Chapter 13
Nutrition Potential of African Wild Leafy Vegetables: Evidence from Semiarid Central Tanzania

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Abstract African wild leafy vegetables (AWLVs) are receiving more attention concerning the potential health advantages of consuming vegetables. The proximate composition, mineral, and vitamin contents of seven AWLVs consumed locally by rural populations of the semiarid Dodoma region in Tanzania were determined. AWLVs showed significant amounts of iron, calcium, and protein as well as a moderate amount of β-carotene and vitamin C. Raw *Cleome hirta* had higher iron and calcium levels (26.7 and 1153.6 vs. 44.8 mg/100 g and 2104.1 mg/100 g, respectively) than raw *Cleome gynandra* (Cg-RL). High calcium contents were also revealed in both raw *Ceratotheca sesamoides* (Cs-RL, 1059.5 mg/100 g) and dried with *Cucumis dipsaceus* (Cs&Cd-DL, 2794.5 mg/100 g). Raw *Ipomoea obscura* had a high iron concentration (55.2 mg/100 g), which was 100 times greater than that in cultivated sweet potato leaves. Iron was also present in significant amounts in the raw *Ipomoea sinensis* subsp. *blepharosepala* (Isb-RL) and Cs-RL (41.5 mg/100 g and 39.9 mg/100 g, respectively). 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.

Keywords Leafy · Tanzania · Semiarid · Proximate composition · Micronutrients

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13.1 Introduction

The previous chapters (Chaps. 6, 10, and 12) provided evidence that frequent consumption of wild foods during the rainy season in the semiarid area, especially by the "poor," can be a contributing factor to their health. This is in line with the overall objective of the book to understand the changing dietary patterns, indigenous foods, and wild foods. The analysis in this chapter focuses on wild leafy vegetables, which can be seen as contributing wild foods during the rainy season.

Some studies have researched the nutritional value of African wild leafy vegetables (AWLVs) from other nations or areas. Nutrients from the same species may differ depending on the geographical and meteorological circumstances of a certain place (Maseko et al., 2018). For example, the study by Msuya et al. (2009) asserts that several species of bitter lettuce (*Launaea cornuta*) and cat's whiskers (*Cleome gynandra*, Cg) in Kongwa district, Dodoma area, have higher iron and β-carotene levels than those in Tanga and Arusha regions. Furthermore, it is thought that the use of AWLVs is declining on a global scale. This chapter has therefore focused on the significance of consuming AWLVs and examined their nutritional qualities. The collective of leafy vegetables that typically grow wild will be referred to as AWLV in this chapter. These vegetables are grown more organically, with little or no use of pesticides, and are low in calories, nutrient-rich, and fiber-rich to support health and well-being. Seven AWLVs consumed locally by rural inhabitants in the semiarid Dodoma region of Tanzania were examined for their proximate composition and mineral and vitamin levels.

13.2 African Wild Leafy Vegetables Use and Knowledge in Africa

AWLVs are naturally growing plants that can be consumed as food. Traditional vegetables have traditionally been used as dietary supplements and medicine by African ethnic groups (Ntuli, 2019). AWLVs have the potential to significantly contribute to both food security and human health given that they provide sufficient levels of nutrients, vitamins, and minerals. In addition, AWLVs diversify diets, making them more enticing and healthier. It is therefore a methodological shortcoming that diet surveys frequently overlook wild species in favor of cultivated ones. In many ethnic groups' knowledge systems, wild vegetables form a distinctive cultural realm (Powell et al., 2014).

Although other African nations have acknowledged the role of wild leafy vegetables in ensuring food security, Tanzanians seldom use them, especially in cities. The main reasons are poverty and lack of knowledge of adequate feeding practices. However, it is interesting to note that rural areas (e.g., the semiarid Dodoma region of Tanzania) continue to retain their traditional knowledge of wild crops. By replacing edible native species, modern agricultural methods have exacerbated

"hidden hunger" (micronutrient deficiency), even though they have been successful in supplying calories (Modi et al., 2006). The World Health Organization (WHO) has suggested a daily intake of more than 400 g of vegetables and fruit per person to regulate or lessen the hidden hunger challenge. However, due to the high cost of vegetables and fruits, it has been particularly difficult, especially for low-income urban residents, to afford the recommended amount. On the other hand, these AWLVs are readily available to people in rural areas at no cost; they can be picked up from private gardens, abandoned lots, or the wild (Faber et al., 2010). African wild vegetables also allow for a more varied diet, serve as a source of appropriate macro- and micronutrients, and lower disease vulnerability (Kissanga et al., 2021). In terms of sustainability and viability, these plants can be particularly resilient to environmental changes and provide residents with an alternative during periods of drought or food scarcity.

