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ORIGINAL ARTICLE

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Nutrient composition of leaves and seeds in selected African Indigenous Vegetables (AIVs): Potential for addressing malnutrition in children under five in Sub-Saharan Africa

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ABSTRACT

Background: In Sub-Saharan Africa, approximately 64 million children under the age of five are at risk of acute malnutrition due to chronic poverty, climate change and reliance on nutrient-deficient staple foods, such as maize, which is commonly used as a weaning food. To mitigate the burden of malnutrition, resource-poor households should utilize readily available, nutritious, and climate-resilient raw materials to fortify weaning foods and improve child nutrition.
Aims: This study aimed to provide scientific evidence that the malnutrition among children under five in sub-Saharan Africa may be alleviated by utilizing locally available raw materials for the fortification of weaning foods. The findings are intended to inform nutritionists in designing food-based approaches and community-level interventions to reduce child malnutrition. Additionally, food technologists may apply this information in formulating weaning foods or incorporating it into local nutritional databases for food fortification. The data may also be utilized in therapeutic feeding programs for children suffering from acute malnutrition.
Subjects and Methods: The leaves and seeds of widely consumed African Indigenous Vegetables (AIVs)—*Amaranthus cruentus*, *Amaranthus hypochondriacus*, *Amaranthus spinosus* and *Cleome gynandra*—were analyzed for proximate composition (crude protein, ash, crude fiber and crude fat), macro-minerals (calcium, phosphorous, magnesium and potassium) and micro-minerals (iron, manganese, and zinc). The mean nutritional composition for each sample was statistically compared within and across species to ascertain significant differences.
Results: The results indicate that AIVs are rich in macronutrients, macro-minerals and micro-minerals essential for the development of children under five, which often lacking in commonly used weaning foods. The leaves exhibited higher protein and ash content compared to the seeds, while the seeds showed significantly higher crude fat levels than the leaves ($p < 0.05$). The lowest crude fiber content was recorded in *Amaranthus hypochondriacus* seeds (5.48 ± 0.22%), whereas the highest was observed in *Cleome gynandra* seeds (20.05 ± 1.11%). *Amaranthus hypochondriacus* leaves displayed the highest calcium content (4.27 ± 0.61 %), and the highest iron content was found in the leaves of *Amaranthus cruentus* (2515.64 ± 8.73 mg/g). These findings suggest that the concurrent use of leaves and seeds from AIVs has significant potential to reduce malnutrition in children under five when incorporated into weaning foods. Furthermore, utilizing both seeds and leaves minimizes waste and improves food and nutrition security.
Conclusions: Malnutrition among children under five in sub-Saharan Africa may be mitigated through the fortification of weaning foods using both the leaves and seeds of African Indigenous Vegetables. This approach offers a sustainable and locally adaptable solution to improve child nutrition and food security.

Keywords: Nutritional composition, African indigenous vegetables, traditional food systems, food and nutrition security, climate-change, weaning foods.

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1 INTRODUCTION

The increased frequency and incidences of climate induced natural disasters in recent years have intensified food and nutrition insecurity in Sub Saharan Africa (Baptista *et al.*, 2022). Consequently, this has resulted in renewed interests and increased reliance on traditional food systems. A traditional food system can be defined as "all food from a particular culture available from local resources and culturally accepted. It includes socio-cultural meanings, acquisition/processing techniques, use, composition, and nutritional consequences for people using the food"

(Kuhnlein & Receveur, 1996). Traditional food systems are often neglected as they are perceived to be food for the poor (Qwabe & Pittaway, 2023) and regarded as low in economic value (Akinola *et al.*, 2020). However, traditional food systems have been shown to play a critical role in food and nutrition security (Arumugam *et al.*, 2020). Traditional food consumption and production practices can improve nutritional security by mitigating disruptive dietary transitions, providing nutrients and improving agricultural resilience (Deaconu *et al.*, 2021). African indigenous vegetables (AIVs) form part of these traditional food systems and are important to food and nutrition security. The adaptability and resilience to stress of AIVs provides farmers with the required coping strategies to mitigate the effects of climate change (Capuno *et al.*, 2015). AIVs provide quality nutrition at low prices (Mwanga *et al.*, 2020). Furthermore, AIV species do not require large amounts of fertilizer and chemicals (Bokelmann *et al.*, 2022). Therefore, AIVs have unique characteristics and can contribute towards the achievement of the first three Sustainable Development Goals (SDGs), especially in Sub-Saharan Africa where there are increased incidences of climate extremes.

