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Nutrients and antinutrient constituents of *Amaranthus caudatus* L. Cultivated on different soils

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ABSTRACT

This study investigated variations in the concentration of nutrients, antinutrients and mineral content of *Amaranthus caudatus* harvested from different soil types at various stages of maturity. Four out the five soils namely; sandy clay loam, silty clay loam, clayey loam and loam were experimentally formulated from primary particles of silt, clay and sand in line with the United State Department of Agriculture's (USDA) soil triangle protocol. The unfractionated soil was used as the control. After harvesting at pre-flowering (61 days after planting), flowering (71 days after planting) and post-flowering (91 days after planting) stages, nutrient and antinutrient analyses were carried out following Association of Official Analytical Chemists (AOAC) and other referenced methods while the Inductively Coupled Plasma-Optical Emission Spectrometer was used to determine mineral compositions of the plant samples. The results of the study revealed that particle size and physicochemical properties of the soil influenced the number of minerals deposited in plant tissues. It was further observed that the nutritional properties of the plant change as plant ages. For an optimal yield of vitamins A and E, clayey loam proved to be the best soil particularly when *A. caudatus* is harvested before flowering but for vitamin C, sandy clayey loam yielded the highest output at the same stage. Similarly, clayey loam and loam soils yielded the highest proximate compositions at flowering and pre-flowering; however, mineral elements (micro and macro) were highest in control and loam soils.

1. Introduction

Overdependence on a few major crops such as potato, wheat, maize, and rice over the years has been the root cause of malnutrition affecting two billion people worldwide (Hashimoto et al., 2012; Stein, 2010). This is one of the major failures of food systems globally as the nutritional needs of every household could not be guaranteed. In the last four decades, the world has experienced somersaults of agricultural policies which have resulted in a decline in nutrients and food diversity (Alston et al., 2013; Famogbiele, 2013; Hawkes et al., 2012). There is, therefore, an urgent need to embrace diversification of dietary intake as a food-based step to improve the biological value of diets. This can be achieved by shifting attention to alternate crops capable of providing essential nutrients needed for body upkeep and achieve diet diversity (Jimoh et al., 2018; Joshi et al., 2018).

Recently, the safety profile of natural products has gained endorsement as potential sources of new therapies and as a viable supplement to common pharmacological options (Atanasov et al., 2015; Dixon, 2001; Shen, 2015). A number of amaranth species have been profiled and proven to possess natural therapeutic remedies for cancer, convulsion, diabetes, helminthic infections, inflammation, cardiovascular complications and hepatic disorders (Jimoh et al., 2019a; Zambrana et al., 2018). This is a welcomed development particularly to low-income earners who cannot afford the rising cost of synthetic drugs needed to combat the burden of diseases and associated side effects.

Antinutrients and nutrients in plant-based foods relate in a manner that enhances and coordinates bioavailability of micronutrients to humans (Gemede and Ratta, 2014; Hotz and Gibson, 2007; Welch, 2002). This has placed plants at a central position

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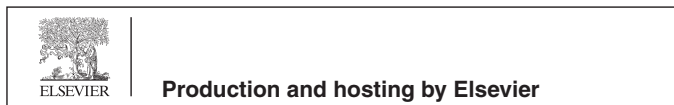
in human nutrition. Among leafy vegetables, amaranths have been generally reported to have excellent nutritional characteristics. This is due to the high content of vital micronutrients such as calcium, magnesium, iron, vitamin C and other essential nutrients such as gluten-free carbohydrate needed for healthy living (Achigan-Dako et al., 2014; Jimoh et al., 2018).

The vegetables and grains of *Amaranthus* species were among the favourite foods in the pre-Colombian America, Aztec, Africa and recently in North America basically for their gluten-free proteins and high-grade essential amino acids composition (Li et al., 2015). Compared to other vegetables, amaranth proteins are of higher quality and in addition, they lack saturated fat and contain low sodium. The nutraceutical properties of the genus and its peculiarity as a depot of bioactive compounds have endeared it to the food and pharmaceutical factories where it is used as primary precursors for drugs and food supplements (Jimoh et al., 2019b; Man et al., 2017; Rusu et al., 2010).

Soil texture greatly influences the rate of water infiltration and retention in the soil (Jalota et al., 2010; Rabot et al., 2018; Ruehle, 2009). Invariably, it determines the quantity and quality of minerals available to plant absorption (Lekshmi et al., 2014). In addition, soil particle size in conjunction with the chemical properties of the soil affects the resultant chemical content of these minerals and their uptake from soil. Also, the accumulation of vitamins and phenolic compounds has been said to have a direct relationship with soil mineral content and it relates in inverse order with the growth rate of plants (Tsao et al., 2006). Therefore, soil and other environmental factors have the capacity to alter a plant's structure and its nutritive properties and ultimately, affect the bioconcentration of nutrients in plant tissues (Adewuyi et al., 2010; Chang et al., 2014a,b).

Considering the reports in some literature that soil texture modulation could affect the nutritional properties of plants at various growth stages (Khaled and Fawy, 2011; Riipi et al., 2002; Stolf et al., 2011), this study investigated how these parameters affect nutrients, antinutrients and minerals accumulation in *A. caudatus* cultivated in different soils. Although the nutritional characteristics of *A. caudatus* have been extensively explored (Alvarez-Jubete et al., 2010; Jiménez-Aguilar and Grusak, 2017; Jimoh et al., 2018; Venskutonis and Kraujalis, 2013); however, there is a dearth of information on the combined effects of soil types and maturity stages on its proximate compositions. Therefore, a combination of these two parameters (soil type and harvest stage) in this study will assist in determining the best time for harvest and the soil with optimal yield in nutrients and mineral accumulation. The final gains of this research will, therefore, lead to the enhancement of diets diversity, increase in food security and assist in combating malnutrition and hunger.

2. Materials and methods

2.1. Experimental soil formulation

A heap of topsoil collected from the University of Fort Hare's Research Farm in Alice, South Africa was air-dried under shade for 4 weeks. The dried soil was ground and sifted into parent particle sizes of clay (<2μm), silt (<50–2 μm) and sand (<2000–50 μm) using iron sieves of designated mesh. Four different experimental soils were formulated by mixing sieved soil particles of clay, silt and sand in relative proportions recommended by the USDA's soil texture triangle (Table 1). The reconstituted soils were used for cultivation alongside with the unfractionated control soil.

2.2. Plant materials, experimental design, cultivation, plant collection and processing

Viable seeds of *A. caudatus* provided by Professor AJ Afolayan of the Medicinal Plants and Economic Development (MPED) Research Centre, Department of Botany, University of Fort Hare were cultivated in summer (between October 2017 and January 2018) in pots filled with reconstituted soils to the near brim. The pot experiment was conducted and organized in three replicates in a Completely Randomised Design (CRD) inside the glasshouse of the Department of Botany, University of Fort Hare under a controlled ambience (average temperature- 24.7 °C; relative humidity- 63%). Plants were consistently irrigated twice daily (morning and evening). At maturity, the shoots comprising leaves and stems were harvested at three growth stages namely; pre-flowering, flowering and post-flowering. The plant samples were sorted according to soil types and stages of harvest and dried in an oven set at 35℃ until a constant weight was attained. This was ground with an electric motor blender. Pulverized samples were transferred into airtight containers and kept in a refrigerator maintained at 4 ℃ for laboratory analyses.

