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Nutritional composition and mineral profile of leaves of *Moringa oleifera* provenances grown in Gaborone, Botswana

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Abstract

Although Moringa is an important vegetable crop elsewhere, its nutritional and non-food uses are not widely known in Botswana community. This study was conducted to determine the chemical composition and mineral contents of leaves of *Moringa oleifera* trees grown in Gaborone, Botswana. The leaf samples were collected from Moringa trees grown in the backyards of six different households in Gaborone city. They were dried separately at 55 ºC for 24 h and then ground to obtain a powder for analysis. The data on the proximate composition of the Moringa samples were subjected to Analysis of Variance to determine statistical differences among the mean values. The overall mean values of moisture, fat, protein, ash, fiber and total available carbohydrates of the leaves were 6.93 ± 0.16, 7.78 ± 0.13, 27.1 ± 0.43, 7.34 ± 0.31, 9.1 ± 1 and 46.5 ± 3%, respectively. The Moringa leaves contained average values of 520 ± 96.0, 7.7 ± 1.3, 30.1 ± 15.5, 0.8 ± 0.1, 82.6 ± 6.4, 1.7 ± 0.2, 1.6 ± 0.2 and 0.02 ± 0.00 mg/100g of Calcium, Iron, Sodium, Zinc, Magnesium, Aluminum, Manganese and Chromium, respectively. Significant differences were observed for moisture, fat, protein and ash contents among the six Moringa samples. The results showed that the leaves are rich in nutrients, particularly with high amounts of protein and ash. This suggests that Moringa leaf could serve as an important protein and mineral supplement in the diet and can be consumed as a vegetable in Botswana. The difference in composition observed between the Moringa leaf samples suggests a possible genotypic difference between the Moringa trees used in this experiment. Thus, there is a need for further study to verify this.

Keywords *Moringa oleifera*, Proximate composition, Mineral content

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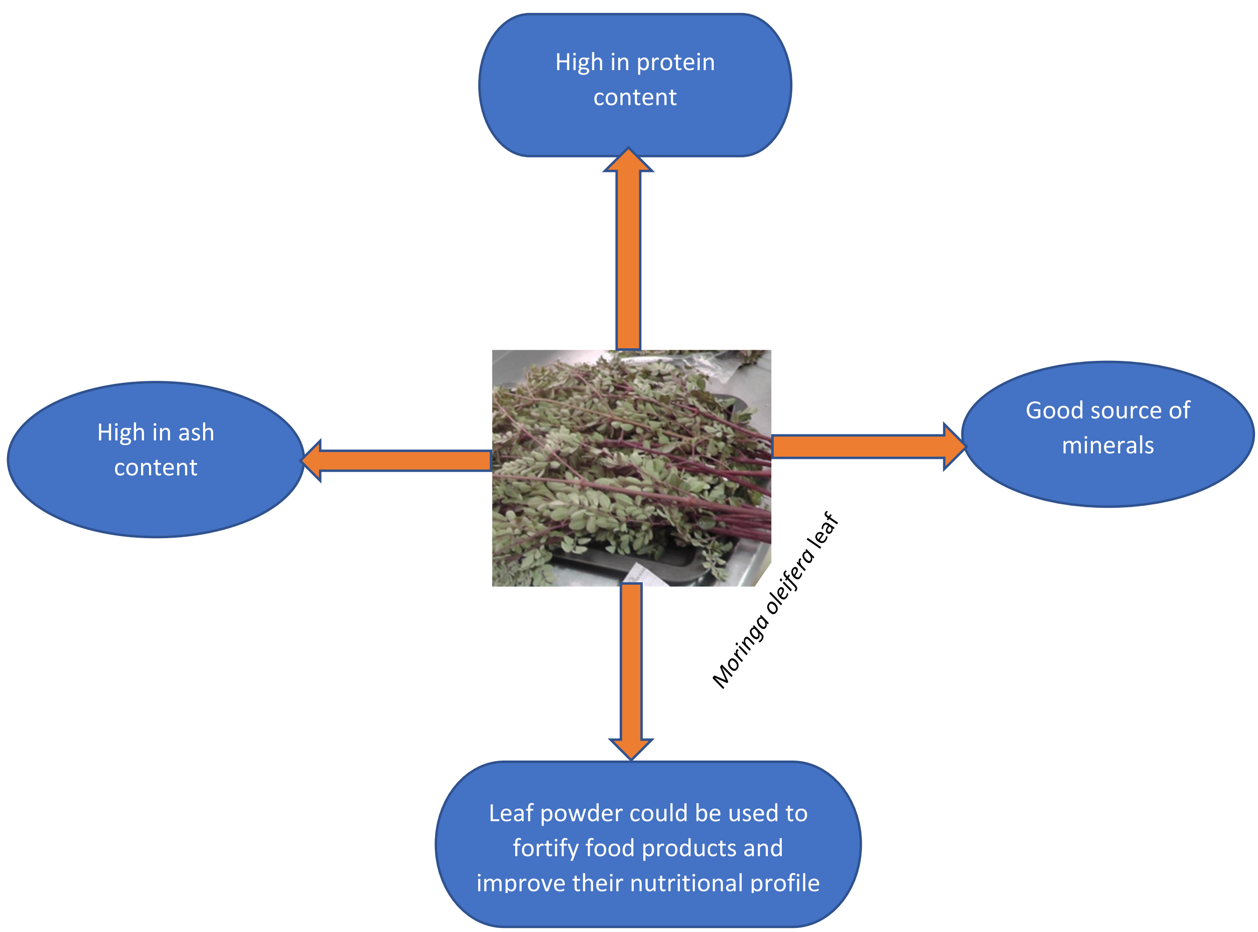
Graphical Abstract