13.3 Current Status of Consuming Wild Leafy Vegetables in Africa

The population of Africa was 1.38 billion in 2021, and by 2030, it is anticipated that it will reach 1.71 billion (Mohajan, 2022). In addition, food insecurity and malnutrition are the leading causes of death and morbidity in Africa. In Africa, 9.3 million children under the age of 5 were overweight in 2019 (Mohajan, 2022). Worldwide, being overweight affects more than seven out of ten children. On the other hand, one of the main problems in developing nations continues to be undernutrition. For example, in Tanzania, the prevalence of undernourishment, severe food insecurity, and stunted growth of children under the age of 5 years was 25.0%, 23.8%, and 31.8%, respectively, in 2019. In the meantime, Sustainable Development Goals (SDGs) 2 and 3 state that by 2030, the world hopes to eradicate hunger, achieve food security, improve nutrition, ensure healthy lives, and advance well-being for people of all ages. Therefore, the production of food must be expanded to address these challenges. Insufficient intake of fruits and vegetables, according to research, affects 44% of children worldwide (UNICEF, 2019), which results in nutrient deficiencies. Furthermore, this deficiency with maternal undernutrition is included as one of the top ten risk factors contributing to mortality (Ezzati et al., 2002). This circumstance emphasizes the significance of utilizing free or inexpensive local resources to acquire a healthy diet. Attention to AWLVs (Smith & Eyzaguirre, 2007) and studies on their nutritious content have raised their significance in this setting (Uusiku et al., 2010). AWLVs can help close dietary gaps by providing wholesome, inexpensive, nutrient-dense alternatives. Some AWLVs are rich in elements that are necessary for maintaining health and fighting off infections, including vitamins, minerals, antioxidants, and even anticancer agents (Maseko et al., 2018).

It is interesting to note that Tanzanians have begun to pay attention to local uses of edible plants, and some nutrients in locally grown wild vegetables have also been investigated. The Dodoma region is part of a semiarid area of central Tanzania where frequent food insufficiencies occur in rural areas. However, because of the consumption of AWLVs, this region has malnutrition rates that are comparable to those of the entire country. For example, 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%. Furthermore, only 24.0% of women in Dodoma have anemia compared with the national average of 28.8% (Tanzania, 2019). Other studies have also reported that women in Dodoma have relatively low anemia due to their intake of green leafy vegetables (Keding et al., 2011; Stuetz et al., 2019). In the Chinangali I village of Chamwino district, Dodoma region, food sufficiency occurs during the rainy seasons, in which the frequency of wild food consumption increases and the main wild foods consumed are leafy vegetables.

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 of attaining these goals can be magnified when the nutritional qualities of locally available edible vegetables are expressed. Therefore, in this chapter, the proximate minerals (iron, sodium, calcium) and vitamins (ascorbic and β-carotene) of seven AWLVs in semiarid Tanzania are presented.

13.4 Materials and Methods

13.4.1 Sample Description and Selection

This study used samples of seven AWLVs grown in the farms of Chinangali I village. The vegetables found on 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), raw *Ceratotheca sesamoides* (Cs-RL) called **ilende/mgulu** (Gogo), and *Cucumis dipsaceus* (Cd-RL) called **ilumbu/hulihuli** (Gogo) were widely distributed.[1] 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 (Msuya et al., 2009).

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) was characterized by round leaves forming a moon shape. Baobab

[1] Plant names in the local language are in bold and Swahili plant names are in bold italics.

(*Adansonia digitata*, Ad) offers edible young leaves called **ikuwi** (Gogo) (Bamalli et al., 2014; Chadare, 2010; Msuya et al., 2009). The edible young leaves of these vegetables were selected for the study.