AIVs are rich sources of macronutrients, macro- minerals, micronutrients and phytochemicals, which function as antioxidants and protect the body from oxidative damage caused by free radicals (Njume *et al.*, 2014). Macro minerals, also referred to as macro-elements, are required in significant quantities in the human body and play a crucial role in various metabolic processes (Ali, 2023). Conversely, micronutrients, or trace elements, are required in smaller concentrations yet are essential for the proper functioning of physiological systems (He *et al.*, 2005). Deficiencies in both macro- and micronutrients contribute substantially to mortality rates among children under the age of five (Engidaw *et al.*, 2023). A proximate analysis of some indigenous leafy vegetables has demonstrated that compared with *Brassica napus* (rape), *Amaranthus hybridus* contained twice the amount of calcium, while other nutrients fall within a similar range. Compared with *Spinacia oleracea* (spinach), *Amaranthus hybridus* contains three times more vitamin C (44 mg/100 g). Calcium levels were 530 mg/100 g. *Amaranthus hybridus* was also found to contain 7, 13, and 20 times more vitamin C, calcium, and iron respectively when compared with *Lactuca sativa* (lettuce). Similarly, *Cleome gynandra* contained 14 mg/100 g, 115 mg/100 g, 9 mg/100 g of vitamin C, calcium, and iron respectively. *Bidens pilosa* was found to be a valuable source of vitamin C (63 mg/100 g), iron (15 mg/100 g), and zinc (19 mg/100 g), compared with *Brassica oleracea* (cabbage). The leaves of *Corchorus tridens* were an excellent source of vitamin C (78 mg/100 g), calcium (380 mg/100 g), and iron (8 mg/100 g). The *Adansonia digitata* leaves were also rich in vitamin C (55 mg/100 g), iron (23 mg/ 100 g), and calcium (400 mg/100 g) (Muchuweti *et al.*, 2009). The substantial nutrient content of AIVs underscores their potential role in food fortification to mitigate the high micronutrient deficiencies in children under five years of age.

A review by Mazike *et al.* (2022) indicates that the commonly consumed parts of AIVs are the leaves and seeds. However, the majority of studies on the nutritional value of AIVs have primarily focused on leaf composition (Maseko *et al.*, 2019; Kamga *et al.*, 2013), with limited research on the nutritional profile of the seeds.

This gap in knowledge is significant, as understanding the comparative nutritional value of these plant components is essential for identifying which part—leaves or seeds— hold greater potential for use in food-based fortification strategies.

Hence, this study was aimed at investigating the nutritional composition of both the leaves and seeds of the most commonly consumed AIVs in Zimbabwe. In Zimbabwe, *Cleome gynandra* and *Amaranthus* spp. are among the most widely consumed AIVs, with 83% and 73% of households, respectively, incorporating them into their diets (Macheka *et al.*, 2022). Therefore, this study specifically examines the nutrition composition of the leaves and seeds of these two species. Given their widespread availability and adaptation to local conditions, AIVs in Zimbabwe represent a promising avenue for enhancing dietary nutrient intake.

2 MATERIALS AND METHODS

2.1 Sample collection and preparation

Fresh leaves and mature dried seeds of the selected AIV species—*Amaranthus cruentus*, *Amaranthus hypochondriacus*, *Amaranthus spinosus* and *Cleome gynandra*—were collected from the Agro-Industrial Park farm (18° 23' 34" S, 31° 49' 2" E), located 40 km from Marondera town, Zimbabwe. This farm is situated within agro-ecological region IIb of Zimbabwe, a highly productive agricultural zone characterized by intensive farming, receiving an annual rainfall ranging of 750 – 1000 mm and an average temperature of 22ºC.