Introduction

Moringa oleifera Lam., hereafter referred to as Moringa, is the most widely cultivated species of the monogeneric family Moringaceae and one of the most useful tropical species. It is indigenous to South Asia and has been introduced as a multipurpose tree with great potential and naturalized in other parts of India, Pakistan, Afghanistan, Bangladesh and Sri Lanka (Khatun et al. 2003). Moringa is a drought tolerant and fast-growing tree, which is also called horseradish or drumstick tree. Its leaves and fruits are eaten as vegetables and the bark has traditionally been used to heal various human illnesses (Bennett et al. 2003). Moringa is widely distributed in the tropics and subtropics where it is grown for its nutritional and medicinal values. The leaves and seeds of Moringa contain essential minerals, vitamins, phenolic compounds, β-carotene, and are good sources of proteins and amino acids (Anwar et al. 2007; Foidl et al. 2001). Moringa leaf is a good source of antioxidants (Khatun et al. 2003) and essential amino acids, such as lysine, tryptophan, cysteine and methionine. In India and Bangladesh, Moringa leaves are used as herbal medicine for the treatment of a wide range of human ailments (Bennett et al. 2003). The leaves are reported to have antidiabetic and hypocholesterolemic properties and are used as thyroid hormone regulator (Fahey 2005; Seifu 2014).

Moringa is one of the exotic trees that was recently introduced to Botswana (Kwaambwa et al. 2012). Reports indicate that it was first introduced to the country around 2003 (Rayl 2005) and has become popularly known for its health benefits (Seifu & Teketay 2020). Despite its recent introduction, Moringa is widespread throughout the country, including in Gaborone areas, and it is now common to see Moringa plant in the backyards of many households in the city where it is mainly used as a shade. Thus, the promotion of the use of Moringa as human food could significantly contribute to nutrition and food security in the country, especially in rural areas.

Despite its various food and non-food applications, Moringa has been given little research and development attention in Botswana. Past works on *M. oleifera* in Botswana focused on incorporating Moringa into the local agroforestry system and agronomic aspects of the plant such as its propagation, growth, and yield (Nduwayezu et al. 2007). Little scientific research if any has been conducted on the post-harvest utilization of the leaves of *M. oleifera* in Botswana. No study has been conducted to exploit the food and non-food applications of *M. oleifera* leaves such as their nutritional value and medicinal properties. Moreover, no work has been done on the processing of *M. oleifera* leaves and the development of value-added Moringa fortified food products.

