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Comparative analysis of nutrients in frequently consumed Indigenous African vegetables: implications for geriatric nutrition

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ABSTRACT

The promotion and consumption of African Indigenous Vegetables (AIVs) offers potential to improve diet quality and reduce the burden of non-communicable diseases among older persons. However, limited information exists on the minerals, vitamins and phytochemicals that contribute to these benefits. This study assessed the nutritional composition of three genotypes of each of four commonly consumed AIVs in Uganda: *Solanum aethiopicum* Shum (E16, E15, *and* E11), *Solanum aethiopicum* Gilo (*G4, G9,* and *G6*), *Amaranthus* sp. (Var. 008, Var. 025, *and* Var. 007), and *Vigna unguiculata* L. Walp (UCU Cow 1, Aseremoya, and Acc23). The vegetables were analysed for minerals (Fe, Zn, Ca, Mg, K), dietary fibre, phytochemicals (anthocyanins, tannins, catechins, polyphenols, chlorogenic acid, gallic acid, ferulic acid, flavonoids), and vitamins (α-tocopherol and β-carotene) using standard procedures and means were separated using One-Way ANOVA. Significant differences ($p < 0.05$) were observed across AIVs. *S. aethiopicum* Shum E16 exhibited the highest mineral levels, while *V. unguiculata* genotypes showed the lowest Mg, Fe, and K content. Iron was highest in *S. aethiopicum* Gilo G4 (8.83 mg/100 g). Leafy vegetables contained greater quantities of phytochemicals, dietary fibre, β-carotene, and α-tocopherol than fruit vegetables. Principal component analysis segregated genotypes based on nutrient profiles: phytochemicals and fibre strongly influenced *V. unguiculata* clustering, minerals influenced *Solanum* spp, and tocopherol and gallic acid distinguished *Amaranthus* genotypes. These findings highlight distinct nutritional advantages across AIV species. *V. unguiculata* exhibited particularly high phytochemical and vitamin content, suggesting its value as a nutrient-dense component of diets aimed at supporting healthy ageing.

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SUBJECTS
Biochemistry; Nutrition; Food Analysis; Fruit & Vegetables

Background

Globally, there is a rapid rise in the burden of non-communicable diseases (NCDs) among adults aged 50 years and above, with recent analyses projecting a rise in prevalence of 10–30 percent and minimal decline in NCD mortality by 2050 (Hu et al., 2025). In Uganda, NCDs disproportionately affect adults aged 50 years and above, and are the leading cause of medically certified health facility deaths and community death (Ministry of Health, 2023). For instance, in the 2023/2024, NCDs in form of endocrine disorders contributed 7.7%, cerebrovascular diseases contributed 5.2%, and hypertensive diseases contributed 3.8% of all medically certified causes of death (Uganda Bureau of Statistics, 2024).

While these diseases can appropriately be managed using dietary interventions; low intake of fruits and vegetables is among the top five known risk factors for NCDs in Uganda yet, the country is rich in

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indigenous fruits and vegetables (Wandera et al., 2015). Africa is indeed rich in a diverse array of vegetables, many of which are nutrient-dense and crucial for food and nutrition security, including leafy greens, root vegetables, and fruits. The majority of indigenous vegetables in Uganda are believed to be medicinal (Chinedu et al., 2011). These vegetables can easily be grown, prepared and consumed with the potential to improve household income, nutrition and subsequently, health outcomes.

Vegetables are important sources of antioxidants which act as scavengers cleaning up free radicals in the body before resulting in damaging health effects (Kaur & Kapoor, 2001). They are rich in fibre that prevents constipation and increases intestinal passage rates by forming a bulky stool. When consumed appropriately, vegetables maintain gut health when they ferment in the colon, increasing the concentration of short-chain fatty acids which have anticarcinogenic properties (Lattimer & Haub, 2010). Several studies have highlighted a strong association between vegetable intake and lower cardiovascular risk factors such as cholesterol and triacylglycerol thus preventing premature cardiovascular disorders (Wandera et al., 2015).

However, the majority of these studies have used fruits and vegetables exotic to Uganda. There is limited documentation on active compounds in African Indigenous Vegetables (AIVs) contributing to the observed health outcomes in humans. Available studies have focused on the presence of a few available minerals and vitamins in a limited number of AIVs (Akinola, 2020; Kamga et al., 2013; Nesamvuni et al., 2001). Dietary guidelines or recommendations for consumption of AIVs are usually based on either anecdotal information; mostly based on nutritional studies in other exotic vegetables. In addition, as far as targeted applications for instance in food for persons ≥ 50 years, the technical preparation and management processes are not tailored. Such inadequate knowledge restricts optimal utilization of nutrient-dense, inexpensive and easily available sources of minerals, vitamins and phytochemicals to address health outcomes, malnutrition and food security (Kwenin et al., 2011).

African eggplant (*Solanum aethiopicum*), cowpea (*Vigna unguiculata*) and *Amaranthus* sp. are the most commonly grown vegetables in Uganda. *S. aethiopicum* is widely consumed in the central region, *V. unguiculata* in the North and Eastern regions while *Amaranthus* sp. is consumed country wide (Sseremba, 2017). The aim of this study therefore was to determine the nutrient profile of these AIVs. Minerals (iron, zinc, calcium, magnesium and potassium), dietary fibre, antioxidants (total anthocyanins, total polyphenols, flavonoid glycosides, chlorogenic acid, ferulic acid, gallic acid, catechin and epicatechin), anti-nutritive compounds (tannins), and vitamins (β-carotene and tocopherol) in these AIVs were determined. The results will inform potential utilization (value addition) of the AIVs for nutraceuticals; optimized recipes for maximum nutritional value and a recommended consumption guide for AIVs in older adults.

