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Comparative Proximate and Mineral Composition of *Moringa oleifera* and *Moringa ovalifolia* Grown in Central Namibia

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Abstract

The objective of this study was to compare the proximate and mineral compositions of *Moringa oleifera* and *Moringa ovalifolia* grown together at Neudamm Experimental Farm in central Namibia. *Moringa oleifera* is well known for its rich nutritional value and was compared to the nutritional value of *M. ovalifolia*, a native plant of Namibia and Angola, which is less studied. Namibia being a semi-arid country, many plants in the rangelands are low in nutrients essential for livestock nutrition. This creates the necessity for planting fodder trees like moringa that withstand the harsh climatic conditions and retain their nutritional quality for the production of sustained livestock supplement. Leaves of both *Moringa* species were harvested with twiglets, shade dried fortnightly and taken to the laboratory where they were ground and passed through 1 mm sieve for proximate and mineral analysis. Statistically, *M. oleifera* nutrient values were significantly different ($P < 0.05$) in moisture, ash, crude protein (CP) and crude fiber (CF) from *M. ovalifolia*, but had no differences in fat, acid detergent fiber (ADF) and neutral detergent fiber (NDF). Also, *M. oleifera* was significantly different ($P < 0.05$) from *M. ovalifolia* in potassium (K), magnesium (Mg), copper (Cu) and zinc (Zn), but there were no differences in calcium (Ca), sodium (Na), phosphorus (P), iron (Fe) and manganese (Mn) values. This implies that both *Moringa* species have similar quantity of Ca, Na, P, Fe and Mn in their leaf tissues. The almost identical nutrient values of the two *Moringa* species, suggests that *M. ovalifolia* could serve as an alternative supplement for livestock since there is a known human-livestock competition for *M. oleifera*, and since *M. ovalifolia* is native and well adapted to the harsh environmental conditions of Namibia.

Keywords: Central Namibia, mineral composition, *Moringa oleifera*, *Moringa ovalifolia*, proximate composition

1. Introduction

The 13 species of *Moringa* trees belonging to the family *Moringaceae* are divided into 3 major groups based on the shapes of their trunks: slender trees, bottle trees and tuberous shrubs. Among the *Moringa* species, *Moringa oleifera* (*M. oleifera*) seems to have been the most adapted plant worldwide, compared to other species. It is also the most widely known. Many studies have been done on its uses and numerous beneficial properties in the plant kingdom (Fuglie, 2001; Olson, 2001; Prince, 2007; Hiawacha Bey, 2010).

Moringa oleifera tree is native to the southern foothills of Himalayans in northern India, but it has been planted around the world and has naturalized in many countries. It has a high growth rate and capacity to produce large quantities of fresh biomass (Fuglie, 2001; Sanchez, Ledin, & Ledin, 2006; Price, 2007). It is commonly known as a horse-radish or drumstick tree in English and used as traditional medicine and livestock feed in many tropical and subtropical countries. Advantageously, it is a rapidly growing drought-resistant-deciduous tree even in poor soils (Fuglie, 2001; Alhakman, Kumar, & Khan, 2013).

Moringa ovalifolia (*M. ovalifolia*), which is described as a bottle tree because of its trunk, is a native tree to Namibia and Angola. This species is generally uncommon, but widespread in western Namibia, as far south as

26 °S; scattered localities in the Karstveld and occasional in the south, while it is common in the central areas. It grows in the wild in both countries. It is a small deciduous tree with a distinctive, squat, swollen stem and branches and is commonly known as "ghost tree or phantom tree". The roots, bark and wood are eaten by goats; trees are also browsed by giraffe (Olson, 2001; Curtis and Mannheimer, 2005; Wyk, Wyk, and Wyk, 2011). Although many studies have shown that *M. oleifera* is readily eaten by animals as a fodder, little is known about *M. ovalifolia* even though it is also proven to be eaten by animals (Foidl, Makkar, & Becker, 2001; Wyk et al., 2011; Alhakman et al., 2013).