The nutritional content of Moringa leaves is affected by genetic, edaphic, phenological and agronomic factors (Ruíz-Hernández et al. 2022). Phenological factors such as age, maturity and leaf colour influence the proximate composition and mineral contents of Moringa leaves (Ruíz-Hernández et al. 2022). Laura (2021) reported that variations in nutritional and mineral composition of leaves of Moringa is based on geographical location especially variations in soil nutrient content. Moreover, Olson et al. (2016) and Oyeyinka and Oyeyinka (2018) reported that the nutritional value of Moringa leaves varies with cultivar and geographical locations where the plant has grown. It was reported that the protein and mineral contents of Moringa leaves vary depending on climate, geographical area where the plant is cultivated, type of soil, water and fertilizers (Sultana 2020). A recent report by Yang et al. (2023) also showed that nutrient contents of *M. oleifera* leaves depends on the geographic area, solar radiation, humidity, soil type, and harvest time.

To date, little information exists on the nutritional composition *M. oleifera* species grown under Botswana's climatic conditions. This study was designed to generate information on the nutritional value and mineral contents of *M. oleifera* grown in Botswana. Such information will help create awareness about the nutritional benefits of Moringa leaves in the country and thereby promote its consumption as a vegetable by Batswana. Moringa leaves are not consumed as a vegetable in Botswana although the leaves are used for their medicinal value mainly in the form of tea (Seifu & Teketay 2020). Thus, demonstration of the nutritional value of Moringa leaves will create awareness and promote its utilization as a vegetable by communities in Botswana.

M. oleifera was reported to be introduced to Botswana from different places including Asia (India), Africa (Malawi, Tanzania, Kenya), and Europe (Netherlands) (Nduwayezu et al. 2007). This suggests that there can be varietal differences and, hence, variations in nutritional composition of Moringa leaves grown in the backyards of individual households in Gaborone.

To date, no research has been conducted on the nutritional quality of leaves of *M. oleifera* trees grown in Botswana. This study was, therefore, conducted to determine the chemical composition and mineral contents of leaves of *M. oleifera* provenances collected from backyards of individual households in Gaborone, Botswana.

Materials and methods

Study site

The Moringa leaf samples used in the present study were collected from backyards of individual households in Gaborone City in March 2018. Gaborone is located at 24° 39′ 29' S and 25° 54′ 44″ E—24.66°S and 25.9°E between Oodi and Kgale Hills on the junction of Notwane River in southeastern Botswana (Morton et al. 2008) at about 15 km from the boarder of South Africa. Gaborone lies at an elevation of 1010 m above sea level and has a hot semi-arid climate.

Description of Gaborone area

The topography of Gaborone city is undulating to flat, with height differences of approximately 50 m. The population of Gaborone has grown to roughly 200 000 inhabitants from 4000 in 1966. It was projected that the population of the city would reach between 300 000 and 1 000 000 in 2020.

Gaborone city has a relatively good vegetation distribution and some pockets of the city have a dense untouched bush cover. The natural vegetation in and around Gaborone is dominated by bushes and deciduous trees (Jonsson 2004). The soil type in Gaborone is predominantly loamy-sand lixisols with depth of up to 1.5 m (Zhai et al. 2003).

The climate of Botswana in General and Gaborone in particular is of hot, semi-arid type. The winter season is dry due to lack of rain and characterized by cold weather. Whereas summer is rainy season and has hot weather. The average annual precipitation and the average annual temperature of Gaborone city is reported be 538 mm and 20.7°C, respectively (Jonsson 2004). The main rainy season is from October to the beginning of April during which 84% of the precipitation occurs (Jonsson 2004).

