Potassium Fertigation to Enhance the Performance of *Hypoxis hemerocallidea*

Patience Seyram Akakpo and Moosa Mahmood Sedibe

Department of Agriculture, Central University of Technology, Free State, Private Bag 6 x20539, Free State, Bloemfontein, 9300, South Africa

Bello Zaid

The Agricultural Research Council, Grain Crops Institute, Private Bag X1251, Potchefstroom, 2520, South Africa

Zenzile P. Khetsha

Department of Agriculture, Central University of Technology, Free State, Private Bag 6 x20539, Free State, Bloemfontein, 9300, South Africa

Mokgaputsiwa P. Theka-Kutumela

Department of Agriculture and Animal Health, College of Agriculture and Environmental Sciences, University of South Africa, Private Bag X6, Florida 1710, South Africa

Fhatuwani N. Mudau

Earth and Environmental Sciences, School of Agricultural, University of Kwa-Zulu Natal, Private Bag X01, Scottsville, Pietermaritzburg 3209, South Africa

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Abstract. Potassium (K) is an essential nutrient in plant metabolism, ionic balance, and stress resistance. In this study, the effects of K on agronomic attributes and on mineral and primary metabolite content in African potato were determined. K was administered hydroponically at four concentrations (4.00, 6.00, 8.00, and 10.00 meq·L⁻¹) using Steiner's universal nutrient solution. Chlorophyll content (CHL), leaf area (LA), fresh corm mass (FCM), number of roots (NR), root fresh weight (RFM), and root dry mass (RDM) were measured 18, 32, and 40 weeks after transplanting. Mineral analysis data were collected at 18 weeks, and primary metabolite data were collected at 32 weeks. Significant effects of K were observed after 18 weeks, and all test concentrations had a positive effect on yield. Calcium and boron significantly accumulated in the corm at 4.00 meq·L⁻¹ K. Alanine and malic acid were the only metabolites affected by K concentrations. More minerals accumulated in the corm at 4.00 meq·L⁻¹ K, whereas at 10.00 meq·L⁻¹ K, more minerals clustered in the leaf. K applied at 4.00 meq·L⁻¹ is recommended when growing African potato using a nutrient solution to improve corm mineral and metabolite accumulation.

Increasing global demand, and the subsequent overexploitation of natural medicinal plant resources calls for the cultivation of medicinal plants to meet growing demands (Chen et al., 2016; Kumar et al., 2016). The African potato (*Hypoxis hemerocallidea*) is one of the most popular medicinal plants in South Africa, used to treat many diseases. It

is widely harvested from wild populations, without intensive commercial cultivation (Kumar et al., 2016; Mofokeng et al., 2020). Only KwaZulu-Natal Province of South Africa has kept aside 250 ha of land to protect the African potato from overexploitation (Mofokeng et al., 2020). Thus, the domestication of wild plants is critical for sustainable development of this industry.

Fertilizers are used to replenish plants with the essential nutrients required for growth, yield, and quality enhancement (Kalaji et al., 2017; Nyakane et al., 2019). However, fertilizers need to be managed properly to achieve maximum plant production. Nutrient imbalances affect plant growth, yield, and metabolite synthesis due to chemical stress (Ávila-Juárez et al., 2017; Verma and Shukla, 2015). The use of a well-balanced nutrient solution is ideal because it ensures optimal plant production (Mugundhan et al., 2011). Therefore, nutrient

solutions are specifically formulated to meet the requirements of specific crops (Ávila-Juárez et al., 2017; Combrink, 2019).

In plants, potassium (K) plays a vital role in metabolism, the cation–anion balance, and stress resistance (Chrysargyris et al., 2017; Hasanuzzaman et al., 2018). However, there is only limited information on the nutrient requirements of the African potato. Therefore, the objective of this study was to determine the effects of K on agronomic attributes, minerals, and the primary metabolite content in this species. This study will also validate whether cultivated medicinal plants are less potent than their wild counterparts.

Materials and Methods

Experimental site. The study was carried out in a 72 m² (12 × 6 m) temperature-controlled greenhouse, located at the Central University of Technology, Free State campus (lat. 29°07'16.78"S, long. 26°12'45.95"E). The site is situated in a semiarid region, at ≈1395 m above sea level. The greenhouse temperature was maintained at a constant 26 °C.

