Nutrient Content of Seven African Wild Leafy Vegetables in Semi-arid Tanzania

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Introduction

The world aims at ending hunger, achieving food security, improving nutrition, ensuring healthy lives, and promoting well-being for people of all age groups by 2030 in the Sustainable Development Goals (SDGs) 2 and 3. However, the prevalences of undernourishment, severe food insecurity, and stunted growth of children under the age of 5 years are 25.0 %, 23.8 %, and 31.8 % respectively in Tanzania[1]. Research indicates that 44 % of children worldwide lack fruits or vegetables in their diet[2], which leads to nutrient deficiencies. Moreover, this deficit with maternal undernutrition is indicated as one of the top 10 risk factors contributing to mortality[3]. This situation underlines the importance of utilizing low-cost local resources to obtain a healthy diet. In this context, the focus on African wild leafy vegetables (AWLVs)[4] along with research on their nutrient content[5-7] has increased its importance.

Local utilization of edible plants in Tanzania has been attracting interest, and some nutrients in non-cultivated indigenous wild vegetables in Tanzania have also been studied. A study indicated the nutrient potentials and high levels of iron and β-carotene in some species cat's whiskers (*Cleome gynandra*, Cg) and bitter lettuce (*Launaea cornuta* (Hochst. ex Oliv. & Hiern) C. Jeffrey)) in Kongwa district, Dodoma region compared with those in Tanga and Arusha regions[8]. However, only a few studies have been conducted on the wild leafy vegetables for their nutritional value, which are from other countries or regions, although nutrients of the same species may differ under severe drought conditions[9].

The Dodoma region is part of a semi-arid area of central Tanzania where frequent food insufficiencies occur particularly in the rural areas. The stunted growth of children under the age of 5 years is observed in 37.2 % of children compared with the national average of 31.8 %, and 17.8 % of children are underweight compared with the national average of 14.6 %; however, only 24 % of women have anemia compared with the national average of 28.8 %[1]. Evidence has also been reported that women in Dodoma have relatively low anemia due to their intake of green leafy vegetables[10,11]. In the Chinangali I village of Chamwino district, Dodoma region, food insufficiency occurs during the rainy seasons in which the frequency of wild food consumption increases, and the main wild food consumed is leafy vegetables. During this time, the indigenous people dry the leafy vegetables and store them for future consumption. The dried leafy vegetables can be consumed throughout the year because their shelf lives have been extended from being fresh (several days) to dried form (some months to a year).

Understanding the nutritional impacts of these alternative food items could partly influence achieving the SDG goals such as reducing poverty, hunger, and diseases. The chance to attaining the goals can magnify when the nutritional qualities of the locally available edible vegetables are expressed. Therefore, in this study, proximate composition and micronutrients (minerals; iron, calcium, sodium, and vitamins; β-carotene, vitamin C) of seven AWLVs in semi-arid Tanzania were investigated.

I. Materials and Methods

1. Sample description and selection

This study used samples of seven AWLVs obtained in the farms of Chinangali I village. The vegetables found in the farms have different names and potentials for society. Among the vegetables, raw Cg (Cg-RL) called "mgagani" in Swahili and "mzimwe" in the native language (Gogo),

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raw *Ceratotheca sesamoides* (Cs-RL) called “ilende” / “mgulu” (Gogo) and *Cucumis dipsaceus* (Cd-RL) called “ilumbu” / “hulihuli” (Gogo) were widely distributed. They are either jointly or separately processed when fresh or dried to form a sticky relish known as “mlenda” (Swahili). Raw *Cleome hirta* (Ch-RL) called “muhilile” (Gogo) has similar uses as Cg-RL, however, it has received little attention in previous research[8].

There were three types of wild sweet potato leaves (“matembele pori” in Swahili). Raw *Ipomoea obscura* or *Ipomoea mombassana* (Io-RL) called “chapali” (Gogo) when crushed and then dried together (Io-CD), or “sagula sagula” when dried separately (Io-DL). Raw *Ipomoea sinensis* subsp. *blepharosepala* (Isb-RL) called “maweza” (Gogo) were characterized by the round leaf forming a moon shape. Baobab (*Adansonia digitata*, Ad) offers the edible young leaves called “ikuwi” (Gogo)[8,12-14]. The edible young leaves of these vegetables were selected for the study.

2. Sample collection and processing

Samples of Cg-RL, Ch-RL, Isb-RL, Cs-RL, Ad-RYL, and Ad-RML were harvested on 2020-03-09 in farms of Chinangali I village Dodoma, Tanzania. About 2 kg of fresh young green leaves were harvested and 1 kg of dry leaves per species Io-CD, Io-DL, and Cs&Cd-DL was collected.

Leaves of Io were processed in two different methods which are practiced traditionally. The first method was sorted to remove damaged leaves, crushed, and molded into a pancake-shaped disc that was dried in the sunlight for 2 days to form the traditional Gogo vegetable called “chapali” (Io-CD). The second method was sorted to remove damaged leaves and dried directly in the sunlight for 2 days to form the traditional vegetable name “sagula sagula” (Io-DL). *C. sesamoides* and *C. dipsaceus* leaves were sorted to remove damaged leaves then mixed, and dried in the sunlight for 2 days (Cs&Cd-DL). The dried leaves are then pounded in a wooden mortar to produce a powdered vegetable traditionally called “ilende” to cook a sticky relish “mlenda”.