Sources of Moringa leaves

Fresh *Moringa oleifera* leaf samples were collected from six different Moringa trees from backyards of households in Gaborone city (Block 10, Block 8, Broadhurst and Phase 4). Leaf samples collected from individual trees were used separately for the laboratory analyses. Gaborone city is divided into different zones and the detail

Table 1 Source of the Moringa leaf samples used for analysis in the present study

Source of sample	Samples used
Block 10	Sample 1 & 2
Block 8	Sample 3 & 4
Broadhurst	Sample 5
Phase 4	Sample 6

area description of the city is described under Sect. 2.2. above. The rainy rainy season in Gaborone is between October and April. Day time temperatures can reach up to 30–35°C or higher in the months of September and October. The soils in the area are generally sandy and shallow and the humidity is low. The vegetation is mainly shrub savannah dominated by acacia tree (Kent & Ikgopoleng 2011). The four sampling sites considered in this study are residential areas located in Gaborone city. In terms of climatic and edaphic factors, as such there is no significant differences between the different zones in the city.

Leaf samples of Moringa were collected from backyards of households located in four sites in Gaborone city as indicated in Table 1.

The households were selected based on the presence of the Moringa tree in their compound. About 3–4 kg of fresh Moringa samples were collected from each location and delivered to the Food Science laboratory at Botswana University of Agriculture and Natural Resources (BUAN). At the laboratory, the leaves were removed from the twigs and small branches by hand. About 2 kg of fresh moringa leaves were prepared for each sample and made ready for oven drying as indicated below.

Preparation of samples

Immediately after harvesting, the *M. oleifera* leaves were washed with cold water to remove dirt and other foreign matter. Then, the leaves were dried at 55 °C for at least 24 h or until the moisture content is below 10% using hot-air oven (Abuye et al. 2003). A laboratory blender was used to grind (to < 0.1 mm size) the dried leaves into powder, which was used for analyses of mineral content and proximate composition. The Moringa powder was put in airtight glass container and stored in cool dry place for a period of about two weeks.

Proximate composition

The moisture and ash contents of the Moringa leaf samples were determined according to AOAC (1996) method 930.15 and method 942.05, respectively. The crude protein (CP) content in percentage was determined by micro-Kjeldahl method as described in AOAC (1996) (method 960.5). The crude fat content was determined by *Soxhlet* method as described by AOAC (1996) (method 920.39C). The crude fiber content was determined by non- enzymatic gravimetric method and total carbohydrate was estimated by difference according to AOAC (1996).

Mineral analysis

The mineral content of *M. oleifera* leaf was analyzed using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES). About 0.3 g of sample was measured and placed in a digestion tube. Then, 9 ml of nitric acid and 3 ml of hydrogen peroxide were added into the tube containing the sample. The sample was, then, digested using a microwave digester (EQ: 002012, microwave digestion system Ethos 1, Magna Analytical, South Africa) for 2 h. The digested clear filtrate was used for mineral analysis. The mineral content of the sample was determined as described by Dos Santos et al. (2016) using the ICP-OES (Perkin-Elmer Optima 5300DV spectrometer, Perkin-Elmer Instruments Co., Ltd. USA). The ICP multi-element standard solution (1000 mg/kg) was prepared. The ICP OES instrument was started, brought to operational conditions and allowed to stabilize. Sample details were, then, filled into the software. The sample was filtered using micro-filters fitted to a plastic syringe, dispensed into 10 ml sampling vials and loaded accurately onto the auto sampler. The equipment tubing was checked to make sure that it was properly aligned. The sample was, then, analyzed, and the progress was viewed until the end of the analysis. The results were expressed as mg/100 g.

Statistical analysis

All determinations were made in three replications and One-Way Analysis of Variance (ANOVA) was used to analyse the data using STATISTIX 8 (STATISTIX 1985–2003 n.d.) Software. Tukey's Honestly Significance Difference Test was used for mean separation when statistical analysis showed significant differences between treatment means (Zar 1996).