2.3. Experimental analysis

With the exception of vitamins A, C and E where fresh samples were used, ground samples were used for the analyses of all nutrients and antinutrient components and all analyses were replicated three times using referenced laboratory protocol. Mineral analyses were carried out using the Inductively Coupled Plasma- Optical Emission Spectrometer standard procedure.

2.4. Effects of soil types on nutritive compositions

2.4.1. Determination of moisture content

The moisture content was determined following the procedures described by (AOAC, 2016) with slight modification. Empty porcelain vessels were oven-dried for one hour at 105 °C, cooled in a desiccator and weighed W_1. Ground samples of *A. caudatus* shoot harvested from the five soil types each weighing (1.000 ± 0.001) g W_2 was put in a vessel and oven-dried to a constant weight at 105 °C. The vessel and its content were transferred into a desiccator to cool off and re-weighed (W_3). The percentage of moisture content was estimated as given in equation [1] below.

$$\%\text{moisture content} = \frac{W2 - W3}{W2 - W1} \times 100 \tag{1}$$

2.4.2. The crude fibre contents

This was evaluated following Śmiechowska and Dmowski (2006) with slight modifications. About 2 g each of powdered

Table 1
Experimental soil formulation in proportions proposed by USDA soil texture triangle technique (Groenendyk et al., 2015).

S/N	Soil types	% Sand	% Silt	% Clay
1	Control soil (SF_1)	unfractionated	unfractionated	unfractionated
2	Sandy Clay Loam (SF_2)	66	13	21
3	Silty Clay Loam (SF_3)	10	60	30
4	Clayey Loam (SF_4)	36	30	34
5	Loam (SF_5)	40	40	20

samples of *A. caudatus* was boiled in 100 mL of 1.25% concentrated H_2SO_4 for 30mins using a digestion tablet, then filtered under pressure. The digested residue was initially washed with boiling water several times until a clear mixture was obtained and later, rinsed with 100 mL of 1.25% NaOH solution. The resulting residue was then dried at 100C, cooled in a desiccator and weighed (F_1). Afterwards, residues were incinerated for 5 h in a muffle furnace at 550C, cooled in a desiccator and re-weighed (F_2). The percentage of crude fibre was estimated as

$$\% \text{ crude fibre} = \frac{F1 - F2}{\text{Original weight of pulverised sample}} \times 100 \tag{2}$$

2.4.3. The crude fat contents

The crude fat was estimated as described in AOAC (2016). About 1 g of pulverised sample was extracted in 100 mL of diethyl ether and then shaken for 24 h on an orbital shaker. The mixture was then filtered and the filtrate collected in previously weighed clean beakers (W_1). The ether extract was further equilibrated with 100 mL diethyl ether, shaken on an orbital shaker for another 24 h and the filtrate was also collected in beaker (W_1). The ether filtrate was concentrated to dryness in a steam bath and oven-dried at 55C and the beaker was reweighed (W_2). The crude fat content was therefore evaluated as

$$\% \text{ crude fat content} = \frac{W2 - W1}{\text{Original weight of pulverised sample}} \times 100 \tag{3}$$

2.4.4. Ash content

The Association of Official Analytical Chemist (AOAC, 2016) protocol was used to determine the percentage ash content of plant samples. Porcelain crucibles labelled with sample codes using a heat resistant marker were oven-dried at 105C for 1 h. The crucibles were cooled in a desiccator and weighed (W_1). Later, 1 g each of the ground samples from various formulated soils was put in the pre-weighed porcelain crucibles and reweighed (W_2). The crucibles with the contents were arranged in a muffle furnace set at 250C for 1 h and subsequently, 550C for 5 h to ash the samples completely. Samples were allowed to cool in a desiccator and then weighed (W_3). The percentage ash content of the samples was evaluated as

$$\% \text{ Ash content} = \frac{W2 - W3}{W2 - W1} \times 100 \tag{4}$$

2.4.5. Crude protein

This was determined by digesting 2 g each of ground samples from formulated soils in a Kjeldahl flask by boiling with concentrated H_2SO_4 (20 mL) until a clear mixture was obtained, using digestion tablet as a catalyst (Adegbaju et al., 2019). The digested extracts were filtered dissolved in 250 mL and then distilled. The aliquot with 50 mL of 45% NaOH was further distilled in a 500 mL round-bottomed flask and 150 mL of the distillate was transferred into a flask having 100 mL of 0.1 M HCl. This was then titrated against 2.0 mol/L NaOH with methyl orange indicator. A yellow colour change indicated the endpoint of titration and the percentage nitrogen content was calculated as given in equation [5] below;

where N = normality and the percentage crude protein was obtained by multiplying the nitrogen value by a constant factor of 6.25 (USDA, 2018)

2.4.6. Neutral detergent fibre (NDF)

The NDF compositions of the samples were determined as described by (Idris et al., 2019) using the equation below;

$$\% \text{ NDF content} = \frac{(W1 + W2) - W1}{\text{Weight of sample}} \times 100 \tag{6}$$

2.4.7. Non-Fibre carbohydrate (NFC)

The non-fibre carbohydrate content of the sample was estimated from the formula

$$\%NFC = 100 - (\% \text{ Ash} + \% \text{ Crude fat} + \% \text{ Crude protein} + \% \text{ NDF}) \tag{7}$$

2.4.8. Energy content

The energy content for each of the sample of *A. caudatus* from different soil treatments was estimated by adding the multiplied value each respectively for total carbohydrate, crude lipid (excluding fibre) and crude protein using factors (17 KJ, 37KJ and 17 KJ) using the conversion factor given by FAO, (2003).

$$\text{Energy content(KJ/100g)} = (CHO \times 17) + (\text{crude fat} \times 37) + (\text{crude protein} \times 17) \tag{8}$$

where CHO is the total carbohydrate determined from the equation [8] below; (Tylutki et al., 2008)

$$CHO = NFC + NDF \tag{9}$$

2.4.9. Vitamin content

Vitamins A, C and E were determined following the methods described by Pearson and Cox, (1976) with slight modifications by Idris et al. (2019).

2.4.10. Vitamin a

One gram each of pulverised samples of the plant was macerated with 20 mL of petroleum ether. This was poured out into a test tube and then evaporated to dryness. Later, 0.2 mL of chloroform–acetic anhydride (1:1, v/v) was added to the residue and 2 mL of TCA-chloroform (1:1, v/v) was added to the solution formed. The absorbance of the resulting solution was measured at 620 nm using the USA made Diagnostic Automation, Inc microplate reader (SN: 259557). Vitamin A standard (retinol) was prepared in the same manner as pulverised samples and measured at the same absorbance. The concentration of vitamin A in the sample was deduced from the standard linear graph equation y = 0.4744x − 0.1947, R^2 = 0.9589.

