weight in air}}{\text{weight in air} - \text{weight in water}}.$$

2.3. Composition Analysis

About 5 kg of minitubers from each treatment were oven-dried at 65 °C for about 48 h and were passed through a 0.5-mm screen using a grinding machine. The ground materials were used in digestion and to determine ash, starch and sugar content. The ash content was determined using the incineration method as explained by Naz et al. [32]. Empty crucibles were weighed (W1) using an electric balance (Ohaus Brainweigh® B1500D Florham Park, NJ, USA) and about 2 g of the sample was placed into the crucible which was weighed (W2). The samples were placed in a muffler furnace for 3 h at 550 ± 10 °C and then in a desiccator for cooling. The crucibles were then reweighed (W3) and the percentage ash content was calculated using the following equation:

$$\text{Ash content } (\%) = \frac{(\text{W3} - \text{W1})}{\text{W2} - \text{W1}} \times 100$$

Total sugars were determined using the method described by AOAC [33]. About 0.2 g of the sample was placed in a centrifuge test tube and two drops of ethanol solution (80% v/v) and 5 mL of distilled water were added. About 25 mL of hot ethanol (80% v/v) was then added to the sample and vortexed. The samples were left for 5 min to cool and they were centrifuged at 2000× g for 30 min at 4 °C using a centrifuge (Eppendorf 5430RV2.4, Hamburg, Germany). The supernatant was decanted into a 100 mL volumetric flask and the extraction was repeated by adding 30 mL of hot ethanol and centrifuged for 30 min. Distilled water was used to top up the final volume of 100 mL. About 10 mL of anthrone reagent was placed into the test tubes and then they were heated in a water bath for about 12 min. The samples were then cooled at room temperature. Blanks were prepared using 1 mL water and all the other reagents were added. The samples were then read at 630 nm against the water anthrone reagent blank. Starch content was evaluated according to AOAC [33]. The residue left after sugar extraction was placed in a test tube and 7.5 mL of 52% perchloric acid was added and left for one hour. About 17.5 mL of distilled water was added to the filtrate. One milligram of the extracted filtrate was pipetted and combined with 1 mL of distilled water. Half a milligram of phenol was added and vortexed. This was followed by an addition of 2.5 mL of concentrated sulphuric acid and vortexing. The samples were cooled at room temperature for ten minutes and vortexing was repeated. For blanks, 0.1 mL of water was used and other reagents were added at the same time. The samples were read for absorbance at 510 nm.

Digestion procedure: About 0.5 g of each sample was placed in a digestion flask followed by 5 mL of concentrated sulphuric acid and the Kjeldahl catalyst. The samples were then placed into the digestion chambers and removed once the mixture became clear. The samples were cooled and the digested mixtures were transferred into a 100 mL volumetric flask where the distilled water was used to top up the 100 mL mark. The digestion mixture was used to determine crude protein and phosphorus content. Crude protein was evaluated according to AOAC [33] using the Kjeldahl method. About 30 mL of sodium hydroxide (40%) was added to 30 mL of the digested sample and distillation was conducted for about 5 min using the Markham distillation apparatus. Ammonia gas was collected in a conical flask that contained 20 mL of 4% Boric acid solutions, along with a few drops of methyl red indicator. The resulting distillate was subsequently titrated against the standard 0.1 N HCL solution until a pink color was observed. A blank was also prepared using the above procedure and the crude protein percentage was determined using the conversion factor of 6.5. Phosphorus was determined calorimetrically as described by Okalebo et al. [34]. About 2.5 mL of the digested mixture was pipetted into a 50 mL volumetric flask and 10 mL of Ammonium vanado-molybdate reagent was added. The volumetric flask was filled to the 50 mL mark using distilled water and the sample was left to stand for 10 min. A blank was prepared using the reagents and 40 mL distilled water. The samples were then read at 430 nm using a spectrophotometer.

2.4. Statistical Analysis

Data were checked for normality and appropriate transformation was conducted to achieve normal distribution. The results were subjected to Analysis of variance (ANOVA) using SAS software version 9.4. The means of the treatments that differed significantly were separated using Tukey's Honest Significant Difference (HSD) test at 5% p-value. Pearson correlation analysis was conducted to determine the relationship between the quality parameters (starch, sugars, crude protein, dry matter, ash content, specific gravity and phosphorus).