Description of the greenhouse facility. The greenhouse was covered using a transparent 200-μm polyethylene covering sheet [Gundle Plastics Group (Pty.) Ltd., Gauteng, South Africa]. During the study, because the structure was made of transparent polyethylene sheets, greenhouse day and night temperatures were said to mimic environmental field conditions. The daylength was like the outside conditions because the structure was completely exposed to the outside environment. The temperature sensor was set at 26 °C to trigger and activates the axial fan to remove hot air within the greenhouse. Relative humidity, maximum and minimum air temperature inside the greenhouse facility were measured with a Vaisala meter. During the study, the greenhouse interior highest temperature was in December with the maximum temperature of 34.50 °C during the day and minimum temperature of 16.00 °C. The lowest temperature was in July with maximum temperature of 20.20 °C and minimum temperature of 0.80 °C at night (Table 1).

Planting, irrigation, and general plant management. African potato plantlets generated from tissue culture were obtained from the Agricultural Research Council of South Africa—Vegetable and Ornamental Plant Institute. The experiment was conducted from 29 Oct. 2018 to 2 Aug. 2019 (plants were grown for nine months). Plants were grown in black 9-L potting bags filled with organic potting media at a 2:1 ratio of pine bark and palm peat. Pine bark support plants growth for more than one growing season without any potential for immobilization of nutrients under greenhouse conditions (Jackson and Wright, 2009). Nutrient solution used to prepare experimental treatments is shown in Table 2.

A custom-made 110-L growing unit (Fig. 1), consisting of a recirculating nutrient solution was used to fertigate experimental plants. The nutrient solutions were adjusted to pH 5.5 ± 0.1 by adding 47 mL 60% nitric acid per 1000 L of

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P.S.A. is the corresponding author. E-mail: mse-dibe@cut.ac.za.

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Table 1. Ambient temperature during 2018 and 2019 growing season.

Months	Avg min. temp (°C)	Avg max. temp (°C)	Avg humidity (%)	Avg wind speed (m/s)	Avg pressure (hpa)
Oct. 2018	10.5	28.5	32.2	2.1	864.3
Nov. 2018	13.2	31.6	25.7	2.7	861.3
Dec. 2018	16.0	34.5	27.9	2.9	859.6
Jan. 2019	17.0	34.4	31.3	2.6	859.4
Feb. 2019	15.5	30.4	49.8	2.3	861.1
Mar. 2019	14.9	30.6	50.5	1.8	862.1
Apr. 2019	10.2	24.4	69.1	1.5	863.6
May 2019	6.6	23.7	63.1	0.9	866.2
June 2019	1.0	20.5	55.5	1.2	868.1
July 2019	0.8	20.2	49.4	1.5	866.8
Aug. 2019	3.8	25.3	27.7	1.7	874.8

Table 2. Mineral composition of the nutrient solution used to evaluate the effect of potassium on cultivated African potato.

Macronutrients (meq·L ⁻¹)						
K levels (meq·L ⁻¹)	K ⁺	Ca ²⁺	Mg ²⁺	NO ₃ ⁻	H ₂ PO ₄ ⁻	SO ₄ ²⁻
4.00	4.00	8.55	2.45	12.00	1.10	2.39
6.00	6.00	7.00	2.00	12.00	1.10	2.39
8.00	8.00	5.44	1.56	12.00	1.10	2.39
10.00	10.00	3.89	1.11	12.00	1.10	2.39

Micronutrients (mg·L ⁻¹)						
K levels (meq·L ⁻¹)	Fe ³⁺ (Fe-EDTA)	Mn ²⁺	Zn ²⁺	B ³⁺	Cu ⁺	Mo ⁶⁺
4.00	1.12	0.54	0.18	0.03	0.02	0.05
6.00	1.12	0.54	0.18	0.03	0.02	0.05
8.00	1.12	0.54	0.18	0.03	0.02	0.05
10.00	1.12	0.54	0.18	0.03	0.02	0.05

Low potassium applied at 4.00 meq·L⁻¹ K; standard or control applied at 6.00 meq·L⁻¹ K; high potassium applied at 8.00 meq·L⁻¹ K; and very high potassium applied at 10.00 meq·L⁻¹.