Materials and methods

Plant materials

A total of twelve (12) plant genotypes of four AIVs consumed in Uganda; African eggplant (*S. aethiopicum* Shum E16, *S. aethiopicum* Shum E15 and *S. aethiopicum* Shum E11), African Eggplant (*S. aethiopicum* Gilo G4, *S. aethiopicum Gilo* G9 and *S. aethiopicum* Gilo G6), Amaranthus (*Amaranthus* sp. Var. 008, *Amaranthus* sp. Var. 007 and Amaranthus sp. Var. 025) and cowpea (UCU cow 1, Aseremoya, and *unguiculate Acc23*) were used in the study.

The plant genotypes utilized in this study were collected from Uganda Christian University seed bank and comprised of advanced lines (cycle 8) and officially released cultivars, developed through a structured breeding program conducted by university-affiliated researchers.

Experimental design

The genotypes were grown under controlled screen house conditions using a completely randomized design (CRD), with three biological replicates per genotype to ensure statistical precision. For biochemical analysis, leaf samples specifically, the third fully expanded leaf from the apex was collected were sampled across replicates. For each genotype, leaves were pooled per genotype to form a composite sample. For fruiting vegetables such as *S. aethiopicum* Gilo, fruit tissues were similarly sampled and pooled.

The pooled samples were immediately processed or stored under appropriate conditions to preserve biochemical integrity, following protocols like those described by Prieto et al. (2018) for biochemical assessments in vegetables. Fresh samples were frozen at −18 °C for 24h and lyophilized for 5h in a Freezone 4.5 lyophilizer (Labconco; Missouri, USA). They were then milled into fine powder, using a mortar and pestle before analysis.

Mineral composition

Minerals (Fe, Zn, Ca, Mg, K) were analyzed using a Microwave Plasma Atomic Emission Spectrometer (MP-AES), following acid digestion of the sample, using the method of Palma et al. (2015). 0.5 g of the powdered sample was weighed and dissolved in HNO_3 and $HClO_4$ (4 ml; 3:1 v/v) and digestion at 210 °C for 2 hours 15 min. The filtrate was analyzed using MP-AES (MP-AES 4200 Agilent technologies, Santa Clara, USA), equipped with an auto-sampler (SPS 4 Agilent Technologies, Santa Clara, USA). Mineral contents were expressed in mg/100g.

Dietary fiber

Dietary fiber was quantified using a Megazyme dietary fibre kit (Megazyme International, Bray, Ireland), based on the AOAC method 985.29 by defatting, hydrolysis and deproteinisation of 1.0 g of powder sample. It was determined as the percentage of the final weight of sample after hydrolysis and deproteinization over the initial weight of sample.

Anthocyanin content

Total anthocyanin content was analysed using the pH differential method AOAC 2005-02 (Lee et al., 2005). Two separate samples (0.05 g each) were extracted in 50 ml potassium chloride buffer (0.025 M; pH 1.0) and the other portion in sodium acetate buffer (0.4 M; pH 4.5) by shaking on an orbital shaker (Heidolph Unimax 1010 DT, Germany), for 2 hours at room temperature. Absorbances of filtrates were read using a UV-VIS spectrophotometer (Jenway 6035, Germany) at wavelengths of 520 and 700 nm, for both solutions. Total anthocyanin content was expressed as cyanidin-3-glucoside (mg/100g) equivalents.

Total polyphenols

Polyphenols were extracted following the method of Illiano et al. (2022). The powder sample (1 g) was added to 3 ml extraction solvent (methanol/water/formic acid in a ratio of 80:19:1 v/v) and homogenised for 15 minutes at room temperature, using a sonicator. The extract was centrifuged (Hermle Z300K, Wehingen, Germany) at 5000 x g for 10 minutes and the supernatant was used to quantify the polyphenols following the Folin-Ciocalteu assay (Lamuela-Raventós, 2018). Absorbance was read at 765 nm in a UV-VIS spectrophotometer (Jenway 6035, Germany), against a gallic acid standard.

Flavonoid glycosides

Flavonoid glycoside content was determined using the method of Da Silva et al. (2015). The powder sample (2 g) was extracted under reflux conditions at 80 °C with 20 ml water-ethanol solution (60% v/v; pH 5.06) for 60 min. The extract was treated with 2% w/v aluminium chloride and absorbance read at 430 nm in a spectrophotometer (Jenway 6035, Germany). Solutions of Quercetin were prepared in a similar way and used as the standard.

Tannins

Total tannin content was determined using the method of 1,10-phenanthroline (Dewi et al., 2014). The powdered sample (0.25 g) was boiled with 50 ml of distilled water. The filtrate was mixed with iron (III)

solution, Acetate buffer, 1,10-phenanthroline solution and EDTA solution. Absorbance was read at 540 nm in a spectrophotometer (Jenway 6035, Germany). Solutions of tannic acid were prepared in a similar way and used as the standard.