Samples were precisely packed in polyethylene bags, labeled, and put in cool boxes embedded with iced thermal gels, at last transported from Dodoma to Dar es Salaam region using an air-conditioned vehicle for experimental studies. Most of the samples were delivered at the International Institute of Tropical Agriculture (IITA) and the others at the Tanzania Bureau of Standards (TBS).

3. Sample Analyses

Samples analyses for proximate composition and minerals were done at IITA and for vitamin C and β-carotene at TBC.

(1) Moisture content determination

Approximately 2 g of each sample was weighed in a preconditioned Petri plates that were pre-heated in an oven set at 105 °C for 2 h and cooled in a desiccator for 2 h. The samples were dried in a hot air oven at 105 °C overnight until constant weight[16].

(2) Ash content determination

About 2 g of each sample was weighed into preconditioned porcelain crucibles that were pre-heated in an oven set at 105 ± 2 °C for 2 h and cooled in a desiccator for 2 h. The samples were placed in a temperature-controlled muffle furnace (Nabertherm GmbH, Lilienthal, Germany) and incinerated at 550 °C for 5 h. The crucibles were transferred to a desiccator, cooled to 29 ± 2 °C, and reweighed (AOAC 2005).

(3) Crude fat determination

The fat contents of samples were determined using the Soxhlet system (Foss SoxtecTM 2043, Hilleroed, Denmark). Aluminum cups were pre-heated in an oven set at 105 ± 2 °C for 2 h, and thereafter cooled in a desiccator for 30 min. Each aluminum cup was filled with 30 mL of petroleum ether and placed under an adapter holding thimble loaded with 2 g of the sample. Each thimble was submerged in boiled petroleum ether for 20 min to extract fat. Fat remaining in the samples were rinsed out by reflux using boiling petroleum ether for 45 min. Excess petroleum ether was recovered by evaporation from each cup into the condenser unit of the Soxhlet system for 10 min. The fat extract was dried in a hot air oven set at 105 °C for 30 min.

(4) Crude fiber determination

Fiber content was determined by the Foss Fibertec

system instructions. Fiber crucibles were first pre-heated in an oven set at 105 °C for 2 h and then filled with 2 g of sample and weighed. The fiber crucibles containing the samples were then fixed underneath glassier columns (Foss Fibertec™ 1020). Then, 100 mL of hot H_2SO_4 (1.25 %) was added in the glassier columns to hydrolyze organic substances (e.g., protein, carbohydrate) with occasional auto-heating for 30 min. Resultant residues were washed with hot deionized water followed by adding hot NaOH (1.25 %) to affect the saponification of fat in the sample over 30 min. The sample residues were further washed with hot water, then dried for 2 h in a hot air oven at 130 °C. The crucibles containing the dried sample residues were ignited in a muffle furnace at 550 °C for 5 h and weighed again after cooling following incineration.

(5) Crude protein levels determination

An aliquot of 2 g of each sample was placed into a labeled Kjeldahl tube followed by adding Kjeltec catalyst [3 selenium oxide (2 g) tablets] and 20 mL of concentrated sulfuric acid (98 %). The tubes and the contents were inserted in the digestion unit (Foss Tecator™ Digester) and digested completely (until white fumes and blackish mass were absent) for 2 h at 400 °C. The digests were cooled to 29 ± 2 °C and then distilled for 5 min using an auto-distillation unit (Foss Kjeltec™ 8200) that had been rinsed and calibrated using the following set up: 80 mL of dilution volume (deionized water); 90 mL of sodium hydroxide (alkali solution 40 %); and 3 mL of mixed indicator (70 mL of 0.1 g methyl red and 100 mL of 0.1 g bromocresol green dissolved in 100 mL methanol). The distillate was collected in the flasks. In addition, it was titrated with 0.104 M hydrochloric acid solution.

(6) Minerals determination

The samples were prepared for determining ash according to the methods described in the AOAC manual[16].

About 5 g of each sample was weighed into preconditioned porcelain crucibles that were pre-heated in an oven set at 105 ± 2 °C for 2 h and cooled in a desiccator for 2 h. The samples were placed in a temperature-controlled muffle furnace (Nabertherm GmbH, Lilienthal, Germany) and incinerated at 550 °C for 5 h. The crucibles were transferred to a desiccator and cooled to 29 ± 2 °C. After obtaining the ash, HCl (6 M) was added in a ratio of 1:1 (about 20 mL). The sample was placed on a hot plate to evaporate the HCl, ensuring that the residue does not crack. To avoid evaporating the acid into a hard cake, evaporation was stopped when the sample was half wet and half caked. The extracts were dissolved in 10 mL of hot distilled water in crucibles and filtered into 50-mL volumetric flasks through a filter paper. The ten milliliters (10 mL) portion of hot distilled water was further added, and a glass rod was used to remove any residue that remained in the crucibles. The extract was then passed through the same filter paper into the 50-mL volumetric flasks and filled up to the mark. The flasks were well shaken, and the samples were transferred to sample bottles ready for analysis. An atomic absorption spectroscopy instrument (Buck Scientific 210 VGP, East Norwalk, CT, USA) was used for recording mineral content in the dilute filtrate solutions.

(7) β-carotene determination

Evaluation of β-carotene in the samples involved a procedure having three parts: sample preparation, standard preparation, and HPLC quantification.