2.4.11. Vitamin C

This was evaluated by macerating 1 g each of the plant samples with 20 mL of 0.4% oxalic acid. The mixture was filtered and 2,6-dichlorophenolindophenol reagent was reacted with the filtrate in ratio 9 to 1. The absorbance of the resulting solution and that of Vitamin C standard solution (ascorbic acid) which was prepared in the same way was read at 520 nm. Vitamin C content of the each

$$= \frac{[(\text{ml std acid} \times \text{N of acid}) - (\text{ml blank} \times \text{N of base})] - (\text{ml std base} \times \text{N of base}) \times 1.4007}{\text{Original weight of pulverised sample}} \tag{5}$$

of the samples was extrapolated from the standard curve y = -0.4
12ln(x) + 0.4621, R² = 0.9633

2.4.12. Vitamin E

Vitamin E content was determined by macerating 1 g each of
the pulverised samples of the harvests from different soils with
20 mL ethanol. The mixture was filtered and to 1 mL of the filtrate,
1 mL each of 0.5% α-α-dipyridine and 0.2% ferric chloride in etha-
nol was added. The solution was made up to 5 mL with distilled
water and absorbance was measured at 520 nm. Vitamin E stan-
dard (∝-tocopherol) solution was prepared in the same manner
and concentration of Vitamin E was determined from the standard
straight-line graph y = 1.9283x − 6.2896, R² = 0.9661

3. Effects of soil types on antinutrient compositions

3.1. Alkaloid content

The method described by Omoruyi et al., (2012) was used to
determine the percentage alkaloid content. About 5 g each of pul-
verized plant samples was mixed with 200 mL of 10% acetic acid in
ethanol and the mixture was left to stand for 4 h in a covered con-
tainer. The mixture was filtered and the filtered extract was con-
centrated to a quarter of its volume on a water bath. Drops of
concentrated ammonium hydroxide were added to the concen-
trated extract until a cloudy fume was formed. The cloudy precip-
itate was allowed to settle and washed with dilute ammonium
hydroxide. The resulting mixture was filtered and the residue
was collected, dried and weighed. The alkaloid content was esti-
mated from the equation [9] given below;

$$\% \ \text{alkaloid content} = \frac{\text{Weight of precipitate}}{\text{Weight of original sample}} \times 100 \qquad (10)$$

3.2. Oxalate content

The oxalate content was determined from the modified titration
procedure described by Unuofin et al., (2017). About 1 g each of the
pulverised plant samples was weighed in a conical flask and 75 mL
of 3 M H_2SO_4 was added and agitated on a magnetic stirrer for one
hour. The mixture was filtered and 25 mL of filtrate collected was
heated to about 90C. The hot aliquot was titrated uninterruptedly
against 0.05 M $KMnO_4$ till a light pink colour change which lasted
for 15 s was observed. This marked the endpoint of titration. The
titre value of each of the plant sample extracts was multiplied by
2.2 mg of oxalate taken as equivalence of 0.05 M of $KMnO_4$ used
for titration.

$$\text{Oxalate content} = 2.2 \text{mg} \times \text{titre value} \qquad (11)$$

3.3. Phytate content

This was determined by weighing 2 g each of plant samples into
a flask and 100 mL of 2% HCl solution was added. The mixture was
allowed to stand for 3 h and filtered. The filtrate (25 mL) was
poured in a separate 250 mL conical flask using 5 mL of 0.3%
ammonium thiocyanate solution as indicator. The desired acidity
was achieved by adding 53.3 mL of distilled water and this was
titrated with standard, 0.001 95 g of iron per mL prepared in iron
III chloride solution until a brownish yellow colour persisted for
5 min (Unuofin et al., 2017) The percentage phytate content was
evaluated as

$$\% \ \text{phytate content} = \text{titre value} \times 0.001 \ 95 \times 1.19 \times 100 \qquad (12)$$

where 1.19 = equilibrium dissociation constant for phytate and Iron
complexes (Heighton et al., 2008).

3.4. Saponin content

The percentage saponin content was estimated by adding five
grams each of powdered plant samples to 50 mL of 20% aqueous
ethanol. The mixture was shaken for 30 min on an orbital shaker,
then heated for 4 h in a water bath set at 55C. Thereafter, the mix-
ture was filtered and residue re-extracted in 200mLof ethanol. The
filtrates from both extractions were collected in a calibrated beaker
and concentrated to about 40 mL in a water bath set at 90C. The
concentrated filtrate was shaken and decanted into a separating
funnel where 20 mL of diethyl ether was added and shaken briskly.
The mixture was allowed to settle in the separating funnel until
two distinct layers (ether and aqueous) were formed. The ether
(upper) layer was discarded and the aqueous (bottom) layer kept
in the collecting beaker. The reserved layer was re-introduced into
the separating funnel and 60 mL of n-butanol was added. The
resulting mixture was shaken vigorously and allowed to settle
until two distinct layers were observed. The lower layer was dis-
carded while the upper layer consisting of butanol extract was col-
lected and evaporated to a constant dry weight in an oven set at
40C (Unuofin et al., 2017). The percentage saponin content of the
sample was estimated from the equation;

$$\% \ \text{Saponin content} = \frac{\text{Weight of concentrated residue}}{\text{Weight of original sample}} \times 100$$
$$(13)$$

3.5. Effect of soil types on elemental compositions

The standard operating procedure described by Aceto et al.
(2002) was adopted in analysing mineral elements in each of the
replicated samples of A. caudatus harvested from different soil.
The Inductively Coupled Plasma- Optical Emission Spectrometer
in the analytical laboratory of the Department of Agriculture and
Rural Development, Kwazulu Natal Province was used to carry
out the elemental analysis.

3.6. Statistical analysis

All experiments were run in three replicates and results were
computed in Microsoft 2010 excel spreadsheet that was used to
express data as mean ± SD. The data obtained were analysed using
MINITAB Release 17 statistical software to compare means using
the Fisher's Least Significant Difference pairwise comparison. The
mean values of nutrients, antinutrients and mineral elements in
the various plant samples from different soils were grouped at
95% Confidence limit (significant level α = 0.05). Means were com-
pared using a one-way analysis of variance. At $p < 0.05$, means
were considered significantly different.

4. Results

4.1. Soil properties

Table 1 shows the physical properties of different soil samples
used for the cultivation of A. caudatus. Table 2 depicts physico-
chemical compositions of formulated soils before and after
planting.

4.2. Effects of soil types on proximate compositions

This study revealed significant differences in proximate con-
tents of A. caudatus harvested from various soils at different growth
stages with regard to moisture, neutral detergent fibre, crude fat,
ash, crude protein, non-fibre-carbohydrate and energy values

Table 2
Physicochemical properties of formulated soil samples before and after planting.

	Soil types	Sample density (g/mL)	P mg/mL	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Exch. Acidity (cmol/L)	Total cations (cmol/L)	Acid sat. %	pH (KCl)	Zn (mg/L)	Mn (mg/L)	Cu (mg/L)
pre-planting	Control	1.2	82	806	918	281	0.09	9.04	1	6.08	7.4	55	15.8
	Sandy clayey loam	1.24	82	826	1013	302	0.07	9.72	1	6.17	7.9	58	15.8
	Silty clayey loam	1.24	78	786	935	276	0.07	9.02	1	6.19	7.1	55	15
	Clayey loam	1.25	82	696	968	288	0.08	9.06	1	6.2	7.3	56	15.1
	Loam	1.21	85	806	945	287	0.07	9.21	1	6.21	7.6	59	15.5
Post-planting	Control	1.13	32	232	3032	368	0.05	18.8	0	7.13	3.1	22	3.8
	Sandy clayey loam	1.17	35	278	3126	344	0.07	19.21	0	7.14	4.1	23	4.8
	Silty clayey loam	1.16	37	211	2877	326	0.06	17.64	0	6.98	4.1	21	4.9
	Clayey loam	1.14	40	228	2751	315	0.06	16.95	0	6.97	12.3	23	4.8
	Loam	1.16	41	274	2771	329	0.04	17.28	0	7.12	3.8	28	5.7

Table 3
Effects of soil types on proximate compositions of *A. caudatus* cultivated on different soil types.