3. Results and Discussion

3.1. Influence of Nutrient Stock Solution Concentrations on Minitubers Dry Matter, Specific Gravity and Starch Content

Tuber dry matter (TDM) was significantly ($p \leq 0.05$) affected by the application of varying nutrient stock solution concentrations (NSSC) (Table 3). Increasing NSSC from 75% to 125% of the ADC-Molo formulation increased the TDM from 17.89% to 24.90%. In previous studies [12,35], increasing nitrogen (N) and phosphorus (P) content increased the photosynthetic rates which increased the vegetative growth ultimately leading to high DM content. Application of high nitrogen content positively influences the photosynthesis efficiency by increasing the interception rate of radiation and photons which results in the increase in partitioning of the TDM, tuber bulking and ultimately high tuber yield formation [24]. According to Akoto et al. [9] increasing P content resulted in increased TDM due to its functions on tuber development, i.e., it plays a role in cell division and synthesis, and tuber starch storage thereby increasing both the tuber size and DM%. The results showed that there were no significant ($p < 0.05$) differences in the TDM among the potato varieties grown. The minitubers dry matter ranged from 20.79% to 21.19%. These results are in line with the National potato council of Kenya [29] where all varieties have a DM of ≥20% (Table 3).

Table 3. Effects of nutrient stock solution concentrations and varieties on minitubers dry matter, specific gravity and starch content.

Treatments	Starch Content (%)	Specific Gravity	Tuber Dry Matter (%)
NSSC			
75 (%)	11.69 b	1.06 b	17.89 b
100 (%)	12.57 b	1.09 b	20.98 ab
125 (%)	15.59 a	1.18 a	24.90 a
MSD	1.15	0.06	5.91
Variety			
Shangi	13.48 a	1.10 a	21.19 a
Nyota	13.03 a	1.11 a	20.79 a
Wanjiku	13.19 a	1.11 a	20.83 a
Unica	13.44 a	1.13 a	21.13 a
MSD	0.81	0.06	2.34
N × V	NS	NS	NS

NSSC: Nutrient Stock Solution Concentrations. NS is not significant ($p \leq 0.05$). N: Nutrient. MSD: Minimum significant difference. V: Variety. Means sharing the same letter in column are not significantly different from each other (Tukey Honest significant difference at $p \leq 0.05$).

Specific gravity (SG) It is regarded as one of the crucial indicators for potato quality as it is positively correlated with starch content and tuber dry matter [27]. In this study, SG was significantly ($p \leq 0.05$) influenced by the application of nutrient stock solution concentrations but not variety and interactions between NSSC and variety. Evaluating SG using seed potatoes is critical as it ensures the selection of seeds with the specific qualities and attributes desired by potato growers, processors and consumers. Specific gravity can be influenced by the nutrient compositions [36]. In this study, N125 reported a high SG of 1.18 as compared to N100 (1.09) and N75 (1.06) (Table 3). The results are similar to the findings of Bekele et al. [37] who noted that increasing nitrogen, phosphorus and phosphorus fertilizers rates led to high SG. There were no significant differences between the potato varieties with the application of varying nutrient concentrations. It was similarly reported that the specific gravity of Shangi and Unica did not differ significantly with the application of different phosphorus fertilizer rates [9]. A specific gravity of greater than 1.10 reported indicates that the varieties are highly suitable for the processing of dehydrated and fried products. These characteristics boost high product recovery rates, reduce oil absorption and lower energy consumption during processing, and generally result in superior quality of fried products [1].

Starch is the primary component of the tuber dry matter and accounts for about 50–80% of the total DM [38]. Increasing nutrient concentrations significantly ($p \leq 0.05$) increased starch content with N125 reporting 15.59% and N75 reporting 11.69% (Table 3). These results could be attributed to the increase in potassium application which increased the activation of the starch synthase enzymes responsible for starch synthesis [24,39]. Thus, it is possible that our observation could be linked to the K increase in the nutrient solutions. Additionally, it was reported that increasing phosphorus application increased the storage of starch due to its role in the cell division and synthesis, and enzyme activation which are involved in starch synthesis, i.e., fructose-1,6-bisphosphate and ADP-glucose pyrophosphorylase [35]. The potato varieties did not significantly ($p \leq 0.05$) differ in the starch content; while the interaction between NSSC and variety was also not significant ($p \leq 0.05$).

3.2. Influence of Nutrient Stock Solution Concentrations on Ash, Crude Protein, Total Sugars and Phosphorus Contents of Minitubers

Ash content Increasing the nutrient stock solution concentrations (NSSC) significantly ($p \leq 0.05$) affected the ash content. However, no significant ($p < 0.05$) interactions were observed between the varieties as well as the interaction between NSSC and varieties. The ash content in N125 (7.12%) NSSC was significantly higher ($p \leq 0.05$) than N100 (5.92%) and N75 (5.83%) (Table 4). The increase in ash content with an increase in nutrient concentration may be due to the higher availability of mineral nutrients in the media hence higher absorption by the apical rooted cuttings [40]. Similarly, it was reported that the ash content of potato tubers increased with an increase in fertilizer application [41]. The varieties had ash content ranging from 5.77% to 6.89%.