The collected leaves and seeds were thoroughly washed using deionized water and air-dried on countertops in the food laboratory at Marondera University of Agricultural Sciences and Technology for a period of fourteen days. Following drying, the samples were weighed using a CBX Compact Balance (Adam Equipment). Four replicates of the dried leaves and seeds from each species were subsequently dispatched to the African Forage Fodder Feed and Food Quality Reference Laboratory (AF4rica-Lab), at the University of Pretoria, South Africa, for proximate, macro mineral, and micro-mineral analyses. All analyses were conducted within four weeks of sample collection to ensure data integrity.

2.2 Sample analysis

2.2.1 Ash, crude fiber and crude fat analysis

Near Infrared Spectroscopy (NIRS) was employed to determine the concentrations of ash, crude fiber and crude fat. The analysis was conducted using a Perten NIRS Instrument DA7250 (manufactured by Perkin Elmer), which utilizes diode array technology for precise measurements.

2.2.2 Crude protein analysis

The total nitrogen content of the samples was determined using the Kjeldahl method, performed on the Autoanalyzer (AA3 Segmented Flow Analyzer by SEAL Analytical). The Autoanalyzer is an automatic system that integrates distillation and titration processes, designed in accordance with the classical Kjeldahl method for total nitrogen determination. This instrument ensures high accuracy in dozing and titration. The total nitrogen content obtained was converted to crude protein using a conversion factor of 6.25.

2.2.3 Mineral Analysis

The samples were subjected to digestion using a nitric acid and perchloric acid mixture in a 4:1 v/v to facilitate the determination of macro minerals (calcium, phosphorus, magnesium, potassium) and micro minerals (iron, manganese, and zinc). Following the digestion process, the mineral content was determined using an Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) specifically the AVIO 500 model manufactured by PerkinElmer. The instrument was calibrated with certified reference materials obtained from Labmix24 to ensure the accuracy and reliability of the analytical results.

2.3 Statistical data analysis

Each sample was replicated four times, and the data was expressed as the mean ± standard deviation (SD). Analysis of Variance (ANOVA) to determine significance differences between treatments (different parts within species and similar parts across species) was done using SAS/STAT Software Version 9.2. Post hoc analysis (Tukey) was performed to determine significantly different treatments at 5% level of significance ($p < 0.05$).

3 Results

3.1 Proximate composition

The results presented in Table 1 demonstrate that, across all analyzed AIV species, the protein and ash content were significantly higher in the leaves compared to the seeds. Leaves of *Cleome gynandra* (38.47 ± 1.23 %) exhibited the highest protein content, whereas those of *Amaranthus spinosus* displayed the lowest (20.07 ± 1.11 %). This disparity between the two species was statistically significant ($p < 0.05$). In terms of ash content, the leaves of *Amaranthus cruentus* (19.04 ± 0.00 %) contained a significantly higher proportion than those of *Cleome gynandra* (18.21 ± 0.02 %). Regarding crude fiber, the seeds of *Amaranthus hypochondriacus* recorded the lowest content (5.48 ± 0.22 %), while the highest crude fiber content was observed in the seeds of *Cleome gynandra* (20.05 ± 1.11%). With respect to crude fat, the seeds of all analyzed species contained a significantly greater amount of fat compared to their leaves. Furthermore, the seed of *Cleome*

Table 1. The proximate composition (crude protein, ash, crude fiber and crude fat) of leaves and seeds of *Amaranthus cruentus*, *Amaranthus hypochondriacus*, *Amaranthus spinosus* and *Cleome gynandra*