Fig. 1. Schematic representation of the growing unit and irrigation system used to grow African potato plants using potassium concentrations (4.00, 6.00, 8.00, and 10 meq·L⁻¹).

Table 3. Effects of potassium applied at 4.00, 6.00, 8.00 and 10 meq·L⁻¹ K concentration on agronomic attributes of African potato.

K levels (meq·L ⁻¹)	18 wk data collection										32-wk data collection									
	Chlorophyll ₁	LA ₁	Height ₁ (cm)	FCM ₁ (g/plant)	DCM ₁ (g/plant)	No. of roots ₁	RFM ₁ (g/plant)	RDM ₁ (g/plant)	No. of leaves ₁	LFM ₁ (g/plant)	Chlorophyll ₂	LA ₂	Height ₂ (cm)	FCM ₂ (g/plant)	No. of roots ₂ (g/plant)	RFM ₂ (g/plant)	RDM ₂ (g/plant)	No. of leaves ₂	LFM ₂ (g/plant)	LDM ₂ (g/plant)
4.00	16.21 ± 11.33 b	59.02 ± 30.10 ab	78.56 ± 10.24 a	54.13 ± 19.24 a	23.66 ± 5.00 a	64.09 ± 21.43 a	4.01 ± 1.54 a	9.33 ± 3.26 a	18.50 ± 10.38 a	5.06 ± 3.68 a	14.20 ± 10.16 a	83.65 ± 65.00 a	73.93 ± 6.78 a	15.62 ± 3.55 a	4.20 ± 1.13 a	12.00 ± 2.44 a	18.01 ± 5.08 a	1.08 ± 0.30 a	9.50 ± 1.04 a	19.16 ± 13.24 a
6.00	13.10 ± 12.18 b	39.15 ± 27.79 b	67.65 ± 12.66 a	34.91 ± 10.53 b	23.33 ± 7.33 a	61.97 ± 34.55 a	3.75 ± 2.32 a	9.00 ± 3.52 a	9.16 ± 6.55 a	2.92 ± 2.12 a	9.84 ± 11.01 a	53.90 ± 59.21 a	67.23 ± 4.52 a	13.01 ± 5.11 a	3.21 ± 1.14 a	11.33 ± 2.25 a	17.16 ± 7.26 a	1.06 ± 0.58 a	9.16 ± 2.48 a	15.66 ± 10.89 a
8.00	20.48 ± 10.71 ab	63.91 ± 29.01 ab	76.96 ± 8.61 a	42.14 ± 16.07 ab	27.83 ± 7.37 a	72.27 ± 28.54 a	4.12 ± 2.05 a	9.50 ± 2.66 a	14.00 ± 7.48 a	3.49 ± 1.66 a	14.65 ± 8.33 a	67.64 ± 46.74 a	66.51 ± 6.08 a	14.35 ± 4.43 a	3.98 ± 1.31 a	12.33 ± 3.26 a	19.25 ± 7.54 a	1.16 ± 0.53 a	10.00 ± 1.89 a	16.83 ± 7.46 a
10.00	28.51 ± 7.10 a	87.59 ± 19.21 a	73.23 ± 7.94 a	57.13 ± 14.52 a	27.83 ± 3.81 a	78.42 ± 22.37 a	4.92 ± 1.58 a	7.83 ± 2.71 a	18.50 ± 9.46 a	4.07 ± 2.17 a	6.53 ± 6.01 a	51.76 ± 43.52 a	72.71 ± 9.69 a	12.70 ± 5.30 a	3.43 ± 1.50 a	10.00 ± 1.26 a	14.56 ± 4.71 a	0.87 ± 0.33 a	8.50 ± 1.37 a	13.00 ± 9.46 a
LSD _T 0.05	11.81 ^{NS}	57.52 ^{NS}	8.98 ^{NS}	4.66 ^{NS}	1.39 ^{NS}	2.73 ^{NS}	7.10 ^{NS}	0.51 ^{NS}	2.08 ^{NS}	10.59 ^{NS}	11.81 ^{NS}	57.52 ^{NS}	8.98 ^{NS}	4.66 ^{NS}	1.39 ^{NS}	2.73 ^{NS}	7.10 ^{NS}	0.51 ^{NS}	2.08 ^{NS}	10.59 ^{NS}
LSD _T 0.05	10.72*	29.47*	11.28 ^{NS}	17.49*	6.59 ^{NS}	28.99 ^{NS}	2.07 ^{NS}	2.89 ^{NS}	9.36 ^{NS}	2.56 ^{NS}	10.72*	29.47*	11.28 ^{NS}	17.49*	6.59 ^{NS}	28.99 ^{NS}	2.07 ^{NS}	2.89 ^{NS}	9.36 ^{NS}	2.56 ^{NS}