Results and discussion

Proximate composition

Significant difference ($p = 0.001$) was observed in moisture content among the leave samples analyzed (Table 2). The mean moisture content of the Moringa leaf samples analyzed ranged from 6 ± 0.3—7.8 ± 0.46%. The overall mean moisture content (6.93%) of the Moringa leaf in the present study is higher than the moisture content (3.2%) reported by Oluduro (2012) for Moringa leaf grown in Southwestern Nigeria. Other researchers have reported

Table 2 Mean proximate composition of *Moringa oleifera* leaves collected from Gaborone city

Sample*	Moisture (%)	Fat (%)	Protein (%)	Ash (%)	Fiber (%)	CHO (%)
1	6.0 ± 0.03^{c}	7.4 ± 0.37^{b}	28.9 ± 0.26^{ab}	8.1 ± 0.15^{ab}	11.2 ± 0.67^{a}	38.3 ± 0.58^{a}
2	6.4 ± 0.03^{bc}	7.1 ± 0.00^{b}	24.9 ± 0.43^{c}	6.6 ± 0.20^{cd}	ND	59.8 ± 2.72^{a}
3	7.1 ± 0.12^{ab}	7.8 ± 0.00^{ab}	26.4 ± 0.21^{bc}	9.1 ± 0.26^{a}	10.1 ± 0.25^{a}	44.7 ± 3.18^{a}
4	7.8 ± 0.46^{a}	8.4 ± 0.00^{a}	26.9 ± 0.12^{abc}	7.7 ± 0.37^{bc}	12.3 ± 0.71^{a}	42.4 ± 4.01^{a}
5	7.2 ± 0.15^{ab}	8.4 ± 0.00^{a}	29.4 ± 0.06^{a}	7.0 ± 0.20^{bc}	11.2 ± 0.78^{a}	36.6 ± 5.92^{a}
6	7.1 ± 0.08^{ab}	7.5 ± 0.00^{b}	26.8 ± 1.38^{abc}	5.6 ± 0.18^{d}	9.6 ± 0.58^{a}	57.4 ± 11.19^{a}
Overall mean	6.9 ± 0.16	7.8 ± 0.13	27.2 ± 0.43	7.4 ± 0.31	9.1 ± 1.00	46.5 ± 3.00

Means with different superscripts in a column are significantly different ($p < 0.05$); CHO = Total available carbohydrates; ND = not determined; Values in the table are mean ± standard error of three replications; *Samples 1 & 2 were collected from Block 10, samples 3 & 4 were collected from Block 8, sample 5 was collected from Broadhurst, and sample 6 was collected from Phase 4 of Gaborone city

moisture content values of 9.53 and 11.76% for Moringa leaf grown in Bloemfontein, South Africa (Busani et al. 2011), and Nasarawa State of Nigeria (Ogbe & John 2011), which are higher than the value observed in the present study. However, the result of the present study is in agreement with the moisture value (6.88%) reported by Mikore and Mulugeta (2017) for Moringa leave grown in Ethiopia. The variation in moisture content observed between Moringa leaf samples analyzed in the current study and values reported in the literature might be associated to the variation in stage of maturity of the leaf samples, and it could also be related to difference in drying method employed.

Significant difference ($p = 0.002$) was observed in protein content among the six Moringa leaf samples analyzed (Table 2). The mean protein content of the Moringa leaf samples analyzed varied from 24.9 ± 0.43—29.4 ± 0.06%. The difference in crude protein content observed between the six *Moringa oleifera* samples collected from Gaborone suggests varietal difference between the Moringa trees considered, and it could also be attributed to difference in fertility of soil on which the Moringa trees have grown, leaf maturity and water availability. The difference between the Moringa trees used in the present study could easily bee seen from the morphological variation in the colour of the Moringa leaf samples as indicated in Fig. 1.


A
B

Fig. 1 Morphological variations in colour of *Moringa oleifera* leaf samples collected from Block 10 (**A**) and Broadhurst (**B**) areas in Gaborone city