Sample preparation

Samples were prepared through extraction, concentration, partitioning, saponification, and drying. Extraction of β-carotene was performed according to the method described by Kimura et al.[18], with minor modifications to the number of solvents used (acetone and petroleum ether). During the extraction, approximately 1 g of sample was weighed (Mettler Toledo Excellent plus XP 205, Greifensee, Switzerland) into glass tubes, and 5 mL of cold acetone (refrigerated at 4 °C for about 2 h) was added. The mixture was then homogenized using a homogenizer (T 25 digital Ultra-Turrax, IKA, Staufen, Germany) for 1 min at 3,600 rpm. Extractions (with acetone) were performed five times until a colorless residue was obtained; the final total volume of the extract was 25 mL. The supernatant (acetone extract) was pipetted into a 250-mL separating funnel (containing 10 mL of petroleum ether) for partitioning. The mixture was allowed to separate for approximately 3 min and the lower aqueous phase was discarded. The petroleum ether phase was washed 3-4 times with 20 mL of distilled water.

This procedure (partitioning) was repeated to extract all β-carotene in the sample to obtain a total volume of 20 mL. To prevent emulsion, washing was performed slowly along the walls of the funnel without shaking; when emulsion occurred, saturated sodium chloride (NaCl) solution was added to break the emulsion. Residual water was removed by passing the extract through a small funnel with glass wool containing approximately 15 g of anhydrous sodium sulfate.

Standard solution preparation

For standard preparation, 1 g/L of the β-carotene reference standard (99.9 %, Sigma Aldrich, St. Louis, MO, USA) was prepared in a 10 mL amber-colored volumetric flask. This solution was further diluted to 100 mg/L in a volumetric flask to obtain the working solution with concentrations 1, 5, 10, 20, 25, and 30 mg/L. The concentrations were used to obtain the standard calibration curve.

HPLC quantification

Quantification conditions were adapted from Zeb[19] using HPLC (Shimadzu Nexera X2, Kyoto, Japan) equipped with LC–30Ad pump, degasser (DGU–20A3R) membrane, 105-capacity autosampler (SIL-30AC), diode array detector (SPD-M30A), and column oven (CTO-20AC). The mobile phase solvent A was methanol: deionized water (92:8, v/v) buffered with 10 mm ammonium acetate; solvent B was deionized water with 0.01 mm ammonium acetate and solvent C was methyl tertiary butyl ether (100 %) run isocratically at 80:18:2 %. A Zorbax Eclipse Plus C18 Reverse phase 5 µm 4.0×150 mm column was used, the oven temperature was set to 30 °C, detection wavelength was 450 nm, the run time was 12 min, peak detection time was 9.8 min, the flow rate was 1.5 mL/min, and the injection volume was set to 10 µL.

(8) Vitamin C determination

Sample preparation

Vitamin C determination used slightly modified procedures of Rizzolo[20]. To about 5 g of each sample in 50-mL Teflon tubes on weighing by digital balance (Excellent plus XP 205), 30 mL of 6 % metaphosphoric acid was added. The mixture was homogenized by polytron homogenizer (T 25 digital Ultra-Turrax) set at 3,600 rpm for 5 min. 50 mL of double-distilled water was added to a homogenate and the resultant vortexes for 1 min (Talboys Troemner LLC, Thorofare, NJ, USA). The heterogeneous formed was centrifuged at 2,415 g for 5 min (300R-Hettich, Tuttlingen, Germany). Resulted upper supernatant was filtered through a 0.45 µm micro filter (Whatman, Maidstone, UK) into 1.5 mL HPLC vials ready for injection.

Standard preparation

A stock solution of 1,000mg/L of ascorbic acid standard (99.9 %, Carlo Erba Reagent, Barcelona, Spain) in 0.02 % metaphosphoric acid was prepared. This solution was further diluted to different concentrations (1, 3, 5, 8, 10, 15, and 20 mg/L) which were later used to generate the calibration curve.

HPLC Determination

HPLC conditions for the analysis of ascorbic adhered to Mazurek and Jamroz procedure[21]. Shimadzu Nexera X2 HPLC a pump (LC–30AD), membrane degasser (DGU–20A3R), 105-capacity auto-sampler (SIL-30AC), diode array detector (SPD-M30A), and column oven (CTO-20AC) was used. A mobile phase: 0.02 % metaphosphoric acid (pH 2.4): methanol= 95:5 with a low-pressure gradient was used (Table 1). A Zorbax Eclipse Plus C18 Reverse phase 5 µm 4.0×150 mm column was used. The detection wavelength was 245 nm, with a run time of 9 min, a peak detection time of 1.9 min, a flow rate of 1.0 mL/min, and an injection volume of 10 µL.

Table 1 HPLC gradient conditions for determining ascorbic acid content

Time (min)	0.02% phosphoric acid	HPLC methanol
2.5	95	5
5	20	80
6	20	80
7	95	5

4. Statistical analysis

The statistical analysis was performed using IBM SPSS Statistics 21.0 (Armonk, NY, USA). Data are expressed as the means ± standard deviation of duplicate experiments. A one-way analysis of variance was performed to compare the means. Turkey's HSD test were used to verify the

variance homogeneity and identification of significant differences ($p < 0.05$).

II. Results and Discussion

(1) Proximate composition of leafy vegetables

Results of the proximate composition of the seven AWLVs are summarized in Table 2.