The Tukey's Student range test was used to separate means. Statistical significance at $P < 0.05$, *** $P < 0.001$, ** $P < 0.001$, * $P < 0.05$, NS = not significant at $P < 0.05$, ± standard deviation, LSD_T 0.05 = least significant difference at 5% level of significance. Means with the same letter within a column are not significantly different ($P < 0.05$). Subscripts 1 and 2, represent the first, and second data collection, respectively.

LA = leaf area, FCM = fresh corm mass, DCM = dry corm mass, RFM = root fresh weight, RDM = root dry mass, LFM = leaf fresh weight, LDM = leaf dry mass.

water to lower HCO₃⁻ to 0.40 meq·L⁻¹ and EC was kept at 1.62 ± 0.01 mS·cm⁻¹ (Combrink, 2019). Each growing unit had an irrigation pump with a 700 L·h⁻¹ flow rate capacity.

Irrigation was scheduled and adjusted according to the age of plants, season, and the moisture content of the growing media (Mofokeng et al., 2020). Accumulation of salts in the growth media was minimized by applying large volumes of nutrient solution (3-h irrigation) in each irrigation cycle to ensure 10% to 15% leaching (Nyakane et al., 2019). Nutrient solutions were replaced with fresh solution once a month to avoid nutrient imbalances (Khetsha and Sedibe, 2015). Micronutrients used in all experimental treatments were prescribed by Combrink (2019).

Experimental design. Four levels of K were evaluated: 4.00, 6.00, 8.00, and 10.00 meq·L⁻¹, arranged in a randomized complete block design with six replications. Each experimental unit had five potted plants. Levels of K and the anions and cations used in this study are shown in Table 2. Agronomic attribute data collection was taken at three time points: 18, 32, and 40 weeks.

Agronomic attributes. Chlorophyll content (CHL), leaf area (LA), fresh corm mass (FCM), root fresh weight (RFM), and root dry mass (RDM) were determined at 18, 32, and 40 weeks. LA was determined using a portable leaf area meter (CI-202 portable Laser Leaf Area Meter; CID Bio-Science Inc., Camas, WA). CHL was measured at harvest using a portable non-destructive chlorophyll meter (CCM-2000; Opti-Sciences Inc., Hudson, NH) (Sedibe, 2020). The masses of fresh and dry roots, and corms were measured using a laboratory scale (Denver Instrument APX-602, Bohemia, NY). The roots and corms were washed immediately under running tap water while still attached to the mother plants. For each plant, the roots were counted and then detached from the corm for weighing. The corm was also detached from the plant afterward and weighed. All measurements for each plant took ≈5 min. Harvested materials were oven dried before dry mass and the mineral content measurements.

Mineral analysis. Plant material obtained from the corms and leaves was oven dried at 60 °C for 72 h after mineral analysis (Singh and Praharaj, 2017). Leaf and corm K, Ca, P, Mg, Fe, Zn, Mn, B, and Cu were determined using atomic emission spectrometry with inductive coupled plasma optical emission spectrometry (ICP-OES) (Optima 4300 DV ICP-OES; PerkinElmer Inc., Waltham, MA). The Dumas combustion method was used for total nitrogen determination in a Leco FP-528 combustion nitrogen analyzer (LecoCorp, St. Joseph, MO). Plant sulfur was determined by ICP-OES using an extract solution (Horiba Jobin Yvon, Ultima, Edison, NJ) (Sedibe and Allemann, 2012). Mo was determined by the calorimetric method after digesting samples with

Fig. 2. Effects of potassium (4.00, 6.00, 8.00, and 10 meq·L⁻¹) on root fresh weight of African potato collected 40 weeks after transplanting. Standard error (SE) is shown on the bar chart, the same letter on the bar charts denotes nonsignificance ($P < 0.05$), replications per treatment, $n = 6$.