Catechin and epicatechin

Catechin and epicatechin contents were determined using the method of Kingori et al. (2018). The samples (0.2 g) were extracted with hot methanol:water (7:3 v/v) mixture. The filtrate was analysed with HPLC (Shimadzu LC-20AD, Shimadzu Corporation, Japan), equipped with a prominence Autosampler (SIL-20A HT, Shimadzu Corporation, Japan) ad UV-VIS detector (SPD-20A, Shimadzu Corporation, Japan). The catechin classes were separated on a reversed phase C18 column (Agilent Zorbax Eclipse Plus; 150 mm x 4.6 u x 5 mm) with a mobile phase consisting of Water: acetonitrile: methanol: acetic acid: ethyl acetate in a ratio of 77.5:18:2:0.5:2. Detection was carried out with a UV Prominence detector at 278 nm using catechin and epicatechin external standards.

Vitamins (β-carotene and α-tocopherol)

Vitamins (β-carotene and α-tocopherol) were extracted from the samples using the simultaneous extraction procedure (Blanco et al., 1995). 2.5 g were weighed into a 100 ml conical flask, to which 49 ml acetone:hexane solution (3:2 v/v) and 1 ml of 0.1% butylated hydroxytoluene (BHT) was added. The filtrate was saponified with ethanolic potassium hydroxide (0.5 M), washed with 10% w/v sodium chloride solution; dried, dissolved in absolute ethanol and analyzed using HPLC system (Shimadzu LC-20AD, Shimadzu Corporation, Japan), equipped with a prominence Autosampler (SIL-20A HT, Shimadzu Corporation, Japan) ad UV-VIS detector (SPD-20A, Shimadzu Corporation, Japan). The mobile phase consisted of methanol: dichloromethane: water in the ratio 79: 18: 3; and the separation was done isocratically at a flow rate of 1 ml/min. Detection was carried out at 450 nm and 298 nm for β-carotene and α-tocopherol respectively and quantification was done using β-carotene and α-tocopherol standards.

Chlorogenic and ferulic acids

Chlorogenic and ferulic acid concentrations were determined following the method of Suleymanova et al. (2019). Powdered sample (1 g) was extracted with 70% ethyl alcohol in a boiling water bath under reflux for 1 hour, allowed to cool to room temperature, and filtered through a PTFE nylon filter; 0.22 µm. The extract (20 µl) was injected into the HPLC system (Shimadzu LC-20AD, Shimadzu Corporation, Japan), equipped with a prominence Autosampler (SIL-20A HT, Shimadzu Corporation, Japan) ad UV-VIS detector (SPD-20A, Shimadzu Corporation, Japan) and a column oven (CTO-10AS, Shimadzu Corporation, Japan). Separation was performed on a C18 column (Agilent Zorbax Eclipse Plus; 150 mm x 4.6 u x 5 mm). The mobile phase consisted of phosphate buffer (pH 2.2). The buffer is prepared by dissolving 27.2 g of potassium dihydrogen phosphate in purified water to a volume of 1 litre, followed by adjustment of the pH using orthophosphoric acid. Chromatographic parameters were flow rate: 1 ml/min, column temperature: 25 °C and run time of 15 minutes. Detection was by means of a UV Prominence detector at 330 nm. Chromatograms were processed with Lab solutions software and standards of chlorogenic and ferulic acid were prepared in a similar way for quantification.

Gallic acid

Gallic acid was quantified using the method of Suleymanova et al. (2019), with an HPLC system (Shimadzu LC-20AD, Shimadzu Corporation, Japan) with a UV Prominence detector at 210 nm. The sample (1 g) was extracted with 70% ethyl alcohol in a boiling water bath under reflux for 1 hour, allowed to cool to room temperature and filtered through a PTFE nylon filter; 0.22 µm. The extract (20 µl) was introduced into the HPLC system by means of an autosampler. HPLC conditions were as follows: Column: Agilent Zorbax

Eclipse Plus; 150 mm x 4.6 u x 5 mm; mobile phase: phosphate buffer (pH 2.2); flow rate: 1 ml/min, column temperature: 25 °C and run time: 15 minutes.

Data analysis

The means were separated using One-Way ANOVA in MINITAB® software and significance of differences determined using Fisher's individual error rate at 5% ($p < 0.05$). Principle component analysis (PCA) was performed using XLSTAT (2018) to determine relationships between chemical composition and genotype.

Results

Tables 1–5 show that there were significant differences among the compounds studied, except for chlorogenic acid.

Mineral content

Table 1 shows the mineral composition of the AIVs. There were significant differences ($p < 0.05$) among the different genotypes for all the minerals studied. Zinc composition ranged from 6.2–16.2 mg/100g and showed significant variations ($p < 0.05$) among the AIVs. The concentration of zinc was the highest in *S. aethiopicum* Shum E16 and the lowest in *S. aethiopicum* Shum E11. Calcium content ranged from 113.76–395.95 mg/100g and was significantly different ($p < 0.05$) among the AIVs. Its concentration was the highest in *S. aethiopicum* Shum E16 and the lowest in *S. aethiopicum* Shum E15. Magnesium content was the highest in *Amaranthus* sp. Var. 025 (779.11 mg/100g) and the lowest in *V. unguiculata* Aseremoya (236.3 mg/100g). Potassium content was the highest in *S. aethiopicum* Gilo G9 (1077.77 mg/100g) and the lowest in *V. unguiculate Acc23* (358.37 mg/100g). On the other hand, iron

Table 1. Mineral content of the different AIV genotypes.