The overall mean crude protein content (27.22 ± 0.43%) of the Moringa samples analyzed in the current study is higher than the value (22.8%) reported by Sanchez et al. (2006) for *M. oleifera* leaves. However, it is in agreement with the report of Yang et al. (2023) who indicated that the protein content of *M. oleifera* dry leaves is 27.1 g/100 g (DW) and that of fresh leaves is 6.7 g/100 g, which is two times greater than that of milk. Other researchers have reported variable protein contents for *Moringa oleifera* leaf ranging from 19 to 29% (Sanchez-Machado et al. 2010; Sultana 2020). Mikore and Mulugeta (2017) reported a crude protein content of 24.8% for *M. oleifera* leaf, which is lower than the value observed in the current study. The results revealed that *Moringa oleifera* leaf contains high amounts of protein, suggesting that inclusion of Moringa leaf in traditional foods or consumption of Moringa leaf as vegetable will significantly boost nutritional values of meals and meet the protein requirements of consumers whose diet is mainly based on carbohydrate sources. The high protein content of the Moringa leaves means that Moringa leaf powders can be used to fortify cereal-based products such as breads, pasties and snacks and thereby improve their nutritional value by increasing their protein content. A recent report by Trigo et al. (2023) indicated that incorporation of Moringa leaf powder into products, such as bread, pastries, snacks and beverages, increases the protein, essential amino acids, minerals and fiber contents and thereby improve the nutritional profile of these products. They also reported that owing to its high nutritional value, the dried Moringa leaf powder can be used as an alternative to milk and eggs and help vegetarians to consume the same protein content.

Fortification of dairy products such as yoghurt and cheese with Moringa leaf powder showed an increase in the contents of the amino acids alanine, glutamine and tyrosine and an improvement in antioxidant activity of the products (Trigo et al. 2023). Vegetable drinks can also be fortified with Moringa dried leaf powder with a resulting improvement in nutritional value in terms of protein and phenolic content and antioxidant capacity (Trigo et al. 2023).

The mean fat contents of *M. oleifera* leaf samples analyzed showed statistically significant difference ($p=0.001$) (Table 2). The mean fat content varied from 7.1—8.4%. The difference in fat content observed between the Moringa leaf samples analyzed in the current study could be associated to difference in the nutrient contents of the soil on which the Moringa trees have grown, and it could also be attributed to genotypic variations between the Moringa trees. The overall mean fat content of the *M. oleifera* leaf samples analyzed in the present study (7.8 ± 0.13%) (Table 2) is higher than the fat contents of 2.3%, 5.2% and 6% reported by Agbogidi and Ilondu (2012), Fuglie (2001) and Gopalakrishnan et al. (2016), respectively.

Significant difference ($p=0.001$) in ash content was observed among the Moringa leaf samples analyzed (Table 2). The mean ash content of the leaf samples analyzed varied from 5.6 ± 0.18—9.1 ± 0.26%. The difference in ash content observed between the six Moringa leaf samples indicate possible varietal difference between the *Moringa oleifera* samples analyzed. The ash content of the Moringa samples could also be related to the soil type in which the Moringa trees have grown. The overall mean ash content (7.4 ± 0.31%) is lower than the value 15.6% reported by Mikore and Mulugeta (2017) for *Moringa oleifera* leaf grown in Ethiopia. This difference may be attributed to variations in climatic conditions between the two locations and provenance differences. Aslam et al. (2005) reported variations in mineral contents in *M. oleifera* leaves and pods obtained from different regions of the Punjab Province of Pakistan. The average ash content is also lower than the value 10.6% reported by Busani et al. (2011) for Moringa trees grown in South Africa. The results of the present study showed that the Moringa leaf samples had high ash content and high ash content in a food is considered as a measure of mineral content (Sultana 2020) suggesting that Moringa leaves have high concentrations of mineral elements important in human nutrition.

No significant difference ($p>0.05$) in fiber content was observed among the Moringa leaf samples analyzed in the current study (Table 2). The fiber content of the Moringa leaf samples ranged from 9.6 to 12.3%. The overall mean fiber content is higher than the value (6.13%) reported for *M. oleifera* leaf by Mikore and Mulugeta (2017). Dietary fiber plays a vital role in human health (Ijarotimi et al. 2013). For example, it helps to prevent and treat gastrointestinal disorders, obesity, hypertension and diabetes (Lattimer & Haub 2010).