Stages of harvest	Soil types	% Ash	% Crude fat	% Crude protein	% NDF	% NFC	% Moisture	Energy value (KJ/100 g)
Pre-flowering	Control	25.51 ± 0.78[b]	1.53 ± 0.04[b]	25.30 ± 0.06[d]	43.33 ± 1.51[a]	4.33 ± 0.71[a]	6.43 ± 0.04[a]	1297.00 ± 13.99[a]
	Sandy clayey loam	28.28 ± 0.77[ab]	1.50 ± 0.06[b]	27.90 ± 0.38[c]	41.15 ± 3.12[ab]	1.18 ± 2.66[a]	6.04 ± 0.08[b]	1249.34 ± 11.87[ab]
	Silty clayey loam	28.50 ± 0.69[ab]	2.17 ± 0.24[a]	30.50 ± 1.01[ab]	38.39 ± 1.32[bc]	0.44 ± 0.14[a]	6.14 ± 0.10[ab]	1259.05 ± 16.44[ab]
	Clayey loam	29.60 ± 0.57[a]	2.01 ± 0.00[a]	28.90 ± 0.17[bc]	35.26 ± 1.03[c]	4.23 ± 0.29[a]	5.81 ± 0.17[b]	1236.93 ± 9.54[b]
	Loam	29.04 ± 2.58[a]	2.17 ± 0.03[a]	31.52 ± 0.99[a]	34.96 ± 0.57[c]	2.32 ± 4.17[a]	5.92 ± 0.21[b]	1249.87 ± 43.21[ab]
Flowering	Control	29.24 ± 2.34[a]	1.93 ± 0.32[a]	26.20 ± 0.22[a]	38.52 ± 1.00[a]	4.12 ± 0.80[a]	6.27 ± 0.13[ab]	1241.51 ± 46.22[a]
	Sandy clayey loam	29.77 ± 1.82[a]	2.36 ± 0.01[a]	29.24 ± 0.70[a]	39.20 ± 4.77[a]	0.00 ± 0.00**	5.53 ± 0.29[c]	1241.20 ± 31.04[a]
	Silty clayey loam	28.29 ± 0.86[a]	1.96 ± 0.12[a]	28.63 ± 1.18[ab]	40.08 ± 0.72[a]	1.05 ± 1.43[ab]	6.08 ± 0.28[bc]	1258.34 ± 12.02[a]
	Clayey loam	29.20 ± 0.68[a]	2.04 ± 0.38[a]	29.86 ± 0.11[a]	38.86 ± 2.02[a]	0.05 ± 3.19[ab]	5.92 ± 0.07[bc]	1244.31 ± 3.84[a]
	Loam	27.26 ± 0.25[a]	2.43 ± 0.49[a]	27.33 ± 0.50[bc]	38.86 ± 2.09[a]	4.12 ± 2.37[ab]	6.75 ± 3.00[a]	1285.18 ± 14.04[a]
Post-flowering	Control	26.75 ± 0.26[a]	1.72 ± 0.14[bc]	18.79 ± 0.37[a]	47.34 ± 0.40[a]	5.41 ± 0.64[a]	7.01 ± 0.25[a]	1279.64 ± 7.24[d]
	Sandy clayey loam	24.69 ± 0.16[b]	1.49 ± 0.11[c]	14.21 ± 0.61[c]	42.10 ± 18.60[a]	7.16 ± 4.52[a]	6.92 ± 0.06[a]	1310.14 ± 4.79[c]
	Silty clayey loam	24.04 ± 0.64[b]	1.74 ± 0.10[bc]	13.81 ± 0.02[c]	54.23 ± 1.73[a]	6.19 ± 1.00[a]	6.92 ± 0.25[a]	1326.11 ± 8.86[bc]
	Clayey loam	23.86 ± 0.39[bc]	2.09 ± 0.13[a]	17.14 ± 0.12[b]	50.46 ± 0.02[a]	6.46 ± 0.38[a]	7.07 ± 0.21[a]	1336.33 ± 3.93[ab]
	Loam	22.98 ± 0.39[c]	1.92 ± 0.13[ab]	16.77 ± 0.53[b]	50.37 ± 1.92[a]	7.97 ± 1.93[a]	6.30 ± 0.10[b]	1347.74 ± 4.01[a]

NDF = Neutral Detergent fibre; NFC = Non-Fibre Carbohydrates. Note: Means were ranked along the column using Fischer's LSD at α level of 0.05, means that do not share a letter are significantly different.

(Tables 3). At the pre-flowering stage, samples from clayey loam and loam had the highest ash values (no significant difference at $p < 0.05$) and the least ash content was found in plants from the control soil whereas silty clayey loam and sandy clayey loam soils yielded comparable ash content. At flowering stage, all samples had comparable ash content while at post-flowering, lowest ash was also found in the loamy soil; however, harvest from control soil recorded the highest ash content whereas samples from sandy clayey loam and silty clayey loam had no significant difference. The percentage crude fat was high and comparable in harvests from loam, silty clayey loam and clayey loam soils at pre-flowering but at flowering stage, all soil types yielded equivalent fat content ($p < 0.05$). At post-flowering stage, sandy clayey loam and clayey loam soils yielded the lowest and highest fat respectively.

Similarly, the crude protein yield varied between soil types and stages of harvest. The highest and lowest protein yields were respectively recorded in plant cultivated on loam and control soils at the pre-flowering stage. However, harvests from the control, sandy clayey loam and clayey loam soils yielded comparably high crude protein at pre-flowering while loam soil yielded the lowest. At post flowering, protein content had dropped significantly in all soil types, unlike pre-flowering and flowering samples where protein contents were comparably high (Table 3). Conversely, analysis of moisture data showed overlapping effects of soil types and stages of harvest on moisture content. At pre-flowering, highest moisture was recorded in plant samples cultivated on control soil while the least moisture was recorded in the harvests from sandy clayey loam, clayey loam and loam. In flowering samples, the highest moisture was recorded in harvest from loamy soil whereas

sandy clayey loam yielded the least. In contrast, lowest moisture was recorded in loam at the post-flowering stage however; there is no significant difference in moisture content of plant samples from other soils.

In flowering and post-flowering samples, no variability was recorded in the non-detergent fibre (NDF) however; the highest NDF was recorded in the pre-flowering harvest from control soil while NDF was comparably low in samples from clayey loam and loam soils. The non-fibre carbohydrate (NFC) content was at its peak in all post-flowering samples (no significance difference at $p < 0.05$). At flowering, highest NFC was recorded in the control soil sample while pre-flowering samples had no significant difference in NFC in all harvests from all soils.