Genotype	Zinc (mg/100g)	Calcium (mg/100g)	Magnesium (mg/100g)	Potassium (mg/100g)	Iron (mg/100g)
Amaranthus sp. Var. 008	7.45 ± 0.13^{e}	166.93 ± 1.67^{d}	672.79 ± 12.13^{bcd}	624.15 ± 4.65^{h}	8.26 ± 0.34^{ab}
Amaranthus sp. Var. 025	11.59 ± 0.33^{c}	170.21 ± 0.46^{d}	779.11 ± 5.10^{a}	799.18 ± 4.75^{e}	7.09 ± 0.06^{bcd}
Amaranthus sp. Var. 007	6.34 ± 0.47^{g}	135.35 ± 1.35^{f}	634.36 ± 13.12^{e}	676.19 ± 0.97^{f}	8.73 ± 0.31^{a}
V. unguiculata ucu cow 1	6.66 ± 0.02^{fg}	236.05 ± 1.25^{b}	434.81 ± 2.01^{f}	677.03 ± 1.55^{f}	6.00 ± 1.34^{d}
V. unguiculata Aseremoya	8.56 ± 0.02^{d}	125.07 ± 1.61^{g}	236.30 ± 1.51^{g}	457.40 ± 1.21^{i}	6.70 ± 0.40^{cd}
V. unguiculate Acc23	12.48 ± 0.04^{b}	135.30 ± 1.25^{f}	239.53 ± 0.90^{g}	358.37 ± 1.63^{j}	7.69 ± 0.73^{abc}
S. aethiopicum Shum E16	16.23 ± 0.64^{a}	395.95 ± 1.28a	687.46 ± 6.13^{bc}	1073.18 ± 2.80^{a}	6.54 ± 0.47^{cd}
S. aethiopicum Shum E15	8.53 ± 0.24^{d}	113.76 ± 0.75^{h}	682.29 ± 8.94^{bc}	862.75 ± 1.80^{d}	8.60 ± 0.65^{a}
S. aethiopicum Shum E11	6.21 ± 0.32^{g}	222.82 ± 12.75^{c}	659.61 ± 45.39^{d}	656.27 ± 9.12^{g}	8.07 ± 0.69^{ab}
S. aethiopicum Gilo G4	11.08 ± 0.48^{c}	151.69 ± 1.21^{e}	701.74 ± 4.41^{b}	876.10 ± 1.11^{c}	8.83 ± 0.92^{a}
S. aethiopicum Gilo G9	8.33 ± 0.35^{d}	114.38 ± 1.84^{h}	692.49 ± 40.98^{b}	1077.77 ± 2.15^{a}	7.74 ± 0.88^{abc}
S. aethiopicum Gilo G6	7.13 ± 0.11^{ef}	237.14 ± 1.56^{b}	640.52 ± 14.26^{de}	961.96 ± 16.55^{b}	8.47 ± 1.19^{a}

Results are presented as mean ± standard deviation for triplicate analyses. Means with different superscripts in the same column are significantly different ($p < 0.05$).

Table 2. Dietary fiber, β-carotene and α-tocopherol content of the different AIV genotypes.

Genotype	β-carotene (mg/Kg)	α-tocopherol (mg/Kg)	Dietary fiber (g/100g)
Amaranthus sp. Var. 008	51.33 ± 16.84^{d}	6.59 ± 0.12^{de}	4.03 ± 0.15^{c}
Amaranthus sp. Var. 025	8.42 ± 1.97^{f}	43.98 ± 1.86^{c}	4.01 ± 0.09^{c}
Amaranthus sp. Var. 007	51.50 ± 10.87^{d}	38.21 ± 2.62^{cd}	4.22 ± 0.05^{a}
V. unguiculata ucu cow 1	161.40 ± 26.57^{a}	3.00 ± 0.30^{e}	4.01 ± 0.04^{c}
V. unguiculata Aseremoya	127.25 ± 4.29^{b}	106.83 ± 1.37^{a}	4.22 ± 0.02^{a}
V. unguiculate Acc23	143.12 ± 7.76^{ab}	6.89 ± 0.54^{de}	4.18 ± 0.02^{ab}
S. aethiopicum Shum E16	80.97 ± 3.63^{c}	8.23 ± 0.00^{de}	4.06 ± 0.03^{bc}
S. aethiopicum Shum E15	46.06 ± 9.55^{d}	80.65 ± 7.59^{b}	3.96 ± 0.06^{c}
S. aethiopicum Shum E11	48.72 ± 12.67^{d}	99.94 ± 15.99^{a}	3.98 ± 0.08^{c}
S. aethiopicum Gilo G4	15.88 ± 4.77^{ef}	22.62 ± 0.93^{d}	3.70 ± 0.18^{d}
S. aethiopicum Gilo G9	1.25 ± 0.31^{f}	ND	4.01 ± 0.05^{c}
S. aethiopicum Gilo G6	38.20 ± 11.03^{de}	10.09 ± 1.94^{de}	3.78 ± 0.00^{d}

Results are presented as Mean ± Standard deviation for triplicate analyses. Means with different superscripts in the same column are significantly different ($p < 0.05$). ND = Not detectable.