Indigenous Vegetable	Plant Part	Proximate (mean %)			
		Crude Protein (%DM)	Ash (%DM)	Crude Fibre (%DM)	Crude Fat (%DM)
Amaranthus Cruentus	Leaf	27.96^{aW} ± 0.72	19.04^{aW} ± 0.0	10.74^{aW} ± 0.11	0.87^{aW} ± 0.06
	Seed	15.97^{bW} ± 0.33	6.03^{bW} ± 0.38	14.51^{bW} ± 1.65	4.78^{bW} ± 0.28
Amaranthus Hypochondriacus	Leaf	23.19^{aX} ± 0.03	18.73^{aW} ± 0.25	12.23^{aW} ± 0.04	1.62^{aW} ± 0.06
	Seed	15.68^{bW} ± 0.57	2.26^{bX} ± 0.04	5.48^{bX} ± 0.22	4.6^{bW} ± 0.30
Amaranthus Spinosus	Leaf	20.07^{aY} ± 1.11	18.45^{aW} ± 0.29	14.04^{bX} ± 0.38	2.1^{aW} ± 0.20
	Seed	16.44^{bW} ± 0.28	4.63^{bY} ± 0.17	14.57^{bW} ± 0.10	5.65^{bW} ± 0.81
Cleome Gynandra	Leaf	38.47^{aZ} ± 1.24	18.21^{aW} ± 0.02	13.98^{aX} ± 0.11	2.74^{aW} ± 0.35
	Seed	19.67^{bX} ± 0.17	6.15^{bW} ± 0.04	20.05^{bY} ± 1.11	20.59^{bX} ± 4.54

Note. Superscripts a and b indicate variation among the leaf and seed of the same species. Superscripts W, X, Y, Z indicate between species variation of the same plant part ($p \leq 0.05$)

gynandra exhibited the highest crude fat content, measured at 20.59 ± 4.54%.

3.2 Macro-minerals

As illustrated in Table 2, the concentrations of the macro-minerals; calcium, magnesium and potassium were consistently higher in the leaves compared to the seeds across all selected African Indigenous Vegetables (AIVs). Specifically, the leaves of *Amaranthus hypochondriacus* exhibited the highest calcium content (4.27 ± 0.61%), while those of *Cleome gynandra* recorded the lowest (1.58 ± 0.10%). These differences in calcium content were significant ($p < 0.05$). Regarding magnesium, the leaves of *Amaranthus cruentus* demonstrated the highest concentration (1.57 ± 0.05%), whereas the leaves of *Cleome gynandra* leaf displayed the lowest (0.50 ± 0.01%). The observed variations in magnesium content between the leaves and seeds were also found to be statistically significant ($p < 0.05$).

With respect to potassium, the leaves of *Amaranthus spinosus* presented the highest potassium concentration (3.80 ± 0.43%), while those of *Amaranthus cruentus* displayed the lowest (3.38 ± 0.04%). These differences were statistically significant ($p < 0.05$). In the case of phosphorous, the leaves of *Cleome gynandra* contained the highest phosphorous content (0.86 ± 0.13%), whereas no significant differences were observed among the analyzed *Amaranthus* species.

Table 2. The macro-minerals (calcium, phosphorous, magnesium and potassium) content of leaves and seeds for *Amaranthus cruentus, Amaranthus hypochondriacus, Amaranthus spinosus* and *Cleome gynandra*

Indigenous Vegetable	Plant Part	Macro-minerals (mean)			
		Ca (%)	P (%)	Mg (%)	K (%)
Amaranthus Cruentus	Leaf	$3.11^{aX} \pm 0.07$	$0.60^{aX} \pm 0.13$	$1.57^{bW} \pm 0.05$	$3.38^{aW} \pm 0.04$
	Seed	$0.53^{bX} \pm 0.04$	$0.57^{aX} \pm 0.08$	$0.38^{aW} \pm 0.03$	$0.51^{bW} \pm 0.04$
Amaranthus Hypochondriacus	Leaf	$4.27^{aY} \pm 0.61$	$0.61^{aX} \pm 0.12$	$1.10^{aX} \pm 0.08$	$3.44^{aW} \pm 0.03$
	Seed	$0.22^{bX} \pm 0.01$	$0.40^{bY} \pm 0.06$	$0.22^{bX} \pm 0.01$	$0.40^{bW} \pm 0.04$
Amaranthus Spinosus	Leaf	$3.67^{aX} \pm 0.57$	$0.51^{aX} \pm 0.10$	$1.01^{bY} \pm 0.09$	$3.80^{aX} \pm 0.43$
	Seed	$0.47^{bX} \pm 0.05$	$0.54^{aX} \pm 0.10$	$0.40^{aW} \pm 0.05$	$0.56^{bW} \pm 0.02$
Cleome Gynandra	Leaf	$1.58^{aZ} \pm 0.10$	$0.86^{bY} \pm 0.13$	$0.50^{aZ} \pm 0.01$	$3.39^{aW} \pm 0.01$
	Seed	$0.52^{bX} \pm 0.02$	$0.61^{aX} \pm 0.07$	$0.30^{bZ} \pm 0.02$	$0.543^{bW} \pm 0.05$