13.4.2 Sample Collection and Processing

Samples of Cg-RL, Ch-RL, Isb-RL, Cs-RL, Ad-RYL, and Ad-RML were harvested on March 3, 2020, from farms in Chinangali I village, Dodoma region, Tanzania. Approximately 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 that are practiced traditionally. The first method was sorted to remove damaged leaves, crushed, and molded into a pancake-shaped disc that was dried in 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 sunlight for 2 days to form the traditional vegetable named **sagula sagula** (Io-DL). *C. sesamoides* and *C. dipsaceus* leaves were sorted to remove damaged leaves, mixed, and dried in 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, placed in cool boxes embedded with iced thermal gels, and finally transported from Dodoma to the Dar es Salaam region using an air-conditioned vehicle for experimental studies. Most of the samples were delivered to the International Institute of Tropical Agriculture (IITA) and the others to the Tanzania Bureau of Standards (TBS).

13.4.3 Sample Analyses

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

13.4.3.1 Moisture Content Determination

Approximately 2 g of each sample was weighed in preconditioned Petri plates that were preheated 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 (AOAC, 2005).

13.4.3.2 Ash Content Determination

Approximately 2 g of each sample was weighed into preconditioned porcelain crucibles that were preheated 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).

13.4.3.3 Crude Fat Determination

The fat contents of the samples were determined using the Soxhlet system (Foss SoxtecTM 2043, Hilleroed, Denmark). Aluminum cups were preheated 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 was 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.

13.4.3.4 Crude Fiber Determination

The fiber content was determined by the Foss Fibertec system instructions. Fiber crucibles were first preheated 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 to 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 and 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.

13.4.3.5 Crude Protein Level 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 into 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 setup: 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.

13.4.3.6 Mineral Determination

The samples were prepared for determining ash according to the methods described in the AOAC manual (AOAC, 2005). Approximately 5 g of each sample was weighed into preconditioned porcelain crucibles that were preheated 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 at a ratio of 1:1 (approximately 20 mL). The sample was placed on a hot plate to evaporate the HCl, ensuring that the residue did 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 filter paper. Ten milliliters (10 mL) 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 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 to record the mineral content in the dilute filtrate solutions.

13.4.3.7 Determination of β-Carotene

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

Sample Preparation for β-Carotene

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. (2007), 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 approximately 2 h) was added. The mixture was then homogenized using a homogenizer (T 25 digital Ultra-Turrax, IKA, Staufen, Germany) for 1 min at 3600 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 β-carotene

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 working solutions with concentrations of 1 mg/L, 5 mg/L, 10 mg/L, 20 mg/L, 25 mg/L, and 30 mg/L. The concentrations were used to obtain the standard calibration curve.

HPLC quantification for β-carotene

Quantification conditions were adapted from (Zeb, 2017) using HPLC (Shimadzu Nexera X2, Kyoto, Japan) equipped with an LC-30Ad pump, degasser (DGU-20A3R) membrane, 105-capacity autosampler (SIL-30 AC), diode array detector (SPD-M30A), and column oven (CTO-20 AC). 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 reversed-phase 5 μm 4.0 × 150 mm column was used, the oven temperature was set to 30 °C, the detection wavelength was 450 nm, the run time was 12 min, the peak detection time was 9.8 min, the flow rate was 1.5 mL/min, and the injection volume was set to 10 μL.

13.4.3.8 Determination of Vitamin C

Sample Preparation for Vitamin C

Vitamin C determination used slightly modified procedures of (Rizzolo, 1984). To approximately 5 g of each sample in 50-mL Teflon tubes weighed by a digital balance (Excellent plus XP 205), 30 mL of 6% metaphosphoric acid was added. The mixture was homogenized by a polytron homogenizer (T 25 digital Ultra-Turrax) set at 3600 rpm for 5 min. Then, 50 mL of double-distilled water was added to a homogenate, and the resultant vortexed for 1 min (Talboys Troemner LLC, Thorofare, NJ, USA). The heterogeneous formed was centrifuged at 2415 g for 5 min (300R-Hettich, Tuttlingen, Germany). The resulting 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 for Vitamin C

A stock solution of 1000 mg/L 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 mg/L, 3 mg/L, 5 mg/L, 8 mg/L, 10 mg/L, 15 mg/L, and 20 mg/L), which were later used to generate the calibration curve.