The moisture content of raw leaves of vegetables ranged from 48.3 to 73.3 g/100g whereby the highest moisture content was observed in Cd-RL (73.3 g/100g) followed by that in Cg-RL (71.5 g/100g), and the lowest value was observed in the matured raw baobab leaves (Ad-RML, 48.3 g/100g) followed by that of Ad-RYL (65.4g/100g). The moisture content of Ch-RL, Ad-RYL (the young raw baobab leaves), Cs-RL ($p = 0.06$); and that of Io-CD and Io-DL ($p = 0.597$) were not significantly different. However, the remaining leafy vegetables were significantly different ($p < 0.001$). The dried leaves (sun-dried) had moisture content ranged from 12.4 to 14.1 g/100g. The mixture of dried leaves (Cs&Cd-DL) had lower ($p < 0.001$) moisture content compared to that of Io-DL or Io-CD.

The moisture content of the studied vegetables was approximately 10 % less than values 77-93 % previously reported[5-7, 22, 23]. The difference may have resulted from the difference in morphological and physiological characteristics of AWLVs. Differences in contents of water-soluble vitamins such as vitamin C and folic acid may have also contributed to the observed variations.

The highest protein content was observed in Cs-RL (13.3g/100g) and the lowest in Cd-RL, 1.6g/100g). The protein contents obtained in the mixture of Cs&Cd-DL and Ad-RYL ($p = 1.00$), and that of Ch-RL and Ad-RML ($p = 0.407$) were not significantly different, however, that in the remaining leafy vegetables differed significantly ($p < 0.001$). Cg-RL, Ch-RL, and Isb-RL contained protein contents that were higher than previously reported 5.68 % in *C. gynandra*[5], 4.84 % in *C. hirta*[24], and 6.37 % in *I. batata*[25]. Cs-RL and Cd-RL had lower protein contents than previously reported 29.85 %[26] and *C. sativus* 5.71 %[27] by similar studies. For the young raw baobab leaves, the protein content was below the range (5-17 %), while that of the mature baobab leaves, the protein was within the range reported in the corresponding study by Heuzé et al[28]. During processing of Io-RL the protein contents were significantly decreased from 10.1 % to 5.2 % when dried (Io-DL) ($p < 0.001$), and from 5.2 to 4.1 % when crushed (Io-CD) ($p < 0.001$). Awol reported less amount of protein in *I. batata* compared to *I. obscura*[25].

The reasonable amounts of protein observed in the samples suggest the use of AWLVs in promoting the formation of hormones that control coordination systems,

Table 2 Proximate composition of selected raw and dried leafy vegetables (per 100 g edible portion)

Scientific name	Gogo name	Condition	Abbrev.	Moisture	Protein	Fat	Fiber	Ash
				(g/100g)				
Cleome gynandra	Mgagadi, Mzimwe	Raw	Cg-RL	71.5±0.2 ^{b}	12.3±0.1 ^{b}	3.2±0.2 ^{a}	8.6±0.1 ^{e}	11.6±0.7 ^{e}
Cleome hirta	Muhilile	Raw	Ch-RL	65.5±0.8 ^{de}	9.1±0.2 ^{d}	1.5±0.1 ^{c}	7.4±0.2 ^{f}	19.0±0.2 ^{a}
Ipomoea obscura or *Ipomoea mombassana*	Chapali	Raw	Io-RL	66.9±0.3 ^{cd}	10.1±0.2 ^{c}	1.5±0.1 ^{c}	9.4±0.3 ^{de}	14.3±0.2 ^{cd}
	(pl. Mapali)	Crushed & Dried	Io-CD	13.3±0.6 ^{gh}	4.1±0.1 ^{g}	1.5±0.0 ^{c}	8.9±0.2 ^{de}	15.3±0.3 ^{c}
	Sagula sagula	Dried	Io-DL	14.1±0.1 ^{g}	5.2±0.0 ^{f}	1.3±0.0 ^{cd}	9.2±0.4 ^{de}	13.4±0.3 ^{d}
Ipomoea sinensis subsp. *blepharosepala*	Maweza	Raw	Isb-RL	68.1±0.1 ^{c}	8.2±0.1 ^{e}	0.8±0.1 ^{e}	9.7±0.1 ^{d}	14.2±0.2 ^{de}
Ceratotheca sesamoides	Ilende, Mgulu	Raw	Cs-RL	65.5±0.8 ^{de}	13.3±0.1 ^{a}	1.2±0.2 ^{cde}	8.8±0.2 ^{e}	16.9±0.2 ^{b}
Ceratotheca sesamoides & *Cucumis dipsaceus*	Ilende	Dried	Cs& Cd-DL	12.4±0.2 ^{h}	3.7±0.0 ^{h}	3.0±0.1 ^{a}	7.7±0.3 ^{f}	12.2±0.3 ^{e}
Cucumis dipsaceus	Ilumbu, Hulihuli	Raw	Cd-RL	73.3±0.2 ^{a}	1.6±0.0 ^{i}	2.2±0.2 ^{b}	12.0±0.4 ^{b}	10.1±0.7 ^{f}
Adansonia digitata	Ikuwi	Raw young	Ad-RYL	65.4±0.4 ^{e}	3.6±0.1 ^{h}	1.0±0.2 ^{de}	10.7±0.4 ^{c}	6.0±0.2 ^{h}
		Raw Mature	Ad-RML	48.3±0.8 ^{f}	9.4±0.4 ^{d}	2.3±0.2 ^{b}	14.9±0.1 ^{a}	7.3±0.1 ^{g}

Results expressed as mean ± SD, n=3. Samples with different superscript letters across the column indicates statistical different according to Turkey's HSD test.

growth, body repair, and maintenance. In addition, the AWLVs can be used in the management of protein deficiencies as stipulated in the TFNC report[29].