Note. Superscripts ^{a} and ^{b} indicate variation among the leaf and seed of the same species. Superscripts $^{W, X, Y, Z}$ indicate between species variation of the same plant part ($p \leq 0.05$)

3.3 Micro-minerals

Table 3 presents the concentrations of the micro-minerals; iron, manganese and zinc in the analyzed AIVs. The highest iron content was recorded in the leaves of *Amaranthus cruentus* (2515.64 ± 8.73 mg/g), followed by *Cleome gynandra* leaves (1145.62 ± 14.46 mg/g). Furthermore, *Amaranthus Cruentus* recorded high iron content in both leaves and seeds.

Table 3. The micro-mineral (iron, manganese, and zinc) content of leaves and seeds *Amaranthus cruentus, Amaranthus hypochondriacus, Amaranthus spinosus* and *Cleome gynandra*

Indigenous Vegetable	Plant Part	Microelements (mean)		
		Fe (mg/g)	Mn (mg/g)	Zn (mg/g)
Amaranthus Cruentus	Leaf	$2515.64^{aW} \pm 8.73$	$58.64^{aW} \pm 5.77$	$79.75^{aW} \pm 8.38$
	Seed	$394.61^{bW} \pm 18.84$	$58.81^{aW} \pm 3.63$	$50.77^{bW} \pm 8.49$
Amaranthus Hypochondriacus	Leaf	$253.70^{aX} \pm 29.20$	$235.96^{bX} \pm 18.09$	$29.99^{cX} \pm 2.57$
	Seed	$140.65^{bX} \pm 1.85$	$72.53^{aW} \pm 3.64$	$43.82b^{XW} \pm 6.19$
Amaranthus Spinosus	Leaf	$164.22^{aY} \pm 23.39$	$248.47^{bX} \pm 83.40$	$50.56^{bY} \pm 10.41$
	Seed	$179.08^{aY} \pm 21.85$	$81.77^{aW} \pm 6.95$	$38.47^{bX} \pm 3.16$
Cleome Gynandra	Leaf	$1145.62^{aZ} \pm 14.46$	$297.56^{bX} \pm 4.43$	$69.85^{aW} \pm 15.71$
	Seed	$162.33^{bY} \pm 11.64$	$52.25^{aW} \pm 1.98$	$51.12^{bW} \pm 3.86$

Superscripts a and b indicate variation among the leaf and seed of the same species. Superscripts W, X, Y, Z indicate between species variation of the same plant part (p≤0.05).

Regarding manganese levels, the leaves of *Amaranthus hypochondriacus* (235.96 ± 18.09 mg/g), *Amaranthus spinosus* (248.5 ± 83.4 mg/g), and *Cleome gynandra* leaf (297.56 ± 4.43 mg/g) exhibited high levels of manganese, with no statistically significant differences observed among them at a significance level $p < 0.05$. In contrast, the leaves of *Amaranthus cruentus* (58.64 ± 5.77 mg/g) demonstrated markedly lower manganese levels, which were significantly different from those of the other leaf samples ($p < 0.05$).

Concerning zinc concentrations, the leaves of *Amaranthus hypochondriacus* displayed the lowest zinc content (29.99 mg/g ± 2.57) among analyzed samples.