HPLC Determination for Vitamin C

HPLC conditions for the analysis of ascorbic acid adhered to (Mazurek & Jamroz, 2015). A Shimadzu Nexera X2 HPLC pump (LC-30 AD), membrane degasser (DGU-20A3R), 105-capacity auto-sampler (SIL-30 AC), diode array detector (SPD-M30A), and column oven (CTO-20 AC) were used. A mobile phase of 0.02% metaphosphoric acid (pH 2.4): methanol = 95:5 with a low-pressure gradient was used (Table 13.1). A Zorbax Eclipse Plus C18 reversed-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 13.1 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

13.5 Statistical Analysis

The statistical analysis was performed using IBM SPSS Statistics 21.0 (Armonk, NY, USA). Data are expressed as the means ± standard deviations of duplicate experiments. A one-way analysis of variance was performed to compare the means. Tukey's HSD test was used to verify the variance homogeneity and identify significant differences ($p < 0.05$).

13.6 Results and Discussion

13.6.1 Proximate Composition of Leafy Vegetables

The results of the proximate composition of the seven AWLVs are summarized in Table 13.2. The moisture content of raw leaves of vegetables ranged from 48.3 g/100 g to 73.3 g/100 g, whereby the highest moisture content was observed in Cd-RL (73.3 g/100 g) followed by that in Cg-RL (71.5 g/100 g), and the lowest value was observed in the matured raw baobab leaves (Ad-RML, 48.3 g/100 g) followed by that of Ad-RYL (65.4 g/100 g). The moisture contents of Ch-RL, the young raw baobab leaves (Ad-RYL), and Cs-RL ($p = 0.06$) and those of Io-CD and Io-DL ($p = 0.597$) were not significantly different. However, the remaining samples were significantly different ($p < 0.001$). The dried leaves (sun-dried) had moisture content ranging from 12.4 g/100 g to 14.1 g/100 g. The mixture of dried leaves (Cs & Cd-DL) had lower ($p < 0.001$) moisture content compared with that of Io-DL or Io-CD.

The moisture content of the studied vegetables was approximately 10% less than previously reported values of 77–93% (Jansen van Rensburg et al., 2004; Odhav et al., 2007; Schönfeldt & Pretorius, 2011; Uusiku et al., 2010; van Jaarsveld et al., 2014). The difference may have resulted from the difference in morphological and physiological characteristics of AWLVs. Differences in the 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 (13.3 g/100 g), and the lowest was observed in Cd-RL (1.6 g/100 g). 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, those in the remaining samples 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* (Schönfeldt & Pretorius, 2011), 4.84% in *C. hirta* (Agea et al., 2014), and 6.37% in *I. batata* (Awol, 2014). Cs-RL and Cd-RL had lower protein contents than previously reported 29.85% (Fasakin, 2004) and *C. sativus* 5.71% (Attar & Ghane, 2017) by similar studies. For the young raw baobab leaves, the protein content was below the range (5–17%), while for the mature baobab leaves, the

Table 13.2 Proximate composition of selected raw and dried leafy vegetables (per 100 g edible portion) (Sakamoto et al., 2022)

Scientific name	Gogo name	Condition	Abbrev.	Moisture	Protein	Fat	Fiber	Ash
				(g/100 g)				
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}

The results are expressed as the mean ± SD, $n = 3$. Samples with different superscript letters across the column indicate significant differences according to Tukey's HSD test

protein was within the range reported in the corresponding study by Heuzé et al. (2016). During the 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 protein in *I. batata* than in *I. obscura* (Awol, 2014).

The reasonable amounts of protein observed in the samples suggest the use of AWLVs in promoting the formation of hormones that control coordination systems, growth, body repair, and maintenance. In addition, AWLVs can be used in the management of protein deficiencies, as stipulated in the (TFNC, 2014).