HNO₃ and HClO₄ (Singh and Praharaj, 2017).

Primary metabolite analysis. Only the corms were used to determine primary metabolites. The corm samples were prepared using the method described by Nsibandé et al. (2018). Primary metabolites were determined using the ultra high-performance liquid chromatography (UHPLC)–mass spectrometry analysis method described by Mncwangi et al. (2014). The UHPLC analysis was performed on a Waters Acquity UHPLC system with photodiode array detection (Waters, Milford, MA).

Statistical analysis. Analysis of variance was conducted using statistical analysis software program (SAS Institute Inc., 2017) with

the general linear model procedure. The Tukey's Student range test was used to separate means that were significantly different, at a P value of 0.05, as described by Steel and Torrie (1980). A principal component analysis (PCA) was done using XLSTAT 2015.04.36025 statistical software.

Results

Agronomic attributes. Different concentrations of K had significant effects on agronomic attributes after the first harvest (Table 3). CHL₂, LA₂, and FCM₂ were significantly affected by K application at 10.00 meq·L⁻¹ ($P < 0.05$). CHL₂ was significantly higher in plants grown at 10.00 meq·L⁻¹ K ($28.51 \pm$

7.10) than plants at 6.00 meq·L⁻¹ K (13.10 ± 12.18) and 4.00 meq·L⁻¹ K (16.21 ± 11.33). LA₂ and FCM₂ were also increased in plants grown in 10.00 meq·L⁻¹ K (87.59 ± 19.21 and 57.13 ± 14.52 , respectively) compared with those grown in 6.00 meq·L⁻¹ K (39.15 ± 27.79 and 34.91 ± 10.53 , respectively).

For the third stage of data collection (40 weeks) only fresh corm mass (FCM₃), number of roots (NR₃), root fresh weight (RFM₃), and root dry mass (RDM₃) were measured because plants were experiencing dieback during the winter months (June–August). Out of these agronomic attributes, only RFM₃ and RDM₃ were significantly affected by K levels ($P < 0.05$) (Figs. 2 and 3). The highest RFM₃ (74.82 ± 24.12) was at 10.00 meq·L⁻¹

Fig. 3. Effects of potassium (4.00, 6.00, 8.00, and 10 meq·L⁻¹) on root dry mass of African potato collected 40 weeks after transplanting. Standard error (SE) is shown on the bar chart, the same letter on the bar charts denotes nonsignificance ($P < 0.05$), replications per treatment, $n = 6$.

Table 4. Effects of potassium applied at 4.00, 6.00, 8.00, and 10 meq·L⁻¹ K concentration on mineral accumulation in the leaf and the corm of African potato.