Table 3. Anthocyanin, polyphenol, flavonoid glycoside and tannin content of the different AIV genotypes.

Genotype	Anthocyanin content (mg/100g)	Total polyphenol content (g/100g)	Flavonoid glycoside content (g/100g)	Tannin content (mg TAE/g)
Amaranthus sp. Var. 008	1.32 ± 0.01^{i}	8.94 ± 0.00^{b}	2.540 ± 0.002^{e}	4.256 ± 0.098^{g}
Amaranthus sp. Var. 025	11.67 ± 0.03^{c}	5.20 ± 0.03^{h}	1.785 ± 0.002^{f}	6.836 ± 0.429^{d}
Amaranthus sp. Var. 007	1.40 ± 0.06^{h}	11.63 ± 0.03^{a}	3.305 ± 0.002^{c}	4.712 ± 0.119^{f}
V. unguiculata ucu cow 1	9.95 ± 0.03^{d}	8.51 ± 0.06^{c}	4.554 ± 0.231^{b}	11.033 ± 0.161^{c}
V. unguiculata Aseremoya	11.96 ± 0.06^{b}	8.13 ± 0.08^{d}	4.886 ± 0.011^{a}	16.749 ± 0.406^{b}
V. unguiculate Acc23	14.49 ± 0.02^{a}	7.76 ± 0.06^{e}	4.978 ± 0.013^{a}	18.601 ± 0.183^{a}
S. aethiopicum Shum E16	2.02 ± 0.02^{f}	7.20 ± 0.00^{f}	3.098 ± 0.005^{d}	4.577 ± 0.093^{fg}
S. aethiopicum Shum E15	1.50 ± 0.01^{g}	3.86 ± 0.03^{i}	1.199 ± 0.002^{g}	6.046 ± 0.043^{e}
S. aethiopicum Shum E11	2.16 ± 0.00^{e}	6.26 ± 0.00^{g}	2.608 ± 0.004^{e}	4.885 ± 0.037^{f}
S. aethiopicum Gilo G4	2.15 ± 0.05^{e}	2.91 ± 0.03^{k}	0.214 ± 0.002^{h}	4.774 ± 0.185^{f}
S. aethiopicum Gilo G9	0.69 ± 0.04^{j}	3.39 ± 0.03^{j}	0.020 ± 0.005^{i}	4.885 ± 0.161^{f}
S. aethiopicum Gilo G6	1.32 ± 0.01^{i}	2.98 ± 0.09^{k}	0.087 ± 0.004^{i}	4.675 ± 0.119^{f}

Results are presented as Mean ± Standard deviation for triplicate analyses. Means with different superscripts in the same column are significantly different ($p < 0.05$).

Table 4. The concentration of catechins among the different AIV genotypes.

Genotype	Catechin (mg/Kg)	Epicatechin (mg/Kg)	Epigallocatechin (g/Kg)
Amaranthus sp. Var. 008	1762.3 ± 19.9^{b}	254.3 ± 6.4^{h}	2.26 ± 0.06^{h}
Amaranthus sp. Var. 025	1770.7 ± 4.7^{b}	435.7 ± 28.5^{g}	4.13 ± 0.01^{g}
Amaranthus sp. Var. 007	613.0 ± 19.3^{e}	4.7 ± 1.5^{i}	4.75 ± 0.20^{g}
V. unguiculata ucu cow 1	709.7 ± 6.7^{de}	757.0 ± 3.0^{e}	3.11 ± 0.03^{h}
V. unguiculata Aseremoya	3504.0 ± 550.8^{a}	579.3 ± 59.5^{f}	9.07 ± 0.29^{e}
V. unguiculate Acc23	1068.7 ± 13.6^{c}	2229.0 ± 20.7^{a}	8.07 ± 0.14^{f}
S. aethiopicum Shum E16	1003.3 ± 25.4^{c}	1829.3 ± 17.6^{b}	13.93 ± 0.06^{d}
S. aethiopicum Shum E15	1026.7 ± 0.6^{c}	1870.3 ± 6.1^{b}	13.76 ± 0.02^{d}
S. aethiopicum Shum E11	937.7 ± 5.7^{cd}	1052.7 ± 13.7^{d}	13.72 ± 0.08^{d}
S. aethiopicum Gilo G4	711.3 ± 3.8^{de}	1899.7 ± 20.6^{b}	16.89 ± 0.11^{b}
S. aethiopicum Gilo G9	693.3 ± 49.6^{de}	1630.7 ± 137.4^{c}	15.16 ± 0.48^{c}
S. aethiopicum Gilo G6	491.0 ± 44.0^{e}	1623.0 ± 100.5^{c}	17.84 ± 1.74^{a}

Results are presented as Mean ± Standard deviation for triplicate analyses. Means with different superscripts in the same column are significantly different ($p < 0.05$).

Table 5. Chlorogenic, gallic acid and ferulic acid content of the different AIV genotypes.