The energy value of *A. caudatus* yield estimated in (KJ/100 g) varied in pre-flowering samples. Analysis of results obtained shows that plants from the control before flowering recorded the highest energy density while the lowest energy was recorded in pre-flowering samples of clayey loam soil. At flowering, energy values were not significantly different between harvests from different soil types however, the sample from loamy soil was the richest in energy value. (Table 3).

4.3. Effects of soil types on mineral elements

Table 4a shows macronutrients in *A. caudatus* cultivated in different soils at various growth stages. The major elements tested were calcium (Ca), magnesium (Mg), sodium (Na), phosphorus (P) and potassium K. The order of increasing order of mineral yields per 100 g of plant sample is Na < P < Mg < Ca < K. At pre-

Table 4a
Effects of soil types on macronutrient compositions of *A. caudatus* harvested at different growth stages.

Stages of harvest	Soil types	Ca (mg/100 g DW)	Mg (mg/100 g DW)	Na (mg/100 g DW)	P (mg/100 g DW)	K (mg/100 g DW)	K/Ca + Mg (mg/100 g DW)
Pre-flowering	Control soil	1715.00 ± 7.07[a]	810.00 ± 14.14[a]	105.00 ± 7.07[a]	605.00 ± 91.92[a]	7970.00 ± 5.66[a]	1340.00 ± 0.00[a]
	Sandy clayey loam	1605.00 ± 34.60[a]	715.00 ± 13.4[a]	65.00 ± 0.71[cd]	510.00 ± 11.31[a]	8735.00 ± 40.30[a]	1635.00 ± 26.16[a]
	Silty clayey loam	1525.00 ± 3.74[a]	690.00 ± 9.90[a]	55.00 ± 0.71[d]	460.00 ± 8.48[a]	8420.00 ± 40.31[a]	1635.00 ± 26.16[a]
	Clayey loam	1590.00 ± 38.18[a]	700.00 ± 9.90[a]	85.00 ± 0.71[b]	460.00 ± 11.31[a]	7765.00 ± 147.78[a]	1450.00 ± 1.41[a]
	Loam	1705.00 ± 7.78[a]	755.00 ± 0.71[a]	80.00 ± 0.00[bc]	500.00 ± 1.41[a]	9425.00 ± 2.12[a]	1640.00 ± 4.24[a]
Flowering	Control soil	1580.00 ± 4.24[a]	665.00 ± 0.71[bc]	110.00 ± 1.41[ab]	480.00 ± 1.41[ab]	8525.00 ± 29.00[a]	1635.00 ± 7.78[b]
	Sandy clayey loam	1550.00 ± 18.38[a]	650.00 ± 2.83[c]	75.00 ± 0.71[b]	515.00 ± 2.12[a]	9300.00 ± 26.87[a]	1825.00 ± 10.61[a]
	Silty clayey loam	1800.00 ± 8.49[a]	710.00 ± 0.00[a]	70.00 ± 1.41[b]	495.00 ± 0.71[ab]	8345.00 ± 10.61[a]	1440.00 ± 2.83[c]
	Clayey loam	1690.00 ± 7.07[a]	695.00 ± 0.71[ab]	115.00 ± 3.54[ab]	480.00 ± 0.00[ab]	8495.00 ± 45.96[a]	1535.00 ± 3.54[bc]
	Loam	1615.00 ± 6.36[a]	705.00 ± 0.71[a]	130.00 ± 1.41[a]	470.00 ± 2.82[b]	8515.00 ± 55.86[a]	1570.00 ± 5.66[bc]
Post-flowering	Control soil	1415.00 ± 12.02[b]	615.00 ± 2.12[b]	110.00 ± 0.00[a]	375.00 ± 0.71[a]	8055.00 ± 2.12[a]	1700.00 ± 11.31[a]
	Sandy clayey loam	1395.00 ± 7.78[b]	540.00 ± 1.41[c]	60.00 ± 1.41[b]	340.00 ± 0.00[bc]	7755.00 ± 10.61[b]	1740.00 ± 5.66[a]
	Silty clayey loam	1380.00 ± 7.07[b]	565.00 ± 3.54[bc]	75.00 ± 2.12[b]	335.00 ± 0.71[c]	7250.00 ± 0.00[c]	1610.00 ± 8.49[ab]
	Clayey loam	1615.00 ± 0.71[a]	695.00 ± 2.12[a]	55.00 ± 70.71[b]	360.00 ± 1.41[a]	7835.00 ± 2.12[b]	1455.00 ± 2.12[bc]
	Loam	1650.00 ± 5.66[a]	700.00 ± 0.00[a]	80.00 ± 2.83[ab]	345.00 ± 0.71[bc]	7265.00 ± 12.02[c]	1325.00 ± 0.71[c]

Note: Means were ranked along the column using Fischer's LSD at α level of 0.05, means that do not share a letter are significantly different.

Table 4b
Effects of soil types on micronutrient compositions of *A. caudatus* harvested at different growth stages.

Stages of harvest	Soil types	Zn (mg/100 g DW)	Mn (mg/100 g DW)	Cu (mg/100 g DW)	Fe (mg/100 g DW)
Pre-flowering	SF1	2.20 ± 3.11[a]	3.00 ± 0.00[a]	0.8 ± 0.14[a]	73.10 ± 11.03[a]
	SF2	0.00 ± 0.00[**]	2.60 ± 0.08[a]	0.50 ± 0.02[a]	50.15 ± 2.87[ab]
	SF3	0.00 ± 0.00[**]	2.25 ± 0.08[a]	0.35 ± 0.03[a]	34.05 ± 0.03[b]
	SF4	1.70 ± 0.24[a]	2.15 ± 0.49[a]	0.90 ± 0.57[a]	37.60 ± 1.02[ab]
	SF5	3.05 ± 0.01[a]	2.70 ± 0.01[a]	0.45 ± 0.01[a]	53.40 ± 0.34[ab]
Flowering	SF1	2.95 ± 0.02[a]	2.70 ± 0.03[a]	0.55 ± 0.01[a]	70.05 ± 1.41[a]
	SF2	2.85 ± 0.02[a]	2.45 ± 0.04[a]	0.35 ± 0.01[b]	37.7 ± 1.43[b]
	SF3	3.00 ± 0.01[a]	2.75 ± 0.01[a]	0.45 ± 0.01[ab]	43.70 ± 0.65[ab]
	SF4	3.10 ± 0.01[a]	2.45 ± 0.01[a]	0.55 ± 0.01[a]	42.60 ± 0.58[ab]
	SF5	5.15 ± 0.61[a]	2.95 ± 0.01[a]	0.60 ± 0.00[a]	63.40 ± 1.37[ab]
Post-flowering	SF1	2.50 ± 0.01[a]	2.85 ± 0.04[a]	0.50 ± 0.00[a]	72.10 ± 2.39[ab]
	SF2	2.10 ± 0.01[b]	2.85 ± 0.02[a]	0.60 ± 0.00[a]	93.70 ± 1.15[a]
	SF3	1.80 ± 0.01[b]	2.75 ± 0.01[a]	0.55 ± 0.01[a]	78.95 ± 0.33[a]
	SF4	2.05 ± 0.01[b]	2.85 ± 0.01[a]	0.50 ± 0.00[a]	44.45 ± 0.52[b]
	SF5	2.00 ± 0.01[b]	2.85 ± 0.01[a]	0.55 ± 0.01[a]	63.20 ± 0.64[ab]

Note: Means were ranked along the column using Fischer's LSD at α level of 0.05, means that do not share a letter are significantly different. Data with '**' indicates lack of data for nutrient (s) under consideration.

flowering and flowering stages, Ca yield was comparable in plant samples while at post-flowering, the highest Ca yield was recorded in harvests from loam and clayey loam soils. In addition, Ca content dropped significantly in post-flowering harvests particularly in control, sandy clayey loam and silty clayey loam soils. The magnesium composition of the samples also followed the pattern of calcium in different soils especially at pre-flowering stage. At flowering, the lowest magnesium was recorded in sandy clayey loam while the highest was recorded in harvests from silty clayey loam and loam soils.