K levels (meq·L ⁻¹)	Leaf mineral (mg·kg ⁻¹)										
	N (%)	K	Ca	S	P	Mg	Fe	Zn	Mn	B	Mo
4.00	2.62 ± 0.03 a	47,028.55 ± 5,493.44 a	9,003.51 ± 1,200.54 a	2,985.87 ± 327.11 a	2,341.07 ± 455.59 a	2,286.36 ± 125.91 a	95.63 ± 7.56 a	41.41 ± 4.89 a	39.81 ± 3.62 a	97.61 ± 26.95 a	3.52 ± 0.30 a
6.00	2.62 ± 0.10 a	41,408.76 ± 6,432.39 a	7,854.18 ± 1,000.40 a	3,007.14 ± 382.71 a	1,862.92 ± 265.31 a	2,115.12 ± 192.72 a	101.18 ± 21.35 a	43.01 ± 4.91 a	32.53 ± 2.47 a	108.93 ± 14.96 a	3.44 ± 0.47 a
8.00	2.55 ± 0.12 a	50,395.13 ± 1,190.80 a	8,187.40 ± 904.01 a	3,571.15 ± 206.47 a	2,051.62 ± 142.47 a	2,349.02 ± 290.11 a	97.27 ± 11.29 a	43.12 ± 3.66 a	32.92 ± 8.57 a	90.00 ± 23.28 a	4.08 ± 0.68 a
10.00	2.65 ± 0.09 a	54,292.19 ± 5,897.76 a	7,142.46 ± 617.95 a	3,740.86 ± 747.46 a	1,922.37 ± 159.29 a	2,388.82 ± 397.49 a	85.57 ± 9.18 a	45.89 ± 5.40 a	38.89 ± 16.69 a	84.81 ± 31.14 a	3.61 ± 0.46 a
LSDT 0.05	0.20 ^{NS}	10,328.00 ^{NS}	2,022.50 ^{NS}	884.96 ^{NS}	613.42 ^{NS}	608.54 ^{NS}	28.28 ^{NS}	9.02 ^{NS}	18.57 ^{NS}	56.00 ^{NS}	0.81 ^{NS}

K levels (meq·L ⁻¹)	Corm mineral (mg·kg ⁻¹)										
	N (%)	K	Ca	S	P	Mg	Fe	Zn	Mn	B	Mo
4.00	3.12 ± 0.57 a	18,988.54 ± 1,131.42 a	9,466.59 ± 2,006.87 a	4,158.93 ± 833.74 a	4,100.17 ± 695.65 a	2,029.86 ± 313.37 a	211.14 ± 58.34 a	168.20 ± 74.98 a	29.39 ± 6.80 a	25.08 ± 1.76 a	12.67 ± 9.41 a
6.00	3.18 ± 0.27 a	17,134.43 ± 3,456.33 a	7,633.48 ± 445.60 ab	4,316.39 ± 204.98 a	3,741.12 ± 304.25 a	2,194.31 ± 319.35 a	128.18 ± 14.61 a	93.78 ± 4.71 a	28.69 ± 5.23 a	20.20 ± 1.10 b	7.09 ± 2.16 a
8.00	3.35 ± 0.05 a	18,709.94 ± 1,485.54 a	6,964.93 ± 381.15 b	4,239.24 ± 95.61 a	3,767.79 ± 205.33 a	2,023.20 ± 102.46 a	144.45 ± 49.09 a	100.31 ± 16.33 a	24.51 ± 1.53 a	18.37 ± 2.56 b	10.25 ± 3.15 a
10.00	2.91 ± 0.13 a	19,906.96 ± 712.01 a	6,121.27 ± 641.62 b	3,656.85 ± 162.58 a	3,497.94 ± 603.82 a	1,905.53 ± 321.20 a	117.94 ± 43.44 a	75.83 ± 1.96 a	26.51 ± 1.25 a	18.53 ± 0.93 b	5.24 ± 1.91 a
LSDT 0.05	0.65 ^{NS}	4,224.1 ^{NS}	2,133.2 [*]	949.85 ^{NS}	778.37 ^{NS}	532.95 ^{NS}	101.69 ^{NS}	75.82 ^{NS}	8.77 ^{NS}	3.89 [*]	10.78 ^{NS}

The Tukey's Student range test was used to separate means. NS, *, **, ***Nonsignificant or significant at $P < 0.05$, 0.001, or 0.0001. $\pm$ = standard deviation, LSD_{0.05} = least significant difference at 5% level of significance. Means with the same letters within a column are not significantly different ($P < 0.05$).

K, which was not significantly higher than plants grown using a nutrient solution containing 4.00 meq·L⁻¹ K (56.12 ± 25.04). There were no significant differences between 4.00, 6.00, and 8.00 meq·L⁻¹ K. RDM₃ of the 10.00 meq·L⁻¹ K treated plants was highest (4.59 ± 1.78), but was not significantly different from the RDM₃ of plants grown in 4.00 (3.31 ± 1.59) and 8.00 (3.18 ± 1.41) meq·L⁻¹ K. The RDM₃ was significantly lower ($P < 0.05$) at 6.00 meq·L⁻¹ K. Although the same trends were not found in the other measured traits, plants grown in 10.00 meq·L⁻¹ produced the highest LA, FCM, RFM, and RDM values.