No significant difference ($p>0.05$) in total available carbohydrates content was observed between the Moringa leaf samples analyzed in the present study (Table 2). The total available carbohydrates content ranged from 36.6 ± 5.92 to 59.8 ± 2.92%. The overall calculated mean carbohydrate content (46.5 ± 3%) is higher than the value (40.4%) reported by Mikore and Mulugeta (2017) for leaves from *M. oleifera* trees grown in Ethiopia.

A study conducted in Botswana to evaluate the nutritional composition of the vegetables *Amarunthus* species, *Cleome gynandra* and *Vigna unguiculata* revealed that the ash (%), fat, protein and fibre contents (g/100g) of the three species were (1.90, 3.0, 2.15), (0.88, 0.66, 0.82), 5.60, 6.42, 4.6), and (1.84, 1.59, 1.2), respectively (Matenge et al. 2017). All the three leafy vegetables were found to be poor in protein, fat and fibre. The *M. oleifera* leaves analyzed in this study contains much higher amounts of protein, ash, fat and fibre as compared to the indigenous vegetables grown and consumed in Botswana.

Generally, the results of the proximate analyses showed that leaves of *M. oleifera* trees grown in Gaborone are important sources of nutrient and could potentially meet the nutrient requirements of people and, thereby, help combat the problem of malnutrition, which is prevalent among the resource-poor people in the country. Of particular interest is the very high protein content of the Moringa leaves, which can be used to alleviate the problem of protein deficiency, especially to the segments of the society, which do not afford to buy proteins of animal origin. The Moringa leaves also contain high ash content, which implies that they can serve as sources of important macro- and micro- minerals, which is verified by the mineral analyses results as indicated in the paragraphs below. The findings of the present study are in agreement with the report of Peñalver et al. (2022) who stated that *M. oleifera* leaf contains high protein and mineral contents and low content of lipids and thus it can be

Table 3 Mineral profile (mg/100 g) of *Moringa oleifera* leaf samples collected from Gaborone city ($n=6$)

Mineral	Minimum	Maximum	Mean ± SD
Ca	281	808	520.0 ± 96.0
Fe	5.18	14.10	7.7 ± 1.3
Na	4.29	103	30.1 ± 15.5
Zn	0.45	1.22	0.8 ± 0.1
Mg	63.08	97.28	82.6 ± 6.4
Al	0.87	2.20	1.7 ± 0.2
Mn	1.21	2.14	1.6 ± 0.2
Cr	0.01	0.02	0.02 ± 0.00

Ca Calcium, *Fe* Iron, *Na* Sodium, *Zn* Zinc, *M* Magnesium, *Al* Aluminum, *Mn* Manganese and *Cr* Chromium, *SD* Standard deviation, *n* number of samples

incorporated into the diet as a functional ingredient or as a fortifier of any kind of food. A recent report by Zungu et al. (2020) indicated that incorporation of 1% Moringa leaf powder in children's snack in South Africa improved the nutritional composition (protein and minerals) of the snacks. The Moringa leaf fortified snacks had higher concentrations of Ca, Mg, K, P, Zn, Mn, Fe and crude protein, but less fat compared to the control.

Mineral content

Moringa leaves have been advocated by several NGOs as well as some food and nutrition experts as excellent sources of vitamins and minerals. The calcium content of the Moringa leaves used in the present study ranged from 281 mg/kg to 808 mg/kg (Table 3). The overall mean calcium content (520 mg/kg) is lower than the value (19,026 mg/kg) reported by Mikore and Mulugeta (2017) for *M. oleifera* leaf. The iron content ranged from 5.18 mg/kg to 14.10 mg/kg (Table 3). The zinc content ranged from 0.65 mg/kg to 1.22 mg/kg (Table 3). Aslam et al. (2005) reported that *M. oleifera* leaves and pods obtained from different regions of Punjab Province (Pakistan) contained significantly high amounts of Fe, Cu, Na, Zn, P, Mn, K, Mg and Ca.