The findings of this study showed that Cg-RL (3.2 g/100 g) and Cs & Cd-DL (3.0 g/100 g) contained the highest fat content, while the lowest content was observed in Isb-RL (0.8 g/100 g), followed by Ad-RYL (1.0 g/100 g). These results agree with the general observation that leafy vegetables are a poor source of plant fat, and they are low lipid-containing foods, thus providing advantages for health use in avoiding obesity (Awol, 2014). The fat contents in Cd-RL, Ad-RML, Cs & Cd-DL, and Cg-RL were significantly ($p < 0.001$) different from those in the rest of the samples. However, those 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 significantly different.

The fat contents observed in leaves of Cg-RL and Ch-RL were higher compared to 0.4–0.9% of *C. gynandra* (Chweya & Mnzava, 1997) and 0.64% of *C. hirta* (Agea et al., 2014), and Cd-RL was lower (2.2%) to 3.00% of *Cucumis sativus* (Attar & Ghane, 2017) reported in related studies. On the other hand, the fat contents of Io (−RL, -CD, and -DL), Cs-RL, and Isb-RL were low compared with 4.6% in Cs-RL (Fasakin, 2004). 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 equipment challenges. The results showed that Ad-RML (14.9 g/100 g) had the highest fiber content, followed by Cd-RL (12.0 g/100 g) and Ad-RYL (10.7 g/100 g), at $p < 0.001$. The fiber contents in Cg-RL, Cs-RL, Io-CD, Io-DL, and Io-RL were not significantly different ($p > 0.005$). The lowest fiber content was observed in Ch-RL (7.4 g/100 g), followed by Cs & Cd-DL (7.7 g/100 g), at $p = 0.965$.

The results revealed that many samples were observed with comparably high values of crude fiber, while fewer samples deviated. This is supported by the observation that AWLVs have been traditionally recognized as great potential sources of fiber (Schönfeldt & Pretorius, 2011). The observed crude fiber contents in the mature and young raw baobab leaves (Ad-RML and Ad-RYL) were lower than those of the same matured plant leaves (10–19%) reported in the literature (Heuzé et al., 2016). The fiber content observed in Cd-RL (12%) in this study was higher than the 10.12% previously reported for *Cucumis sativus* (Attar & Ghane, 2017). Similarly, the fiber contents observed in the raw leaves of *C. gynandra* (8.6%) and *C. hirta* (7.4%) were higher than those previously reported (1.3–1.4%) (Chweya & Mnzava, 1997) and (2.27%) (Agea et al., 2014), respectively, and were slightly higher than those observed in *C. sesamoides* (7.91–8.16%) (Fasakin, 2004). The

variation in 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 agroclimatic conditions, stages of maturity, and the type and 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 contents observed in Cg-RL (11.6%), Ch-RL (19.0%), and Cs-RL (16.9%) were higher than those previously reported: 2.1–3.0% in *C. gynandra* (Chweya & Mnzava, 1997), 2.93% in *C. hirta* (Agea et al., 2014) and 9.38–11.13% in *C. sesamoides* (Fasakin, 2004). Values in Io-RL (14.3%) and Io-CD (15.3%) were higher than those previously reported, 13.74% in *I. batatas* (Awol, 2014). On the other hand, the ash content detected in Cd-RL (10.1%) was lower than that previously reported (20.5%) in *Cucumis sativus* (Attar & Ghane, 2017). The ash contents in the baobab (Ad-RYL and Ad-RML) were lower than the values reported, 7.8–16.3% (Heuzé et al., 2016). Likewise, the variation in mineral contents might be due to the agro-climatic conditions, the stages of plant maturity, and the type and rate of fertilizer application.

13.6.2 Minerals, β-Carotene, and Vitamin C Levels of Leafy Vegetables

Leafy vegetables are chief sources of vitamins and minerals compared with staple food grains. They contain high levels of β-carotenes, vitamin C, iron, calcium, and sodium (Natesh et al., 2017). Table 13.3 summarizes the minerals (iron, calcium, and sodium), β-carotene, and vitamin C of the selected AWLVs.