Genotype	Chlorogenic acid content (mg/100g)	Gallic acid content (g/Kg)	Ferulic acid content (mg/100g)
Amaranthus sp. Var. 008	222.87 ± 61.60^{a}	7.1067 ± 0.3053^{a}	0.098 ± 0.004^{e}
Amaranthus sp. Var. 025	80.03 ± 1.8^{a}	4.8567 ± 0.0404^{de}	0.720 ± 0.773^{de}
Amaranthus sp. Var. 007	52.72 ± 2.60^{a}	2.0667 ± 0.0702^{h}	1.715 ± 0.007^{cd}
V. unguiculata ucu cow 1	153.37 ± 77.69^{a}	5.7500 ± 0.0557^{c}	0.078 ± 0.022^{e}
V. unguiculata Aseremoya	93.34 ± 11.76^{a}	4.7033 ± 0.0611^{e}	0.101 ± 0.004^{e}
V. unguiculate Acc23	56.88 ± 1.33^{a}	4.3867 ± 0.0702^{f}	0.622 ± 0.038^{de}
S. aethiopicum Shum E16	121.17 ± 5.94^{a}	5.1600 ± 0.2227^{d}	8.053 ± 0.082^{a}
S. aethiopicum Shum E15	146.30 ± 5.88^{a}	6.5767 ± 0.0153^{b}	6.328 ± 0.551^{b}
S. aethiopicum Shum E11	167.07 ± 84.82^{a}	6.3033 ± 0.0681^{b}	8.059 ± 1.679^{a}
S. aethiopicum Gilo G4	155.39 ± 70.73^{a}	2.0333 ± 0.1528^{h}	6.965 ± 0.529^{ab}
S. aethiopicum Gilo G9	118.28 ± 1.55^{a}	4.0033 ± 0.4167^{g}	0.133 ± 0.002^{e}
S. aethiopicum Gilo G6	113.31 ± 16.74^{a}	2.1333 ± 0.1943^{h}	2.913 ± 0.277^{c}

Results are presented as Mean ± Standard deviation for duplicate analyses. Means with different superscripts in the same column are significantly different ($p < 0.05$).

content was the highest in S. *aethiopicum* Gilo G4 (8.8 mg/100g) and the lowest in *V. unguiculata* ucu cow 1 (6.0 mg/100g). Overall, S. *aethiopicum* Shum E16 had among the highest concentrations of minerals apart from iron while cowpea varieties had the lowest composition of magnesium, iron, and potassium.

Dietary fiber and vitamins

Table 2 shows the dietary fiber, β-carotene and α-tocopherol content of the different AIV genotypes. There were significant differences ($p < 0.05$) among the different genotypes for dietary fiber and vitamins. The β-carotene ranged from 1.25–161.4 mg/Kg and was highest in *V. unguiculata* ucu cow 1 and lowest in *S. aethiopicum* Gilo G9. Overall, the cowpea genotypes had the highest composition of β-carotene and

S. aethiopicum Gilo genotypes the lowest. α-tocopherol content was highest in *V. unguiculata* Aseremoya (106.83 mg/Kg) and was not detected in *S. aethiopicum* Gilo G9. On the other hand, dietary fiber was highest in *V. unguiculata* Aseremoya (4.2 g/100g) and lowest in *S. aethiopicum* Gilo G9 (3.7 g/100g). Overall, the fruit vegetables (*S. aethiopicum* Gilo genotypes) had lower fibre content than the leafy vegetables.

Anthocyanin, polyphenol, flavonoid glycoside and tannin content

Table 3 shows the anthocyanin, polyphenol, flavonoid and tannin content of the different AIV genotypes. There were significant differences ($p < 0.05$) among the genotypes. The anthocyanin content ranged from 0.7 to 14.5 mg/100g and was highest in *V. unguiculate Acc23* and lowest in *S. aethiopicum* Gilo G9. Overall, the cow pea genotypes had the highest composition of anthocyanin and the *S. aethiopicum* Gilo genotypes the lowest. Total polyphenol content was highest in *V. Amaranthus* sp. Var. 007 (11.6 g/100g) and was lowest in *S. aethiopicum* Gilo G6. On the other hand, flavonoids were highest in *V. unguiculate Acc23* (4.98 g/100g) and lowest in *S. aethiopicum* Gilo G9 (0.02 g/100g). Overall, the fruit vegetables (*S. aethiopicum* Gilo genotypes) had lower phytochemical content than the leafy vegetables.

Catechins

Table 4 shows the catechin content of the different AIV genotypes. There were significant differences ($p < 0.05$) among the genotypes. The total catechin content ranged from 491 to 3504 mg/Kg and was highest in *V. unguiculata* Aseremoya and lowest in *S. aethiopicum* Gilo G6. The epicatechin content was highest in *V. unguiculate Acc23* (2229 mg/Kg) and was lowest in *Amaranthus* sp. Var. 007. On the other hand, epigallocatechin content was highest in *S. aethiopicum* Gilo G6 (17.8 mg/Kg) and lowest in *S. Amaranthus* sp. Var. 008 (2.3 mg/Kg). Overall, the fruit vegetables (*S. aethiopicum* Gilo genotypes) had the highest epigallocatechin content than the leafy vegetables.

Chlorogenic, gallic acid and ferulic acid content

Table 5 shows the chlorogenic acid, gallic acid and ferulic acid content of the different AIV genotypes. There were significant differences ($p < 0.05$) among the genotypes apart from chologenic acid. The chlorogenic acid content ranged from 52.7 to 222.9 mg/100g but was not significantly different among the genotypes ($p > 0.05$). The gallic acid content was highest in *Amaranthus* sp. Var. 008 (7.1 g/Kg) and was lowest in *S. aethiopicum* Gilo G4 (2 g/Kg). Overall, *S. aethiopicum* Shum genotypes had the highest gallic acid content and *S. aethiopicum* Gilo varieties the lowest. On the other hand, ferulic acid content was highest in *S. aethiopicum* Shum E16 (8.06 mg/100g) and lowest in *V. unguiculata* ucu cow 1 (0.08 mg/100g). Overall, *S. aethiopicum* Shum genotypes had the highest ferulic acid content and cowpea varieties the lowest.