Moreover, the highest magnesium yield was recorded in clayey loam and loam soils at post-flowering, while the lowest magnesium was found in sandy clayey loam soil.

The amount of sodium in the analysed plant samples was low compared to other macro elements reported in the analysis. Sodium concentration was highest at flowering than pre-flowering and post-flowering stages. At flowering, harvests from loamy soil had the overall highest sodium content as opposed samples from control soil, which recorded the highest Na at pre-flowering and post-flowering stages. There was a significant depletion in the concentration of phosphorus in post-flowering samples compared to other stages. At flowering, sandy clayey loam yielded sample with the highest P while the least phosphorus yield was

recorded in loamy soil. However, there was no significant difference in phosphorus content of pre-flowering samples. The potassium compositions of the evaluated samples showed no significant difference in pre-flowering and flowering samples, however, there were variabilities in potassium content of post-flowering harvests. At post-flowering, control soil yielded plant sample with the highest potassium while silty clayey loam yielded the least.

4.4. Effects of soil types on phytoextraction of heavy metals

The levels of accumulation of heavy metals such as zinc (Zn), manganese (Mn), copper (Cu) and iron (Fe) in the evaluated samples is presented in Table 4b. This study showed no significant effects of soil types and harvest stages on levels of accumulation of Zn, Mn and Cu in *A. caudatus* although no Zn was recorded in pre-flowering harvests from sandy clayey loam and silty clayey loam soils. However, in post-flowering and flowering harvests, slight variability occurred respectively in Zn and Cu accumulations. At post-flowering, zinc was higher in the control soil samples than other soils where the equivalent amount of Zn was accumulated. At flowering, the quantity of Cu was highest and the same in the

Table 5
Effects of soil types on Vitamins in *A. caudatus* harvested at different growth stages.

Stages of Harvest	Soil types	Vitamin A (mg/kg)	Vitamin C (mg/kg)	Vitamin E (mg/kg)
Pre-flowering	SF1	255.29 ± 8.02[a]	4.83 ± 0.28[c]	101.23 ± 0.04[d]
	SF2	255.78 ± 4.57[a]	6.79 ± 0.08[a]	101.16 ± 0.06[d]
	SF3	259.30 ± 0.32[a]	5.50 ± 0.08[b]	101.45 ± 0.05[c]
	SF4	260.98 ± 0.80[a]	4.17 ± 0.11[d]	102.19 ± 0.03[a]
	SF5	252.51 ± 5.23[a]	3.78 ± 0.29[e]	101.72 ± 0.04[b]
Flowering	SF1	238.39 ± 9.11[c]	5.25 ± 0.17[c]	101.19 ± 0.05[c]
	SF2	254.37 ± 4.80[ab]	6.54 ± 0.19[a]	101.81 ± 0.01[a]
	SF3	245.28 ± 1.66[bc]	6.44 ± 0.09[a]	101.34 ± 0.03[b]
	SF4	255.90 ± 6.83[a]	5.88 ± 0.17[b]	101.39 ± 0.01[b]
	SF5	246.78 ± 2.73[abc]	6.28 ± 0.18[a]	101.21 ± 0.12[c]
Post-flowering	SF1	221.90 ± 7.37[ab]	5.81 ± 0.07[c]	101.44 ± 0.05[b]
	SF2	192.52 ± 5.20[d]	6.72 ± 0.06[b]	101.12 ± 0.16[c]
	SF3	212.90 ± 5.13[bc]	7.22 ± 0.35[b]	101.07 ± 0.03[c]
	SF4	235.01 ± 15.53[a]	6.74 ± 0.33[b]	101.79 ± 0.05[a]
	SF5	199.14 ± 6.20 [cd]	7.91 ± 0.58[a]	101.17 ± 0.02[c]

Note: Means were ranked along the column using Fischer's LSD at α level of 0.05, means that do not share a letter are significantly different.

control, clayey loam and loam soil samples while the least was recorded in the plant sample from sandy clayey loam.

On the contrary, variabilities occurred in the accumulation of Fe content of different soils across the three stages studied. At flowering, the highest and lowest Fe accumulation was recorded in the plant samples from control and silty clayey loam soils respectively. Similarly, plant sample from the control soil accumulated the highest quantity of Fe at flowering stage while the least was recorded in the harvest from sandy clayey loam soil. At post-flowering, the highest equivalent quantity of Fe was recorded in sandy clayey loam and silty clayey loam soils, however; clayey loam yielded the lowest Fe.

4.5. Effects of soil types on vitamin content

The vitamins A, C and E contents of *A. caudatus* are shown in Table 5. The results showed significant variations in the vitamin contents of the plant at various growth stages. Although samples from all soils showed no significant difference in vitamin A at pre-flowering stage, clayey loam yielded the highest Vitamin A at flowering and post-flowering stages. For vitamin C, the highest yield was recorded in the plant sample from sandy clayey loam harvested during flowering while the plant harvest loamy soil yielded the lowest vitamin C.

At post-flowering and flowering stages, the lowest ascorbic acid was recorded in the control soil whereas samples from sandy clayey loam, silty clayey loam and loam had high and equivalent ascorbic acid content. Notwithstanding, the post-flowering plant sample of loamy soil recorded the highest vitamin C content. The laboratory evaluation of the ∝ -tocopherol content of different plant samples showed the highest Vitamin E in pre-flowering and post-flowering harvests from clayey loam while at flowering, the highest Vitamin E was recorded in sandy clayey loam soil. In addition, it was also observed that Vitamin A content of the samples from all soils dropped at post-flowering.

4.6. Effects of soil types on antinutrients

The antinutrient compositions in *A. caudatus* grown on different soils are summarised in Table 6 as a percentage of alkaloids, saponin, phytate and oxalate in original weight of the plant samples. At pre-flowering, plant cultivated on sandy clayey loam recorded the highest yield of alkaloid while the lowest yield was recorded in sample from control soil.

At the flowering stage, plant sample from loamy soil yielded the highest alkaloid whereas all post-flowering samples had equivalent yield of alkaloids except sample from the silty clayey loam. The saponin contents of pre-flowering and post-flowering harvests were comparable to one another, however samples harvested from the silty clayey loam during flowering had the highest saponin. The phytic acid content of tested samples also showed variabilities in quantity at pre-flowering and flowering stages. However, there was no significant difference in post-flowering samples. Furthermore, analysis of results showed no significant difference in the

Table 6
Effects of soil types on antinutrient content of *A. caudatus* harvested from various formulated soils at different growth stages.