Mineral accumulation in the leaf and corm. The leaf and corm mineral contents from African potato are shown in Table 4. Apart from Ca and B in the corm, there was no significant effect of K concentration on leaf mineral concentration for the rest of the target minerals. Ca concentration in the corm was significantly higher ($P < 0.05$) when a low level (4.00 meq·L⁻¹ K) nutrient solution was applied, compared with Ca levels obtained at 8.00 and 10.00 meq·L⁻¹, but did not differ significantly from K levels of 6.00 meq·L⁻¹. Similarly, a significantly high ($P < 0.05$) B content was also measured in plants grown in 4.00 meq·L⁻¹ K nutrient solution, however, no significant differences occurred at 6.00, 8.00, or 10.00 meq·L⁻¹ K.

Primary metabolites. Only alanine and malic acid metabolites were significantly ($P < 0.05$) affected by the concentration of K, as shown in Figs. 4 and 5. Alanine was highest at 10.00 meq·L⁻¹; however, malic acid decreased with increased levels of K in the nutrient solution from 4.00 meq·L⁻¹ K until 8.00 meq·L⁻¹ K, where a 4437261 peak area was recorded.

Principal component analysis. In the PCA, most measured agronomic attributes were loaded positively on PC1 (Fig. 6). PC1 accounted for 55.17%, whereas PC2 accounted for 12.84% of the variation. K concentrations of 4.00, 8.00, and 10.00 meq·L⁻¹ positively loaded most agronomic attributes together.

A very weak negative correlation occurred between K and Ca in both the leaf ($r^2 = -0.39$) and corm ($r^2 = -0.26$). K and B had a strong negative association in the leaf ($r^2 = -0.99$), although no relationship existed between K and B in the corm ($r^2 = -0.05$). Two principal components explained the total variation of 80.36% in mineral accumulation (Fig. 7). PC1 accounted for 51.70%, and PC2 accounted for 28.65%. The K level of 4.00 meq·L⁻¹ positively loaded corm B, P, Fe, Zn, Ca, Cu, and Mn, as well as leaf P and Ca together in one cluster on PC2. Corm K, followed by leaf K, Mg, Mn, N, and S were loaded positively on PC1 when 10.00 meq·L⁻¹ of K was used in the nutrient solution.

The PCA showed that most primary metabolites positively loaded on PC1, except carnitine, glycine, and creatinine,

which loaded negatively on both PC1 and PC2 (Fig. 8). The total percentage of both PCs was only 36.55%, with PC1 accounting for 21.70% and PC2 accounting for 14.85% of the total variation. Most primary metabolites loaded positively at all the applied K concentrations.

Discussion

The concentration of K had a significant effect on agronomic attributes, mineral accumulation, and primary metabolite synthesis in African potato plants. The increased CHL, LA, FCM, RFM, and RDM observed at 10.00 meq·L⁻¹ K might be attributed to enhanced enzyme activity, as K is known to activate enzymes in plant metabolism (Chrysargyris et al., 2017; Koch et al., 2019). Increased CHL content at 4.00 meq·L⁻¹ K, and the consequent increase in other agronomic attributes despite the low K levels, might be due to the higher levels of Ca and Mg, which are also involved in cell growth and enzyme activation (Jones, 2012; Mugundhan et al., 2011).

K and Ca have a strong antagonistic relationship (Nguyen et al., 2017); however, in this study, no significant antagonistic relationship between K and Ca was found. Increased Ca and B accumulation in the corm at the lowest K concentration might be due to the genetic ability of African potato to accumulate nutrients in the corm, even at low soil fertility levels (McAlister and van Staden, 1995).