The findings of this study showed that Cg-RL (3.2 g/100g) and Cs&Cd-DL (3.0g/100g) contained the highest fat content, while the lowest content was observed in Isb-RL (0.8 g/100g) followed by Ad-RYL (1.0 g/100g). These results agree with the general observation that leafy vegetables are a poor source of plant fat and they are low lipid-containing food, thus, advantages health use in avoiding obesity[25]. The fat contents in Cd-RL, Ad-RML, Cs&Cd-DL, and Cg-RL were significantly ($p < 0.001$) different from the rest of samples. However, that of Isb-RL and Ad-RYL ($p = 0.063$; Io-DL, Cs-RL, and Io-RL ($p = 0.376$; Cs-RL, Io-RL, Io-CD and Ch-RL ($p = 0.11$), respectively were not statistically different.

The fat content observed in leaves of Cg-RL and Ch-RL were higher compared to 0.4-0.9 % of *C. gynandra*[30] and 0.64 % of *C. hirta*[24]; and Cd-RL was lower (2.2%) to 3.00 % of *Cucumis sativus*[27] reported in relative studies. On the other hand, fat contents of Io (-RL, -CD, and -DL), Cs-RL, and Isb-RL were low compared to 4.6 % in Cs-RL[26]. Deviation of the findings of this study relative to the results of previous reports might have been attributed to the difference in the geographical location and the agronomical factors.

In this study, crude fiber was analyzed for the sake of dietary fiber due to the equipment challenges. The results showed that the Ad-RML (14.9 g/100 g) had the highest fiber content followed by Cd-RL (12.0g /100g) followed by Ad-RYL (10.7 g/100g) at $p < 0.001$. While the fiber contents in Cg-RL, Cs-RL, Io-CD, Io-DL, and Io-RL were not significantly different ($p > 0.005$). The lowest value of fiber content was observed in Ch-RL (7.4 g/100g) followed by Cs&Cd-DL (7.7 g/100g) at $p = 0.965$.

Results revealed that many samples were observed with comparable high values of crude fiber while fewer samples deviated. This avails to the observation that AWLVs have been traditionally recognized as great potential sources of fiber[5]. The observed crude fiber contents in the matured and the young raw baobab leaves (Ad-RML and Ad-RYL) were lower in comparison to that of the same matured plant leaves (10 % to 19 %) reported in the literature[28]. The fiber content observed in Cd-RL (12%) observed in this study was higher compared to 10.12 % for *Cucumis sativus* previously reported[27]. Similarly, the fiber content observed in the raw leaves of *C. gynandra* (8.6%) and in *C. hirta* (7.4%) were higher compared to previously reported (1.3-1.4 %)[30] and (2.27 %) [24], respectively and were slightly higher than that reported in *C. sesamoides* (7.91-8.16 %)[26]. The variation of fibers in AWLVs may be due to the difference in the geographical region, the mode of processing employed by the Gogo people in this study, the agro-climatic conditions, stages of maturity, and the type and the rate of fertilizer application.

Ash contents ranged from 6.0 % to 19.0 %, and the highest amount was observed in Ch-RL (19.0 %), while the lowest amount was in the baobab (Ad-RYL 6.0 % and Ad-RML 7.3 %). This indicated that AWLVs consumed in Chinangali I village of Chamwino district in the Dodoma region are rich in mineral elements, and upon consumption, they greatly supplement deficiencies related to minerals. There were significant differences ($p < 0.001$) between the ash contents in all the plant leaves studied.

The values of ash content observed in Cg-RL (11.6%), Ch-RL (19%) and Cs-RL (16.9%) were higher compared to previously reported, 2.1-3.0 % in *C. gynandra*[30], 2.93 % in *C. hirta,*[24] and 9.38-11.13 % in *C. sesamoides*[26] respectively. Values in Io-RL (14.3%) and Io-CD (15.3%) were higher compared to previously reported 13.74 % in *I. batatas*[25]. On the other hand, the ash content detected in Cd-RL (10.1%) was lower compared to previously reported 20.5 % in *Cucumis sativus*[27]. While, the ash contents in the baobab (Ad-RYL and Ad-RML) were lower compared to the values reported 7.8-16.3 %[28]. Likewise, the variation in mineral contents might be due to the agro-climatic conditions, the stages of plants maturity, and the type and the rate of fertilizer application.

(2) Minerals, β-carotene, and vitamin C levels of leafy vegetables

Leafy vegetables are chief sources of vitamins and minerals compared to staple food grains. They contain high levels of β-carotenes, vitamin C, iron, calcium, and sodium[31]. Table 3 summarizes minerals (iron, calcium, and sodium), β-carotene, and vitamin C of the selected AWLVs.

Iron content in raw leaves ranged from 1.2 mg/100g

(Ad-RYL) to 55.2 mg/100g (Io-RL) and in dried samples from 43.5 (Cs&Cd-DL) to 68.8 mg/100g (Io-CD). The highest iron content was found in Io-CD (68.8 mg /100g) followed by Io-RL (55.2 mg/100g) then Io-DL (51.1 mg/100g, $p < 0.005$). The lowest iron content was observed in Ad-RYL (1.2 mg/100g) followed by Ad-RML (7.0 mg/100 g, $p < 0.005$).