The iron content in raw leaves ranged from 1.2 mg/100 g (Ad-RYL) to 55.2 mg/100 g (Io-RL), and in dried samples, it ranged from 43.5 mg/100 g (Cs & Cd-DL) to 68.8 mg/100 g (Io-CD). The highest iron content was found in Io-CD (68.8 mg/100 g), followed by Io-RL (55.2 mg/100 g) and Io-DL (51.1 mg/100 g, $p < 0.005$). The lowest iron content was observed in Ad-RYL (1.2 mg/100 g), 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/100 g), Cs & Cd-DL (43.5 mg/100 g), and Ch-RL (44.8 mg/100 g). Similarly, there was no significant difference ($p = 0.671$) between Cs-RL (39.9 mg/100 g) and Isb-RL (41.5 mg/100 g).

The iron content detected in Ad-RYL (1.2 mg/100 g) was significantly lower ($p < 0.005$) than the iron content detected in Ad-RML (7.0 mg/100 g). The difference

Table 13.3 Minerals and vitamins of the selected raw and dried leafy vegetables (per 100 g edible portion) (Sakamoto et al., 2022)

Vegetables	Iron (mg)	Calcium (mg)	Sodium (mg)	β-Carotene (μg)	Vitamin C (mg)
Cg-RL	26.7 ± 0.7 ^{f}	1153.6 ± 16.7 ^{e}	153.9 ± 1.6 ^{c}	3175.5 ± 188.0 ^{b}	13.5 ± 0.2 ^{a}
Ch-RL	44.8 ± 0.0 ^{d}	2104.1 ± 44.6 ^{b}	138.3 ± 0.9 ^{cde}	1449.2 ± 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}	1486.2 ± 3.0 ^{c}	195.9 ± 3.0 ^{b}	2907.3 ± 103.1 ^{b}	6.1 ± 0.1 ^{b}
Io-DL	51.1 ± 1.3 ^{c}	1353.3 ± 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}	1059.5 ± 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}	2794.5 ± 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}	1556.6 ± 7.2 ^{c}	136.4 ± 2.4 ^{cde}	N.D.	0.6 ± 0.0 ^{ef}

The results are expressed as the mean ± SD, $n = 3$. Samples with different superscript letters across the column indicate significant differences according to Tukey's HSD test

Cg-RL raw leaves of *Cleome gynandra*, *Ch-RL* raw leaves of *Cleome hirta*, *Io* raw leaves of *Ipomoea obscura* or *Ipomoea mombassana*, *Io-CD* crush-dried leaves of *Ipomoea obscura*, *Io-DL* dried leaves of *Ipomoea obscura*, *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 *A. digitata*, *N.D.* not detected

contradicts the previously reported results from Mali, where young leaves had higher iron contents (19.31–27.22 mg/100 g) than mature leaves (9.77–10.32 mg/100 g) (Hyacinthe et al., 2015). The iron contents in Cd-RL and Ad-RYL observed in this study were lower to 2400 mg/100 g in *C. dipsaceus* of India (Chandran et al., 2013) and 9.77–27.22 mg/100 g in baobab leaves of Burkina Faso (Hyacinthe et al., 2015), respectively.

Similarly, the iron contents in leaves of Cg-RL (39.0 mg/100 g) and Ch-RL (56.4 mg/100 g) reported in a previous study carried out in Chinoje and Mzula villages, Chamwino district of the Dodoma region, Tanzania, were higher in comparison to results observed in this study carried out in Chinagali I village in the same district (Gowele et al., 2019). On the other hand, the iron content of Cg-RL observed in this study was higher compared with 2.1–14.3 mg/100 g in *C. gynandra* grown in South Africa (Schönfeldt & Pretorius, 2011; van Jaarsveld et al., 2014). 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 iron deficiency leads to anemia. Previous research indicates that anemia in women of Dodoma was lower despite concurrent food deficiency and malnutrition (Keding et al., 2011; Stuetz et al., 2019; Tanzania,

2019). This denotes the role played by the utilization of AWLVs, and thus, they constitute a contributing factor to 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 mg/100 g to 2794.5 mg/100 g. 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 contents ranging from 2794.5 mg/100 g to 1059.5 mg/100 g, and the moderate sources were Io-RL, Cd-RL, Isb-RL, and Ad-RYL, with calcium contents ranging from 943.8 mg/100 g to 372.3 mg/100 g. 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 content ($p < 0.005$).