4 Discussion

The findings of this study demonstrate that the leaves and seeds of AIVs are rich in essential nutrients such as protein, calcium, iron, and zinc, which are critical for the growth and development of children under five years of age. These nutrients are often deficient in staple weaning foods commonly utilized in sub-Saharan Africa. The results indicate the significant potential of AIVs in fortifying weaning foods to address nutritional gaps. Specifically, the leaves of *Cleome gynandra* leaves and *Amaranthus cruentus* leaves exhibite high protein content with the protein levels in *Cleome gynandra* leaves being comparable to those of soyabeans (Hageraats *et al.*, 2023). This suggest that these leaves could be effectively utilized to enhance the protein content of weaning foods. Additionally, the seeds of *Amaranthus hypochondriacus*, which are low in fiber, can be combined with leaves to improve digestibility for young children. Furthermore, *Amaranthus hypochondriacus* or *Amaranthus spinosus* leaves can enhance calcium content, while *Amaranthus cruentus* or *Cleome gynandra* leaves are particularly rich in iron and zinc, making them valuable for improving micronutrient intake.

Protein-energy malnutrition remains a critical issue for children under five, contributing to stunting and cognitive impairments. Despite this, the prevalence of stunting in sub-Saharan Africa persists at 41% (Quamme & Iversen, 2022). Children in this age group require approximately 0.95 g/kg of protein per day (Hudson *et al.*, 2021), a requirement that can be met by fortifying daily foods with small quantities of AIV leaves and seeds. Traditional protein-rich foods such as meat, and meat products, beans, nuts, oats, and peas are often unaffordable for resource-poor households in this region. Notably, the leaves of *Cleome gynandra* (38.47 ± 1.24%) contain higher protein levels than several traditional protein sources, positioning AIVs as a viable and cost-effective alternative for addressing protein deficiencies and fortifying weaning foods.

Calcium-rich foods, including dairy products, almonds, figs, nuts, salmon, soy milk, lentils, broccoli, and fish, these options are frequently inaccessible to low-income households in sub-Saharan Africa. This study reveals that the leaves of *Amaranthus hypochondriacus* (4.27 ± 0.61%) are particularly high in calcium and this indicates the high potential of using AIVs in food-based fortification in weaning foods. Furthermore, the calcium content of dried milk varies from 0.97 to 1.3 % depending on the level of fat (Codex Standards). The leaves of AIVs contain more calcium as compared to dry milk, a good source of calcium. In addition, the findings reveal that the leaves of *Amaranthus cruentus* are exceptionally high in non-heme iron (2515.64 ± 8.73 mg/g) and zinc (79.75 ± 8.38mg/g), further emphasizing the potential role of AIVs in combating micronutrient deficiencies among children under five.

Overall, the nutritional characteristics of AIVs demonstrate significant potential to contribute to the reduction of malnutrition, particularly in sub-Saharan Africa, where the triple burden of malnutrition—encompassing undernutrition, micronutrient deficiencies, and overnutrition—threatens to undermine progress toward Sustainable Development Goal number 2, which aims to achieve zero hunger by 2030. The cultural acceptability, adaptability, and widespread availability of AIVs during the rainy season, coupled with their resilience to drought conditions, further underscore their potential to support the achievement of the first three SDGs, which focus on poverty eradication, food security, and improved nutrition. Unfortunately, although the high accessibility of these nutrient-dense AIVs, the prevalence of child malnutrition remains alarmingly high. This is largely attributed to the fact that AIVs are predominantly consumed by adults as side dishes accompanying carbohydrate-based staples, rather than being integrated into the diets of children under five years of age. Consequently, there is a pressing need to promote the inclusion of AIVs in the diets of young children to address malnutrition effectively in sub-Saharan Africa.

Limitations of the study

While this study highlights the nutritional potential of AIVs, it is important to acknowledge certain limitations. Specifically, there is a need for further research to evaluate the bioavailability of macronutrients, macro minerals and micronutrients present in AIVs.

5 Conclusions

The persistent prevalence of stunting, acute malnutrition, and micronutrient deficiencies among children under five years of age in sub–Saharan Africa, juxtaposed with the abundance of nutrient-dense AIVs in the region, highlights a significant gap in their utilization, especially in the fortification of weaning foods. Addressing this gap through the strategic integration of AIVs into child-feeding practices could play a pivotal role in combating malnutrition and advancing the region's progress toward achieving global nutrition and food security targets.

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