On the other hand, there was no significant difference ($p = 0.052$) between Isb-RL (41.5 mg/100g), Cs&Cd-DL (43.5 mg/100g), and Ch-RL (44.8 mg/100g). Similarly, there was no significant difference ($p = 0.671$) between Cs-RL (39.9 mg/100g) and Isb-RL (41.5 mg/100g).

The iron content detected in Ad-RYL (1.2 mg/100 g) was significantly lower ($p < 0.005$) compared to iron content detected in Ad-RML (7.0 mg/100 g). The difference is contradicting the previously results reported from Mali where young leaves had higher iron contents 19.31-27.22 mg/100g, compared to mature leaves 9.77-10.32 mg/100g[13]. Iron contents in Cd-RL and Ad-RYL observed in this study were lower to 2,400 mg/100 g in *C. dipsaceus* of India[32] and 9.77-27.22 mg/100g in baobab leaves of Burkina Faso[13] respectively.

Similarly, the iron contents in leaves of Cg-RL (39.0 mg/100g) and Ch-RL (56.4 mg/100g) reported in a previous study carried out at Chinoje and Mzula villages, Chamwino district of the Dodoma region, Tanzania were higher in comparison to results observed in this study carried at Chinagali II village in the same district[33]. On the other hand, the iron content of Cg-RL observed in this study was higher compared to 2.1-14.3 mg/100g in *C. gynandra* grown in South Africa[5,7]. The observed differences could be ascribed to the difference in the maturity of the leaves, the agroecological factors, and the farming systems used by the farmers. Iron is required for hemoglobin formation and its deficiency leads to anemia. Previous research indicates anemia in women of Dodoma was lower prevailed despite the concurrent food deficiency and malnutrition[1,10,11]. This denotes the role played by the utilization of AWLVs and thus they constitute a contributing factor for decreasing anemia.

Calcium is essential for a healthy diet and a mineral necessary for life. It plays an important role in building strong and dense bones and teeth. The calcium content observed in this study ranged from 372.3 to 2794.5 mg/100g. The richest sources of calcium were found to be Cs&Cd-DL, Ch-RL, Ad-RML, Io-CD, Io-DL, Cg-RL, and Cs-RL, with calcium content ranged from 2794.5 to 1059.5 mg/100g, and the moderate sources were Io-RL, Cd-RL, Isb-RL and Ad-RYL, with calcium content ranged from 943.8 to 372.3 mg/100g. The results showed that there was no significant difference ($p = 0.243$) between Io-CD and Ad-RML; and between Cs-RL and Cg-RL at $p= 0.600$. On the other hand, all the remaining samples were observed to have a significant difference in calcium

Table 3 Minerals and vitamins of the selected raw and dried leafy vegetables (per 100 g edible portion)

Vegetables	Iron (mg)	Calcium (mg)	Sodium (mg)	β-Carotene (mg)	Vitamin C (mg)
Cg-RL	26.7 ± 0.7 ^{f}	1,153.6 ± 16.7 ^{e}	153.9 ± 1.6 ^{c}	3,175.5 ± 188.0 ^{b}	13.5 ± 0.2 ^{a}
Ch-RL	44.8 ± 0.0 ^{d}	2,104.1 ± 44.6 ^{b}	138.3 ± 0.9 ^{cde}	1,449.2 ± 101.7 ^{c}	0.8 ± 0.0 ^{e}
Io-RL	55.2 ± 1.1 ^{b}	943.8 ± 12.2 ^{f}	224.4 ± 5.2 ^{a}	218.1 ± 20.7 ^{e}	0.6 ± 0.0 ^{ef}
Io-CD	68.8 ± 0.3 ^{a}	1,486.2 ± 3.0 ^{c}	195.9 ± 3.0 ^{b}	2,907.3 ± 103.1 ^{b}	6.1 ± 0.1 ^{b}
Io-DL	51.1 ± 1.3 ^{c}	1,353.3 ± 29.5 ^{d}	232.5 ± 13.7 ^{a}	367.3 ± 46.5 ^{de}	2.1 ± 0.1 ^{d}
Isb-RL	41.5 ± 1.0 ^{de}	495.6 ± 5.4 ^{h}	144.9 ± 0.1 ^{cd}	193.1 ± 10.9 ^{e}	0.8 ± 0.0 ^{e}
Cs-RL	39.9 ± 0.0 ^{e}	1,059.5 ± 11.7 ^{e}	125.7 ± 0.2 ^{e}	735.0 ± 48.7 ^{d}	0.8 ± 0.0 ^{e}
Cs&Cd-DL	43.5 ± 1.7 ^{d}	2,794.5 ± 42.6 ^{a}	151.7 ± 0.1 ^{c}	17,489.1 ± 406.6 ^{a}	4.9 ± 0.1 ^{c}
Cd-RL	7.2 ± 0.2 ^{g}	804.7 ± 9.2 ^{g}	129.0 ± 1.4 ^{de}	466.6 ± 44.3 ^{de}	6.4 ± 0.1 ^{b}
Ad-RYL	1.2 ± 0.1 ^{h}	372.3 ± 34.8 ^{i}	130.9 ± 1.4 ^{de}	304.5 ±12.1 ^{de}	0.4 ± 0.0 ^{f}
Ad-RML	7.0 ± 0.6 ^{g}	1,556.6 ± 7.2 ^{c}	136.4 ± 2.4 ^{cde}	N.D.	0.6 ± 0.0 ^{ef}