The Moringa leaf samples analyzed in the present study also contained other minerals, namely magnesium, sodium, aluminum, manganese and chromium (Table 3). Moringa contains many essential minerals for human growth and development. The calcium content (20.03 g/100 g DW) in *M. oleifera* leaves is 10 times than that in milk, while the potassium content (13.24 g/100g DW) in *M. oleifera* leaves is four times than that in banana (Yang et al. 2023). Owing to its high iron content, the leaf powder of Moringa can be used for treatment of anemia (Fahey 2005; Yang et al. 2023). Moringa leaf powder contains over 92% (28 mg of iron/kg) more iron than beef (2 mg) (Fahey 2005). It was also reported that Moringa contains more Fe as compared to spinach (Fuglie 2001). *M. oleifera* leaf is a good source of zinc and is reported to contain 25.5—31.03 mg of Zn/kg, which is the recommended daily Zn requirement in the diets of adults (Barminas et al. 1998). Although the zinc content (0.8 mg/kg) of the Moringa leaf samples analyzed in the current study is lower than literature reports, the values show that the Moringa leaves of trees planted in Botswana can still contribute towards the zinc content in the diet.

The daily recommended intakes of calcium, iron, zinc, sodium, magnesium and manganese are 1000, 8, 8, 1500, 240, and 1.9 mg/day, respectively (National Institute of Health 2019). This means that the Moringa leaves can provide 520 mg/100 g Ca, 7.7 mg/100 g Fe, 0.8 mg/100 g Zn, 30.1 mg/100 g Na, 82.6 mg/100 g Mg, and 1.6 mg/100 g Mn, which contribute 52% Ca, 96.25% Fe, 10% Zn, 2% Na, 34.4% Mg and 84.2% of the respective daily recommended intakes. The Moringa leaves could serve as good sources of calcium, iron, magnesium and manganese. However, the zinc and sodium contribution of the Moringa leaves is low in relation to the recommended daily intake of these minerals.

The results of the mineral analyses showed that the Moringa leaf samples contain good amounts of the macro-minerals, such as Ca and Mg and micro-minerals in particular iron and zinc. Iron and zinc are among the most critical and essential micro-nutrients needed to prevent mother and child malnutrition and should be provided in adequate supply during pregnancy, breastfeeding and complementary feeding periods, the so-called 1000-days window (Scherbaum 2017). Iron and zinc deficiencies are the most prevalent types of deficiencies in the world. This suggests that consumption of Moringa leaves would help in the reduction of deficiencies associated with these micro minerals.

Conclusion

The results of the proximate composition and mineral analysis of *Moringa oleifera* leaves collected from Moringa trees in Gaborone, Botswana, indicated that the Moringa leaves are rich in nutrients and have potential to be used as nutrient dense additives during preparation of different food types and/or consumed by humans as vegetable. In particular, the Moringa leaves can be used as important sources of proteins and minerals.

Based on the results obtained from this study, the following recommendations are forwarded.

- ❖ The results showed significant differences in composition between Moringa leaf samples collected from different locations and trees in Gaborone, suggesting differences in their genetic makeup. Thus, there is a need to undertake a scientific investigation aimed at characterizing Moringa varieties/provenances grown in Botswana.

❖ In this study, only proximate composition and mineral analysis were conducted on the Moringa leaf samples. Thus, there is a need for further investigations on vitamins, anti-nutritional factors, amino acid profiles and bioactive compounds on the Moringa leaves.

Abbreviations

Mg	Milligram
G	Gram
kg	Kilogram
AOAC	Association of Official Analytical Chemists
Ml	Millilitre
ICP-OES	Inductively Coupled Plasma-Optical Emission Spectrometry
Nitr	Nitrogen
Fe	Iron
Zn	Zinc
K	Potassium
Mg	Magnesium
Na	Sodium
Ca	Calcium
Mn	Manganese
P	Phosphorus
Cu	Copper
Al	Aluminium
Cr	Chromium
BUAN	Botswana University of Agriculture and Natural Resources

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Authors' contributions
EPM: collected data, wrote thesis, analyzed data, ES: designed the study, conceived the research idea, drafted and reviewed the manuscript, DT: reviewed the manuscript and designed the study. All the authors read and approved the manuscript.

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Availability of data and materials
All data supporting this study are included in this manuscript.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interest.

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