Previous studies observed lower calcium contents in raw leaves of *C. gynandra* (260.1 mg/100 g), *C. hirta* (310.5 mg/100 g), *I. obscura* (320.125 mg/100 g), *C. sesamoides* (248.8 mg/100 g), and *C. dipsaceus* (270 mg/100 g) compared with the findings of this study (Chandran et al., 2013; Stuetz et al., 2019). In contrast, the previously reported value of 1961 mg/100 g in Ad-RML was higher than the value observed in this study. Likewise, the observed differences could be due to differences in the maturity of the leaves, agroecological factors, and farming systems used by the farmers.

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

Sodium levels in Cg-RL, Io-RL, and Ad-RML detected in this study were higher compared with the findings previously reported (33.6 mg/100 g, 32.079 mg/100 g, 1.37 mg/100 g) in *C. gynandra* (Chweya & Mnzava, 1997), *I. batatas* (Awol, 2014), and baobab, respectively (Hyacinthe et al., 2015). 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.

The values in Cs-RL (125.7 mg/100 g) and Cd-RL (129.0 mg/100 g) were lower than those in the mixture Cs & Cd-DL (151.7 mg/100 g). The process of crushing may have affected the values of sodium in *I. obscura*. The sodium contents observed

in the raw leaves (Io-RL) were significantly higher ($p = 0.012$) than the sodium contents in the crushed and then dried leaves (Io-CD); however, those of Io-DL and Io-RL were not significantly different ($p > 0.005$), meaning that drying may not affect the sodium content.

β-Carotene was detected in all samples of AWLVs used in this study except in Ad-RML, with the highest in Cg-RL at 3175.5 μg/100 g. The results showed that there were no significant differences ($p > 0.005$) between Io-DL (367.3 μg/100 g), Cd-RL (466.6 μg/100 g), and Ad-RYL (304.5 μg/100 g). Similarly, there was also no significant difference between Io-RL (218.1 μg/100 g) and Isb-RL (193.1 μg/100 g). The remaining samples showed significant differences ($p < 0.005$).

A previous study reported that indigenous AWLVs are good sources of antioxidants, including β-carotene and vitamin C (Gowele et al., 2019; Stuetz et al., 2019). The amount of β-carotene observed in Cg-RL (3175.5 μg/100 g) was higher than 291.04 μg/100 g or 670–1890 μg/100 g in *C. gynandra* (Chweya & Mnzava, 1997; Gowele et al., 2019). Similarly, the amount of β-carotene detected in Ch-RL (1449.2 μg/100 g) was higher than that previously reported (275.02 μg/100 g) in *C. hirta* (Gowele et al., 2019). On the other hand, the amount of β-carotene in Io-RL (218.1 μg/100 g) and Cs-RL (735.0 μg/100 g) was lower than the previously reported data of 1010 μg/100 g and 1960 μg/100 g, respectively (Gowele et al., 2019).

The range of vitamin C in the AWLVs was between 0.4 mg/100 g in Ad-RYL and 13.5 mg/100 g in Cg-RL. The results showed that there were no significant differences ($p = 0.109$) between Ad-RML (0.6 mg/100 g), Io-RL (0.6 mg/100 g), Cs-RL (0.8 mg/100 g), Isb-RL (0.8 mg/100 g), and Ch-RL (0.8 mg/100 g). Likewise, there were no significant differences ($p = 0.405$) between Io-RL (0.6 mg/100 g), Ad-RYL (0.4 mg/100 g), and Ad-RML (0.6 mg/100 g). The remaining samples 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* (Gowele et al., 2019; van Jaarsveld et al., 2014), 15.60 mg/100 g in *C. hirta* (Gowele et al., 2019), and 150–500 mg/100 g in baobab (Chadare, 2010) were observed. Several factors can influence the variations in vitamin C content in AWLVs, such as geographical location, plant variety or species, maturity stage, postharvest treatments, processing methods, storage conditions and time, packaging materials and technology, and cooking time.

13.7 Conclusion

This study shows that the seven evaluated AWLVs in semiarid Tanzania were rich in iron, calcium, and protein compared with the findings of previous research. Furthermore, their β-carotene and vitamin C contents 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 previous reports. The high iron, calcium, and protein contents in the herbal species of this locality may be due to the environment, including the semiarid 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.

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