Results expressed as mean ± SD, n=3. Samples with different superscript letters across the column indicates statistical different according to Turkey's HSD test. Abbreviations: Cg-RL, raw leaves of *Cleome gynandra*; Ch-RL, raw leaves of *Cleome hirta*; Io-RL, raw leaves of *Ipomoea obscura* or *Ipomoea mombassana*; Io-CD, crush-dried leaves of Io; Io-DL, dried leaves of Io; Isb-RL, raw leaves of *Ipomoea sinensis* subsp. *blepharosepala*; Cs-RL, raw leaves of *Ceratotheca sesamoides*; Cs&Cd-DL, dried leaves of *Ceratotheca sesamoides* and *Cucumis dipsaceus*; Cd-RL, raw leaves of *Cucumis dipsaceus*; Ad-RYL, raw young leaves of *Adansonia digitata*; Ad-RML: raw mature leaves of Ad; N.D., not detected.

contents ($p < 0.005$).

Previous studies observed lower calcium contents in raw leaves of *C. gynandra* (260.1 mg/100g), *C. hirta* (310.5 mg/100g), *I. obscura* (320.125 mg/100g), *C. sesamoides* (248.8 mg/100g), and *C. dipsaceus* (270 mg/100g) compared to the findings of this study[11, 32]. On the contrary, 1961 mg/100g in Ad-RML previously reported was higher compared to value observed in this study[13]. Likewise, the observed differences could be due to the differences in the maturity of the leaves, the agroecological factors, and the farming systems used by the farmers.

The highest sodium content was observed in Io-DL (232.5 mg/100g) followed by Io-RL (224.4 mg/100g), Io-CD (195.9 mg/100g), Cg-RL (153.9 mg/100g), Cs&Cd-DL (151.7 mg/100g), and then Isb-RL (1444.9 mg/100g), while the lowest content was observed in Cs-RL (125.7 mg/100g), followed by Cd-RL (129.0 mg/100g), Ad-RYL (130.9 mg/100g), Ad-RML (136.4 mg/100g), and Ch-RL (138.3 mg/100g). The results showed there was no significant difference between Cs-RL (125.7 mg/100g), Cd-RL (129.0 mg/100 g), Ad-RYL (130.9 mg/100g), Ad-RML (136.4 mg/100g), and Ch-RL (138.3 mg/100g, $p = 0.296$). Similarly, there was also no significant difference observed between Ad-RML (136.4 mg/100g), Ch-RL (138.3 mg/100g), Isb-RL (144.9 mg/100g), Cs&Cd-DL (151.7 mg/100g), and Cg-RL (153.9 mg/100g, $p= 0.67$). Likewise, there was no significant difference ($p = 0.787$) between Io-RL (224.4 mg/100g) and Io-DL (232.5 mg/100g). On the other hand, Io-CD (195.9 mg/100g) showed significant difference ($p < 0.005$) to all samples.

Sodium levels in Cg-RL, Io-RL, and Ad-RML detected in this study were higher compared to findings previously reported (33.6 mg/100g, 32.079 mg/100g, 1.37 mg/100g) in *C. gynandra*[30], *I. batatas*[25], and baobab, respectively[13]. This is probably due to the differences in the variety of the plant leaves used and the climate conditions. Indigenous processing techniques applied in handling the AWLVs may also influence the content of sodium in the vegetables.

Values in Cs-RL (125.7 mg/100g) and Cd-RL (129.0 mg/100g) were lower compared to that in the mixture, Cs&Cd-DL (151.7 mg/100g). The process of crushing may have affected the values of sodium in *I. obscura*. Sodium contents observed in the raw leaves (Io-RL) were significantly higher ($p =0.012$) compared to sodium content in the crushed and then dried leaves (Io-CD), however, that of Io-DL and Io-RL were not significantly different ($p > 0.005$) meaning that the drying may not have effect on the sodium content.

β-carotene were detected in all samples of AWLVs used in this study except in Ad-RML with the highest in Cg-RL at 3,175.5 μg/100g. The results showed there was no significant differences ($p > 0.005$) between Io-DL (367.3 μg/100g), Cd-RL (466.6 μg/100g), and Ad-RYL (304.5 μg/100g). Similarly, there was also no significant difference between Io-RL (218.1 μg/100g) and Isb-RL (193.1 μg/100g). The remaining leafy vegetables showed significant differences ($p < 0.005$).

Previous study reported that indigenous AWLVs are good sources of antioxidants including β-carotene and vitamin C[11, 33]. Amount of β-carotene observed in Cg-RL (3,175.5 μg/100g) was higher than 291.04 μg/100g or 670-1890 μg/100g in *C. gynandra*[30, 33]. Similarly, the amount of β-carotene detected in Ch-RL (1,449.2 μg/100g) was higher than previous reported 275.02 μg/100g in *C. hirta*[33]. On the other hand, the amount of β-carotene in Io-RL (218.1 μg/100g) and Cs-RL (735.0 μg/100g) was lower compared to the previous reported data 1010 μg/100g and 1960 μg/100g, respectively[33].