Primary metabolites are vital for growth, development, and the response to environmental pressures (Hong et al., 2016; Khan et al., 2020). Secondary metabolites are biosynthetically produced from primary metabolites (Kumar and Rajesh, 2018). In the current study, alanine increased with higher K concentrations in the nutrient solution. This result concurs with the results of Ibrahim et al. (2012) that have indicated that increasing K increased the production of soluble protein and phenylalanine ammonia-lyase activity in *Labisia pumila*. Therefore, increasing K, and the corresponding increase in alanine production, could promote useful secondary metabolite synthesis in African potato. Malic acid acts as a counter ion for K and Ca cations, particularly in nitrate-dependent plants (Ghazijahani et al., 2018). The rise in Ca at 4.00 meq·L⁻¹ K increased malic acid synthesis, however, increasing K up to 8.00 meq·L⁻¹ K decreased malic acid production. This trend in malic acid synthesis was erratic and inconsistent, which might be due to the combined effects of nutrient imbalances and other environmental conditions that were not tested.

Most agronomic attributes were loaded positively on PC1, with most clustering together at K levels of 4.00, 8.00, and 10.00 meq·L⁻¹. The PCA grouped certain minerals according to the K levels. Leaf P and Ca along with corm B, P, Fe, Zn, Ca, Cu, and Mn clustered positively at 4.00 meq·L⁻¹ K. On the other hand, corm K in addition to leaf K, Mg, Mn, N, and S were attributed to 10.00 meq·L⁻¹ K on PC1. Because the corm is harvested and used for medicinal purpose,

Fig. 4. The peak area of alanine in liquid chromatography–mass spectrometry of African potato plants fertigated using potassium (4.00, 6.00, 8.00, and 10 meq·L⁻¹) nutrient solution. The Tukey's Student range test was used to separate means. Standard error (SE) is shown on the bar chart, the same letter on the bar charts denotes non significance ($P < 0.05$), replications per treatment, n = 6.

Fig. 5. The peak area of malic acid in liquid chromatography–mass spectrometry of African potato fertigated using potassium (4.00, 6.00, 8.00, and 10 meq·L⁻¹) nutrient solution. The Tukey's student range test was used to separate means. Standard error (SE) is shown on the bar chart, the same letter on the bar charts denotes nonsignificance ($P < 0.05$), replications per treatment, n = 6.

nutrient solutions with 4.00 meq·L⁻¹ K could be recommended for fertigating African potato. All K levels used in this study had a positive effect on primary metabolite synthesis, which could positively affect secondary metabolism in these plants (Kumar and Rajesh, 2018).

Conclusion

These results show that the successful cultivation of African potato could be achieved through nutrient management in

a temperature-controlled greenhouse. This study revealed that a high K nutrient solution is needed to improve all the measured agronomic traits, but this did not affect the leaf mineral content. K nutrient solution affected some mineral and primary metabolite components of the corm; therefore, plant parts that are important for medicinal purposes should be investigated further. Since the corm is harvested and used for medicinal purposes, a nutrient solution with 4.00 meq·L⁻¹ K can be recommended to fertigate African potato because this

solution accumulates micronutrients in the corm. Primary metabolite synthesis of African potato at a low K level of 4.00 meq·L⁻¹ might yield useful secondary metabolites responsible for the medicinal properties of African potato. A further secondary metabolite analysis should be conducted to ascertain the right K level for growing African potato of high medicinal quality. It may be beneficial to determine K content of the growth media before planting in future studies because some growth media may contain traces of K.

Fig. 6. Rotated principal component loadings of agronomic attributes of African potato grown using potassium applied at 4.00, 6.00, 8.00, and 10 meq·L⁻¹ K concentration. CHL = chlorophyll content; LA = leaf area (cm²); PH = plant height (cm); FCM = fresh weight of corms (g); DCM = dry mass of the corms (g); NR = number of roots; RFM = root fresh weight (g); RDM = root dry mass (g); NL = number of leaves per plant; LFM = leaf fresh weight (g); LDM = leaf dry mass (g); 1, 2, and 3 represent the first, second, and third data collections, respectively.

Fig. 7. Rotated principal component loadings of mineral accumulation in the leaf and corm of African potato grown using potassium applied at 4.00, 6.00, 8.00, and 10 meq·L⁻¹ -K concentration.

Fig. 8. Rotated principal component loadings of primary metabolites of African potato grown using potassium applied at 4.00, 6.00, 8.00, and 10 meq·L⁻¹ -K concentration.

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