Table 4. Effects of nutrient stock solution concentrations and varieties on minitubers phosphorus content, ash, crude protein and sugar content.

NSSC	P Content (%)	Ash (%)	Crude Protein (%)
75 (%)	0.58 a	5.83 b	6.94 a
100 (%)	0.64 a	5.92 b	7.29 a
125 (%)	0.66 a	7.12 a	8.08 a
MSD	0.14	0.75	3.29
Variety			
Shangi	0.64 a	6.89 a	8.17 a
Nyota	0.63 a	6.33 a	8.13 a
Wanjiku	0.62 a	6.14 a	7.31 a
Unica	0.62 a	5.77 a	7.15 a
MSD	0.15	1.38	2.60
N × V	NS	NS	NS

NSSC: Nutrient stock solution concentrations. NS is not significant ($p \leq 0.05$). N: Nutrient. MSD: Minimum significant difference. P: Phosphorus. V: Variety. Means sharing the same letter in column are not significantly different from each other (Tukey Honest significant difference at $p \leq 0.05$).

Crude protein (CP) The potato nutritional value is determined by the crude protein content [42]. No significant ($p \leq 0.05$) differences were observed with the application of varying nutrient stock solution concentrations (NSSC), potato varieties (Table 4) and the interaction between NSSC and variety. The crude protein ranged from 6.94% to 8.08% following the application of NSSC and ranged from 7.15% to 8.17% for the varieties. Similarly, it was reported that potato crude protein was not significantly different with the application of varying nutrient levels and varieties [1,8,26,32].

Phosphorus The phosphorus content did not differ significantly ($p \leq 0.05$) with the application of nutrient stock solution concentrations and among the varieties (Table 4). The results concur with a study conducted by Adamovičs et al. [42] where there was no difference in phosphorus content with the application of varying fertilizer rates. The high

P content in N125 could be attributed to the high phosphorus concentration in the nutrient solution which increased P uptake in the tubers [43,44]. Shangi recorded the highest value (0.64%) followed by Nyota (0.63%), Unica (0.62%) and Wanjiku (0.61%). There was no significant ($p \leq 0.05$) difference in the NSSC and variety interaction.

Sugar content showed an increasing trend with an increase in nutrient stock solution concentrations (Figure 1). Treatment N125 had a sugar content of 37.97% which was significantly ($p \leq 0.05$) different from N100 (12.14%) and N75 (11.36%). Increasing nitrogen, phosphorus and potassium fertilizers application was reported to increase the total sugar content in potato tuber [45]. There were statistically significant ($p \leq 0.05$) differences in the sugar content between the potato varieties. Unica (31.51%) produced significantly ($p \leq 0.05$) higher sugar content as compared to Nyota (15.80%) and Wanjiku (17.50%) but was not significantly different from Shangi (18.58%) as presented in Figure 2. Sugar content is a heritable character that is affected by a variety, of environmental and cultural practices such as nutrition [5,6].

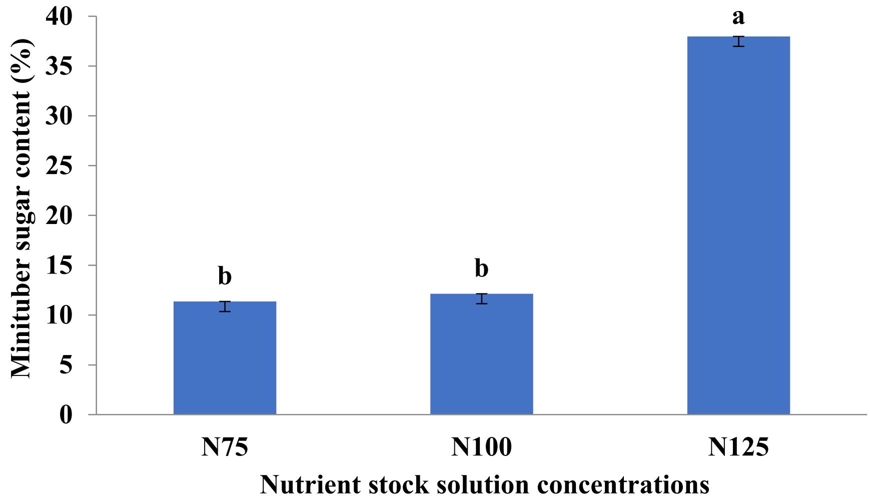

Figure 1. Effect of nutrient stock solution concentrations on the minituber sugar content.