Stages of Harvest	Soil types	% Alkaloid	% Saponin	% Phytate	% Oxalate
Pre-flowering	SF1	2.86 ± 0.19c	11.12 ± 1.83a	12.59 ± 0.29ab	0.55 ± 0.11a
	SF2	3.76 ± 0.21a	17.38 ± 0.80a	15.64 ± 0.19a	0.55 ± 0.11a
	SF3	3.16 ± 0.20b	13.26 ± 11.57a	12.98 ± 1.36ab	0.33 ± 0.11a
	SF4	3.32 ± 0.07b	19.25 ± 0.10a	11.70 ± 0.51b	0.44 ± 0.00a
	SF5	3.09 ± 0.04bc	10.36 ± 5.46a	12.91 ± 1.31ab	0.33 ± 0.11a
Flowering	SF1	2.85 ± 0.12b	18.16 ± 4.73ab	11.87 ± 0.27a	0.33 ± 0.11a
	SF2	2.85 ± 0.60b	16.42 ± 9.77ab	10.80 ± 0.22ab	0.22 ± 0.00a
	SF3	3.11 ± 0.28ab	35.62 ± 9.53a	9.02 ± 1.38b	0.33 ± 0.11a
	SF4	3.13 ± 0.43ab	9.13 ± 4.11b	8.60 ± 0.22b	0.44 ± 0.00a
	SF5	3.70 ± 0.13a	16.51 ± 0.27ab	8.73 ± 0.32b	0.28 ± 0.01a
Post-flowering	SF1	2.46 ± 0.03a	11.74 ± 1.04a	8.02 ± 0.13a	0.22 ± 0.00a
	SF2	2.54 ± 0.06a	4.20 ± 1.33a	9.06 ± 0.22a	0.22 ± 0.01a
	SF3	1.88 ± 0.14b	6.20 ± 2.07a	7.82 ± 0.21a	0.22 ± 0.02a
	SF4	2.46 ± 0.23a	5.86 ± 0.27a	8.54 ± 0.86a	0.22 ± 0.03a
	SF5	2.44 ± 0.00a	7.74 ± 4.85a	7.00 ± 0.99a	0.22 ± 0.04a

Note: Means were ranked along the column using Fischer's LSD at α level of 0.05, means that do not share a letter are significantly different.

percentage of oxalates harvested from different soils at pre-flowering, flowering and post-flowering stages.

5. Discussion

Texture modulation affects the concentration of chemical compounds available in the soil (Biswas et al., 2018). These chemicals find their way up in plants through adsorption or direct absorption from the soil solution. This study supported previous works that soil types, texture and mineral content determine the uptake of minerals in plants (Lester and Eischen, 1996; Tsao et al., 2006) as the number of nutrients, antinutrients and mineral compositions in *A. caudatus* harvested from different soil types varied significantly. Also, variations observed in antinutrient and proximate compositions of the plant at different growth stages indicated that as plant ages, its nutritional characteristics change. There was also, significant difference in the mineral uptake by the plant depending on soil type and stage of harvest. This is evident in the variations observed in the pre-planting and post-harvest analyses of the soil samples where some minerals such as phosphorus, potassium, zinc and manganese got depleted while others appreciated after harvesting (Table 2).

The ash content of the analysed plant samples was high compared to early reports on *A. caudatus* where ash does not exceed 5% (Akin-Idowu et al., 2017; Mekonnen et al., 2018; Nascimento et al., 2014). The high ash value implies that the plant is rich in dietary fibres that provide shelter for digestive organisms in the alimentary tract (Schroeder and Bäckhed, 2016). Generally, *Amaranthus* species have been assessed to contain low values of unsaturated fat (Bressani, 2018). The range of fat content of samples from different soils at various growth stages was lower than those reported in earlier works; 7.1% (Mlakar et al., 2009), 7% (Soriano-García et al., 2018) and 6.43% (Nascimento et al., 2014). In contrast, this was higher than the total fat reported for other *Amaranthus* spp (Topwal, 2019; USDA, 2018).

At pre-flowering and flowering stages, the protein compositions of the samples approximately double the standard reference protein value of 13.56% proposed for grain amaranth by the United States Department of Agriculture in its National Nutrient Database (Jimoh et al., 2018). In addition, the protein values reported were much higher than in previous reports particularly in pre-flowering and flowering samples; 14.96% (Mekonnen et al., 2018), 13.4% (Nascimento et al., 2014), 15.1% (Tapia-Blácido et al., 2007) although stages of harvest were not considered in the earlier studies. Hence, this study implies that for optimal protein yield, the plant is best cultivated on loam and clayey loam soils and respectively harvested before flowering and during flowering. In addition, results from this study suggested that the greenhouse ambience was optimal for protein yield.

The non-fibre carbohydrate (NFC) content (17.51%) was highest in the post-flowering harvests, particularly from sandy clayey loam soil. This suggests that the stage is the best for optimal yield of this carbohydrate although, value is still low compared to earlier reports of 61.4% and 52.18% carbohydrate in amaranths by Alvarez-Jubete et al., (2010) and Akubugwo et al., (2007) respectively. The low NFC composition in all harvests generally may not be unconnected with high protein content of *A. caudatus* from different soils particularly at flowering and post-flowering stages where the carbohydrate may have been traded off for protein production. This is in agreement with previous report that proximate carbohydrate and protein relate in an inverse manner (Elsheikh and Elzidany, 1997). Absence of the NFC in the flowering sample of sandy clayey loam suggests that the carbohydrate yield may have been diverted to ash production as the highest ash composition was recorded in the sample (Priya et al., 2005).

The highest moisture content was recorded in the post-flowering stage particularly in the samples from clayey loam. This was so due to high clay content of the soil which promotes soil water retention. The energy densities of the samples from different soil types also varied between and within soil types and stages of harvest. Using the conversion factor given in (FAO, 2003), the estimated energy densities (from carbohydrate fat and protein contents) of *A. caudatus* in earlier studies were higher than values recorded in this experiment. In Mekonnen et al. (2018), Mlakar et al. (2009), Tapia-Blácido et al. (2007) and Nascimento et al. (2014), energy values of 1499.24, 1729.80, 1842.22 and 1405.81KJ were respectively recorded. However, energy densities were exceedingly higher than the energy value of 97KJ reported for vegetable amaranths reported in USDA, (2018).

Minerals are important components of the human diet. They support life in provision of vital nutrients needed for psychophysical well-being of the body (Jiménez-Aguilar and Grusak, 2017; Welch, 2002). High mineral contents obtained in this research corroborate earlier reports that *Amaranthus* species are depot of essential minerals (Achigan-Dako et al., 2014; Jimoh et al., 2018; Venskutonis and Kraujalis, 2013). Furthermore, variations in the results further showed that soil texture and stage of harvest modulate mineral composition in plants. Hence, most of the evaluated minerals in the plant samples were higher than the recommended dietary allowance (RDA). Calcium, for example, has an RDA of 1000 mg proposed for an adult (Food and Nutrition Board, 1989; Nascimento et al., 2014; Unuofin et al., 2017), a limit that was exceeded in all samples regardless of soil types and stage of harvest. In previous literature, the following calcium values 165 mg, 1287.15 mg, 159 mg, 215 mg and 209 mg were respectively recorded in (Akin-Idowu et al., 2017; Nascimento et al., 2014; Soriano-García et al., 2018; Topwal, 2019; USDA, 2018). However, higher Ca was recorded in this study compared to what was reported in previous literature (Table 4a). Calcium store has been said to promote embryonic skeletal development in females, reduced obesity and attenuation of fat accumulation in young women (Heaney et al., 2002; Maldonado, 2008). Therefore, frequent consumption of *A. caudatus* will boost dietary intake of calcium, thus preventing bone resorption due to ageing, nutritional rickets, periodontal and calcium paradox diseases (Harada and Rodan, 2003; Kremer and Gilsanz, 2016; Pettifor, 2004).