The range of vitamin C in the AWLVs was between 0.4 mg/100 g in Ad-RYL to 13.5 mg/100 g in Cg-RL. The results showed there was no significant differences ($p = 0.109$) between Ad-RML (0.6 mg/100g), Io-RL (0.6 mg/100g), Cs-RL (0.8 mg/100g), Isb-RL (0.8 mg/100g), and Ch-RL (0.8 mg/100g). Likewise, there was no significant differences ($p = 0.405$) between Io-RL (0.6 mg/100g), Ad-RYL (0.4 mg/100g), and Ad-RML (0.6 mg/100g). While the remaining leafy vegetables showed significant differences ($p < 0.005$).

In previous studies, vitamin C contents of 2 mg/100 g or 15.44 mg/100 g in *C. gynandra*[7,33], 15.60 mg/100g in *C. hirta*[33], and 150-500 mg/100g in baobab[12] were observed. Several factors can influence the variations of vitamin C content in AWLVs such as the geographical location, the plant variety or species, the maturity stage, the postharvest treatments, the processing methods, the storage conditions and time, the packaging materials and the technology, and the cooking time.

Conclusion

This study shows that the seven evaluated AWLVs in semi-arid Tanzania were rich in iron, calcium, and protein compared with the findings of previous research. Furthermore, their β-carotene and vitamin C content were within the reported range. Our findings highlighted that *C. hirta*, which has not been as thoroughly studied as *C. gynandra*, exhibited higher calcium and iron contents. *I. obscura* also exhibited high iron content, up to 100 times that of cultivated sweet potato leaves. The protein content in *C. gynandra* was higher than that in the previous reports. The high iron, calcium, and protein contents in the herbal species of this locality may be due to the environment, including semi-arid climate and soil. Together, the results indicate the high potential of these AWLVs to contribute to the improvement of the nutrition status of the local populace.

Authorship

The author's contributions are as follows: KS was responsible for conceptualization, methodology, investigation, resources, writing - original draft, review, and editing, visualization, supervision, project administration, and funding acquisition. LK was responsible for methodology, validation, formal analysis, investigation, data curation, writing - original draft (methodology), review and editing, and visualization. RO contributed to conceptualization, writing - reviewing and editing, and supervision. All co-authors have read and agree with the content of the manuscript.

COI disclosure

The authors have no conflicts of interest to this article.

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Nutrient Content of Seven African Wild Leafy Vegetables in Semi-arid Tanzania

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Abstract

There is increasing attention on African wild leafy vegetables (AWLVs) from the perspective of health benefits of consuming vegetables. Proximate composition, mineral, and vitamin contents of seven AWLVs consumed locally by rural populations of the semi-arid Dodoma region in Tanzania were determined. AWLVs evinced high iron, calcium, and protein contents and moderate β-carotene and vitamin C contents. Compared with raw *Cleome gynandra* (Cg-RL), raw *Cleome hirta* exhibit higher iron and calcium contents (26.7 and 1,153.6 vs. 44.8 and 2,104.1 mg/100 g, respectively). High calcium contents were also revealed in both *Ceratotheca sesamoides* raw (Cs-RL, 1,059.5 mg/100 g) and dried with *Cucumis dipsaceus* (Cs&Cd-DL, 2,794.5 mg/100 g). Raw *Ipomoea obscura* contained high iron contents (55.2 mg/100 g), 100 times higher than cultivated sweet potato leaves even higher crush dried (68.8 mg/100 g). Raw *Ipomoea sinensis* subsp. *blepharosepala* (Isb-RL) and Cs-RL (41.5 and 39.9 mg/100 g, respectively) were also iron-rich. The protein content in Cg-RL was 12.3 g/100 g. Cs&Cd-DL and Cg-RL exhibited the highest β-carotene and vitamin C contents (17,489.1 μg and 13.5 g/100 g, respectively). AWLVs are recommended for managing protein, mineral, and vitamin deficiencies, which are endemic to inhabitants of the Dodoma region and other African countries.

タンザニア半乾燥地野生葉菜類７種の栄養素含有量

阪本公美子，Lilian Kaale, 大森玲子

アフリカ野生の葉野菜は、野菜摂取による健康への寄与の観点から注目されている。本論は、タンザニアの半乾燥地ドドマ州地方の住民が日常的に摂取している７種の葉野菜について分析を行った。生葉 *Cleome gynandra* (Cg-RL) に比べて、生葉・乾燥 *Cleome hirta* ではカルシウムと鉄の含有量が高かった。*Ceratotheca sesamoides* (Cs-RL) は生葉 (Cs-RL) でも *Cucumis dipsaceus* が加わった乾燥葉 (Cs&Cd-DL) でもいずれもカルシウム量が高かった。生葉・乾燥 *Ipomoea obscura* は栽培種のサツマイモ葉に比べて鉄の含有量が 100 倍以上高く、生葉 *Ipomoea sinensis* subsp. *blepharosepala* (Isb-RL) や Cs-RL も鉄の含有量が高かった。Cg-RL のタンパク質量は 12.3g/100g であり、有効な植物性タンパク質供給源となる可能性を見出した。また、分析葉物７種中 Cs&Cd-DL は β カロテン、Cg-RL はビタミン C を最も多く含有した。アフリカの野生葉野菜は、採取したドドマ州の住民だけでなく、アフリカに住む人々にとって、タンパク質、ミネラル、ビタミン不足解消に寄与する可能性が示唆された。

（2022 年 6 月 1 日受理）