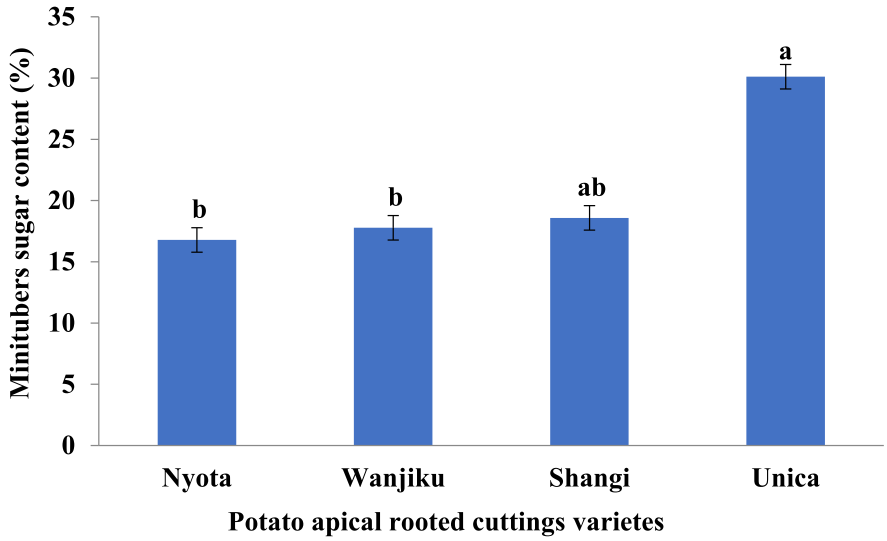

Figure 2. Effect of potato apical rooted cuttings varieties on the sugar content.

3.3. Correlation Analysis

A positive correlation of minitubers quality parameters, i.e., dry matter (TDM) with specific gravity (SG), starch content, phosphorus, ash and sugar content were observed as shown in Table 5. However, a negative correlation was reported between crude protein and all other parameters. A high positive correlation was observed between TDM, SG (0.67 ***) and starch content (0.82 ***). As the specific gravity of the minitubers increased, seed starch content and TDM increased. Previous studies have reported high correlations between SG, TDM and starch content [1,6]. An important seed potato quality is high starch and dry matter content which were positively correlated to specific gravity. Specific gravity is used to estimate tuber dry matter content in determining the better processing quality of the tubers [5]. Starch content, dry matter, specific gravity, and sugar content correlations depend on nutrient rates [12].

Table 5. Pearson correlation coefficients for minitubers quality parameters grown under nutrient stock solution concentrations.

Parameters	Dry Matter	Specific Gravity	Starch Content	P Content	Ash Content	Crude Protein	Total Sugars
Dry Matter	1						
Specific Gravity	0.67 ***	1					
Starch Content	0.82 ***	0.77 ***	1				
Phosphorus	0.042 NS	0.259 **	0.185 NS	1			
Ash Content	0.43 **	0.414 **	0.504 **	0.085 ***	1		
Crude Protein	−0.026 NS	−0.236 NS	−0.219 NS	0.109 NS	−0.050 NS	1	
Total Sugars	0.52 **	0.59 **	0.71 ***	0.185 NS	0.41 *	−0.134 NS	1

P: Phosphorus, NS: Not significant, * Significant ($p < 0.05$) ** significant ($p < 0.01$), *** significant ($p < 0.001$).

4. Conclusions

The results of the current study showed that increasing the nutrient stock solution concentrations from 75% to 125% of the ADC Molo nutrient formulation increased minituber quality parameters, i.e., starch, sugars, dry matter, crude protein, phosphorus, specific gravity and ash content which could contribute to quality potato production. Considering the superiority of the varieties, all varieties did not differ significantly in all parameters apart from sugars where Unica had high content as compared to Nyota and Wanjiku. Understanding the role of adequate nutrient supply in quality seed production should be taken into account. Therefore, it is recommended to apply 125% of ADC-Molo nutrient formulation for optimal minitubers quality. However, it is crucial to acknowledge that the higher nutrient concentration may not necessarily translate into lower production costs. Further research is recommended to evaluate the growth and yield performance of minitubers produced under varying nutrient stock solution concentrations.

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