Magnesium composition of the analysed samples was also found to be well above the RDA value. This implies that the plant is a rich source of magnesium. According to USDA (2018), the reference standard magnesium content in 100 g of cooked amaranth food is 55 mg. This is far below the values obtained in samples from all soil types at various growth stages. Similarly, lower Mg values of 197 mg, 278.33 and 248 mg were correspondingly reported by (Mekonnen et al., 2018; Nascimento et al., 2014; Soriano-García et al., 2018) in the proximate analysis of *A. caudatus*. Magnesium plays critical functions ranging from structural roles in nucleic acids, proteins and polyribosomes to neurotransmitter release, cell adhesion, stabilization of calcium-potassium homeostasis and as a cofactor for enzymatic reactions (Rude, 1998; Stein, 2010). Regular consumption of this plant will, therefore, guarantee optimal concentration of magnesium in the serum.

Sodium is the major cation in extracellular fluid. It is vital for the maintenance of acid-base balance and a precursor for transmission of nerve impulses (He and MacGregor, 2009; Stein, 2010). The renal tubule of kidney houses a sodium hormone regulator called aldosterone which works at variance with sodium level. Despite the sodium retentive capacity of the kidney, some essential losses of sodium still occur through sweating and defaecation which may not necessarily require sodium supplementation (Aburto et al., 2013; Food and Nutrition Board, 1989; Stein, 2010). With an RDA of 200–500 mg sodium proposed for healthy living, all samples

of *A. caudatus* in this study met the minimum 10% sodium allocation expected to have originated from natural salt (He and MacGregor, 2009). The recommended daily allowance for phosphorus is 700 mg/day (Chang et al. 2014a). None of the plant samples met this requirement. Except in post-flowering samples where phosphorus level had depleted significantly, values obtained at pre-flowering and post-flowering compare with what was reported by Nascimento et al. (2014)- 527 mg; Akin-Idowu et al. (2017)- 576.5 mg; and Soriano-García et al. (2018)- 557 mg in different samples of *A. caudatus*.

Potassium is an essential component of a balanced diet. It is of great physiological importance as intracellular and extracellular cations needed for the maintenance of blood pressure, muscular contractility and conduction of nerve impulses (Stein, 2010). At least, 2000 mg of it is desirable for an adult which is available in large quantity in *Amaranthus caudatus*. In this study, soil types did not affect potassium accumulation before and during flowering. However, there exist variations in post-flowering samples. Compared to previous reports on the plant species (Akin-Idowu et al., 2017; Nascimento et al., 2014; Soriano-García et al., 2018; USDA, 2018), potassium content of the investigated species was significantly elevated. This may have been influenced by the low humid condition of the glasshouse. Potassium uptake has been earlier reported to be influenced by humidity and in turn, exerts antagonistic effects on calcium and sodium levels (Voogt, 2002). Consumption of diuretics and some incidents of metabolic disturbance may lead to excessive loss of potassium in the body (He and MacGregor, 2009).

Regardless of soil types, accumulation of macrominerals and heavy metals in *A. caudatus* varied with stage of harvest. Minerals like calcium, magnesium, potassium, sodium and phosphorus were biomagnified in the plant after absorption from the soil. This is evident in their composition as presented in the soil physicochemical analysis (Table 2). However, little concentrations of trace elements (zinc, manganese, and copper) trapped in the plant were translocated in various quantities as manifested in the post-planting soil data (Table 2).

The vitamin content of the samples varied greatly with soil types and stages of harvest. *Amaranthus caudatus* has been reputed for its high vitamin in various publications (Mlakar et al., 2009; National Research Council, 2006; Venskutonis and Kraujalis, 2013). However, the vitamin content of the plant cultivated in different soils under a controlled greenhouse environment was higher than those reported in different kinds of literature. At pre-flowering, there was no significant difference in Vitamin A content of the investigated plant samples. At flowering and post-flowering stages, the highest Vitamin A was recorded in clayey loam while plant samples with the lowest Vitamin A were respectively produced in control and sandy clayey loam soils. These vitamins, although needed in small amount, aid visual system efficiency (Vitamin A), promotes blood circulation and reduce gastric cancer (Vitamin C), reduce incidence of cardiovascular mortality and myocardial infarction (Vitamin E) and generally, they play critical roles in refurbishment of body system and replacement of dead cells when consumed regularly (WHO and FAO, 2004).

As the name suggests, antinutrients are compounds such as oxalic acid, phytates, saponins and alkaloids that restrict the absorption of nutrients in foods. Phytate limits the bioavailability of minerals and digestibility of protein in human nutrition; it also serves as chelator of mineral ions, thereby its high accumulation may lead to health problems (Akande et al., 2010; Idris et al., 2019; Kumar and Sinha, 2018; Spier et al., 2018). However, on exposure to high temperature during cooking, phytic acid molecule gets denatured (Fekadu et al., 2013). The concentrations of phytates in the plant samples investigated in this study were high. Pre-flowering samples had more phytate than flowering and

post-flowering. A downward trend was also observed in phytate contents of samples from all soil types from pre-flowering to flowering and flowering. Saponin composition of the samples varied significantly between soil types at flowering stages. However, no significant difference was observed in pre-flowering and post-flowering harvests. Saponins are high molecular weight haemolytic glycosides that have soapy property and bitter taste (Hostettmann and Marston, 2005). Of all antinutrients evaluated in this study, saponin was the highest especially in flowering and pre-flowering samples of silty clayey loam (35.62%) and clayey loam (19.25%) soils respectively. However, alkaloid content of the samples was low compared to saponin and phytate although much higher than oxalates.

6. Conclusion

In this study, the significant variations observed in the concentration of nutrients, antinutrients and mineral content of *A. caudatus* harvested from different soil types at various stages of maturity show that chemical property of soil is a reflection of its physicochemical characteristics which in turn affect mineral accumulation in plants. Also, variations observed in proximate compositions as well as antinutrient properties of the plant at different growth stages indicated that as plant ages, its nutritional characteristics change. For an optimal yield of vitamins A and E, it is recommended that *A. caudatus* cultivated in clayey loam be harvested before flowering. In addition, the highest yields in proximate compositions were recorded in clayey loam and loam soils at flowering and pre-flowering. Furthermore, maximum mineral yield (micro and macro elements) were also recorded in the control soil and loam soils.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors Contribution Statement

1- MO Jimoh: carried out the experiment right from soil sieving stage to planting and laboratory analyses. He analysed the data collected, interpreted the results and prepared the manuscript.
2- Prof AJ Afolayan: conceived the experiment, provided the materials and equipment used, supervised and revised the manuscript with technical input.
3- Prof FB Lewu: designed and supervised the experiment at various stages, and assisted in the revision of the manuscript with scientific input

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