Principle component analysis

Figure 1 shows the relationship between the chemical composition of the different AIVs and their genotypes. PC1 accounted for 40.6% of the variation in chemical composition while PC2 accounted for 14.6%. The two principal components were able to segregate AIVs by genotype and by chemical composition. PC1 was able to segregate *Solanum* genotypes (*S. aethiopicum* Gilo and *S. aethiopicum* Shum) from the other AIVs. Mineral content greatly influenced segregation of solanum genotypes while tocopherol and gallic acid segregated the amaranths genotypes. Secondary metabolites (anthocyanins, tannins, catechins, polyphenols and flavonoids), ß-carotene and dietary fibre greatly influenced segregation of cowpea genotypes. *S. aethiopicum* genotypes were positively related to mineral composition while the cowpea genotypes were positively associated with secondary metabolites and dietary fibre. PC2 segregated *S. aethiopicum* Gilo and Amaranths varieties from *V. unguiculata* and *S. aethiopicum* Shum. Zinc, iron and polyphenol were the most important parameters segregating the different genotypes.

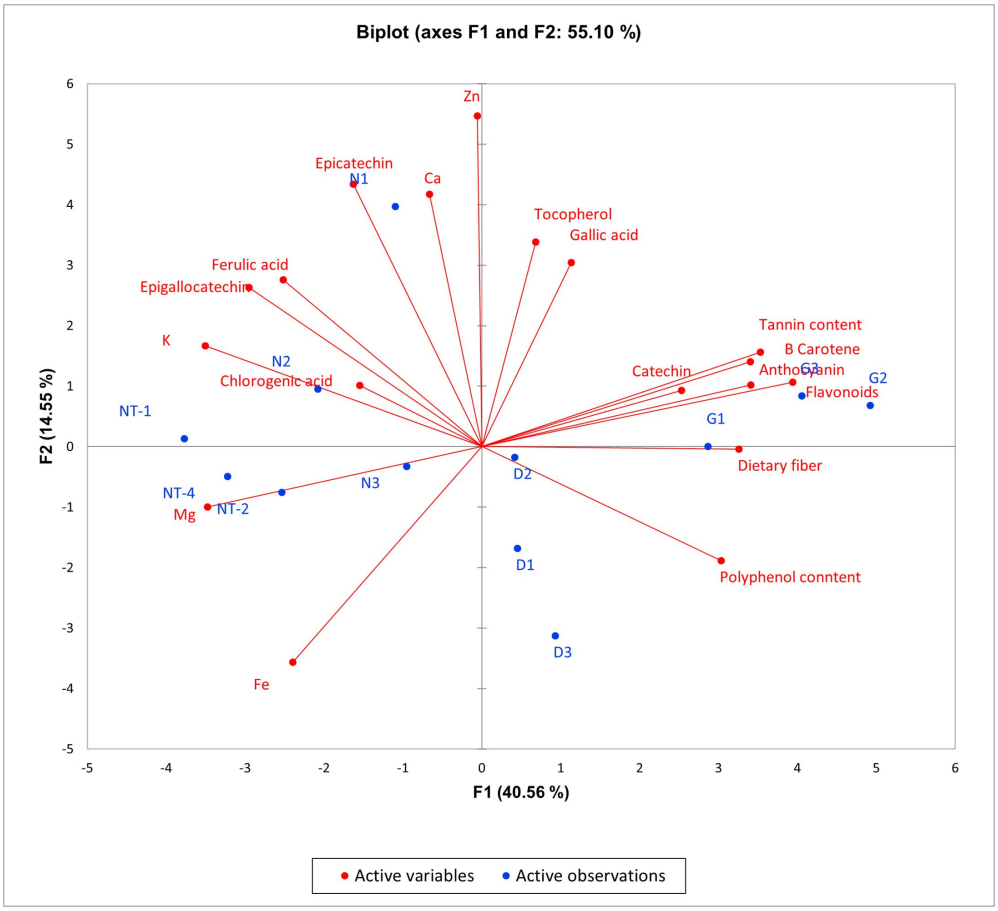

Figure 1. Principal Component Analysis showing the relationship between chemical composition and genotype of the different AIVs. Key to Figure 1: **D1**=Amaranthus sp. Var. 008**, D2**=Amaranthus sp. Var. 025**; D3**=Amaranthus sp. Var. 007; **G1**=*V. unguiculata* ucu cow 1; **G2**=*V. unguiculata* Aseremoya; **G3**=*V. unguiculate Acc23;* **N1**=*S. aethiopicum* Shum E16; **N2**=*S. aethiopicum* Shum E15; **N3**=*S. aethiopicum* Shum E11; **NT-1**=*S. aethiopicum* Gilo G4; **NT-2**=*S. aethiopicum* Gilo G9; **NT-4** =*S. aethiopicum* Gilo G6.

Discussion

Genotypic influence on nutrient composition

There were significant differences in mineral, fibre, vitamins, and phytochemical content across different genotypes of frequently consumed AIVs. In this study, S. *aethiopicum* Shum E16 had overall the highest mineral content, while cowpea varieties had the lowest composition. Calcium and zinc are the most important minerals for the older persons. The calcium and iron content of the AIVs was in the lower range of most AIVs and even exotic vegetables (Kamga et al. 2013; Yang & Keding, 2009). However, zinc, magnesium and potassium content were in the range for AIVs (Kamga et al. 2013; Wasswa & Muyonga, 2021) and compared well with exotic vegetables (Yang & Keding, 2009). The highest iron (198 mg/100g) and zinc (21 mg/100g) in AIVs are found in *Triumfetta annua* (burweed) and *Pterocarpus mildbraedii* respectively (Yang & Keding, 2009). Genotypic variation plays a central role in determining the biochemical composition of AIVs hence important implications for geriatric nutrition and breeding for improved nutritional quality. The highest mineral content exhibited in *S. aethiopicum* Shum E16 is likely due to its efficient nutrient uptake and translocation mechanisms. Conversely, cowpea genotypes showed lower mineral levels, reflecting their physiological capitalisation on seed development over vegetative nutrient storage. This aligns with findings by Byrnes et al. (2017), who demonstrated significant differences in micronutrient accumulation among amaranth genotypes.

The β- carotene, alpha tocopherol, dietary fiber, anthocyanin content was lower than that reported in literature (Nambafu et al. 2021; Onyeka & Nwambekwe, 2007). However, the polyphenol, anthocyanin, flavonoid content was in the range for African indigenous leafy vegetable (Matenge et al. 2017; Moyo

et al. 2013). On the other hand, catechin, chlorogenic acid, gallic acid and ferulic were higher than other AIVs (Matenge et al. 2017; Moyo et al. 2013; Muriuki, 2015). Although variations are highlighted in AIVs, they generally possess higher concentrations of phytochemicals compared to commonly cultivated exotic vegetables such as tomato and cabbage (Yang & Keding, 2009). Several neglected vegetables including but not limited to a (Muriuki, 2015)maranth, spider plant, and African nightshade are increasingly recognized for their nutrient density and resilience (Lara-Arevalo et al., 2024). As a result there is a continuous emphasis the role of underutilized vegetables in enhancing nutritional security due to their high bioactive compound content and adaptability to marginal environments (Marappan et al., 2024). Furthermore, the elevated levels of antioxidants and phenolic compounds in AIVs are linked to their exposure to abiotic stress and evolutionary selection for secondary metabolite production. For example Murthy & Paek (2021) highlighted that underutilized vegetables often synthesize higher levels of bioactive compounds as part of their defence mechanisms, contributing to their health-promoting properties. These nutrient-rich profiles make AIVs particularly valuable for geriatric nutrition, where micronutrient density, antioxidant and anti-inflammatory capacity are critical (Elolu et al., 2023; Shahidi & Ambigaipalan, 2015; Zeb, 2020), reducing the risk of chronic diseases (e.g. cardiovascular diseases and cancers).

Even though important nutrient composition differences were reported among AIVs, this study was limited to a specific geographic region, soil type, climate, agricultural practices, and a selected number of AIV genotypes, which may not be representative of the broader diversity of AIVs in Uganda or Africa as whole. The study also primarily focused on the quantification of minerals and bioactive compounds without delving into the bioavailability and actual health impacts of these compounds in human diets. In this sense, it is projected that AIVs will make a substantial contribution to the WHO worldwide campaign aimed at promoting fruit and vegetable intake in African nations (Smith and Eyzaguirre 2007). Therefore, further 'Genotype X Environment' research is needed to investigate the environmental effect on chemical composition, as well as the bioavailability of these nutrients and bioactive compounds and their actual effects on health outcomes of the elderly.

Conclusion and recommendations

This study underscores the nutritional potential of different AIV genotypes, with significant variability in mineral content, vitamins, and phytochemicals. These findings provide a vivid foundation for the potential utilization of AIVs in value-added nutraceutical applications and the development of optimized dietary strategies for older adults. For instance, the high phytochemical content of *V. unguiculata* genotypes underscores their potential in providing antioxidant and anti-inflammatory formulations, which are crucial for managing age-related health issues. Similarly, the superior mineral profiles of *S. aethiopicum* Shum E16 reinforce its potential as a micronutrient-rich ingredient in functional food products tailored for geriatric nutrition.

Given the genotypic differences in nutrient composition, breeding programs should prioritize AIV genotypes with enhanced dietary quality and bioactive profiles. These priority genotypes/vegetables can be integrated into recipe development to maximize nutritional value and inform culturally appropriate consumption guides for older populations. Nevertheless, to fully realize the health-promoting potential of these vegetables, further research is needed to assess the bioavailability impact of their bioactive compounds. This calls for clinical and epidemiological studies to validate their efficacy and support evidence-based recommendations for their inclusion in public health nutrition programs targeting aging populations.

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CRediT: **Martin Mutambuka**: Formal analysis, Methodology, Writing – original draft, Writing – review & editing; **Mildred Nakanwagi**: Project administration, Writing – review & editing; **Rosemary Bulyaba**: Resources, Writing

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Data availability statement

The dataset used and/or analysed during this current study are available from the corresponding author.

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