Good fodder species contain high levels of protein and some important minerals like phosphorus (P) which make animals grow rapidly (Pace Project, n.d.). The production of additional fodder from dry-land, cultivated grass pastures and plantations of drought-tolerant fodder shrubs should become a priority in dry, mostly desert countries like Namibia so that livestock production could no longer be dependent solely on highly sensitive native rangeland but also include other sources of fodder (Sijssens, 2014). Nutritional and medicinal properties of *M. oleifera* have the potential to alleviate malnutrition, starvation, as well as prevent and heal many diseases and maladies (Hiawacha Bey, 2010). The leaves are highly nutritious, and also considered as a source of beta-carotene, vitamin C, protein, iron and potassium (Makkar and Becker, 2007). Phytochemical analysis of *M. oleifera* have shown that its leaves are particularly rich in potassium, calcium, phosphorous, iron, vitamins A and D as well as in essential amino acids (Mbikay, 2012). Research shows that every 100 g of *M. oleifera* of leaf powder contain 27.1 g of protein, 259 mg of mineral potassium (K), 6.8 mg of vitamin A - -carotene, while the pods contain 2.5 g of protein, 259 mg K in pods (Prince, 2007). In a study by Sanchez-Machado, Núñez-Gastélum, Reyes-Moreno, Ramírez-Wong, & López-Cervantes (2010), chemical composition (of dry leaves) ranged from 19.34% to 22.42% for protein, 1.28% to 4.96% for lipids, 7.62% to 14.60% for ash, and 30.97% to 46.78% for dietary fiber. They concluded that the leaves and flowers are a protein source with an adequate profile of amino acids and ash, while the immature pods show a high content of dietary fiber and low lipid content. The crude protein content of extracted and unextracted moringa leaves was 43.5 and 25.1%, respectively, suggesting that both the extracted and unextracted leaves are good sources of protein for livestock (Foidl, Makkar, & Becker, 2001).

Moringa oleifera leaves have a high potential as a protein source supplement for ruminants and their nutritional value is similar to that of the widely used soybean meal and rapeseed meal (Soliva, Kreuzer, Foidl, Machmuller, & Hess, 2005). It has proven to be a valuable supplement for animals in other countries (Mendieta, Reyes, & Rodriquez, 2007; Ojukwu, 2012). This means that feeding it at the appropriate period of nutritional needs especially during pregnancy for proper foetus development and during lactation for early growth and development of the new born animal is essential.

Moringa can be used as a food for human consumption in addition to being used as feed or fodder for animals. It can be prepared in different forms for human consumption and eaten either raw or dry by animals. In the tropics, it is used as a forage for livestock and in many countries as vegetables that have the potential to improve nutrition, ensure food security, foster rural development and support sustainable land care (Foidl et al., 2011; Joshua and Vasu, 2013). However, whether used as food or feed for livestock, the benefits of moringa have become increasingly obvious and demand concerted national action (Ojukwu, 2012). It is upon this background that this study was undertaken to compare the chemical and nutritional composition of *M. oleifera*, which has been widely researched, with that of *M. ovalifolia* that has scantily been researched and reported in literature.

2. Materials and Methods

2.1 Study Area

A moringa orchard of 0.21 hectares (0.11 hectares for *M. oleifera* and 0.10 hectares for *M. ovalifolia*) was established in 2014 at the Neudamm Experimental Farm of the University of Namibia, about 30 km east of Windhoek. The Experimental Farm has a total area of about 10,187 hectares. Neudamm Campus is located at 22° 30′ 07″ S and at 17° 22′ 14″ E, and at an altitude of 1762 meters above sea level. The farm's temperature ranges between a minimum of -7°C in winter and a maximum of 44°C in summer (University of Namibia, 2011), and received annual average rainfall of 229 mm and 247.8 mm in 2014/2015 and 2015/2016 summer seasons respectively (Beukes, 2017).

2.2 Sample Collection

Thirty-day-old *Moringa oleifera* and *M ovalifolia* leaves with their twiglets were randomly collected from the *Moringa* orchard. Leaves were randomly harvested from each block for both *Moringa* species to compare the chemical and nutritional composition between species as well as among blocks. Data was collected during 2014/2015 and 2015/2016 summer seasons after the trees were well established and had leaves. In Namibia,

summer extends from September to April of the following year when rainfall is more than 99% (Pallett, 1994) and temperatures are optimal for plant growth.

2.3 Sample Preparation

Moringa leaves were dried in the shade for two weeks as described by Madukwe, Ezeugwu and Eme (2013) and taken to the nutrition laboratory of the Ministry of Agriculture, Water and Forestry in Windhoek where subsequent preparation and analysis were done. Leaf samples from both *Moringa* species were ground to powder and allowed to pass through a sieve with circular openings of 1mm diameter and stored in clean and labelled plastic bottles until analysis (AgriLASA, 1993; AOAC, 2006).

2.4 Nutritional Analysis Procedures

Moringa oleifera and *M. ovalifolia* leaf samples were analysed for nutritional composition such as moisture, ash, fat, crude fibre (CF), crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF), carbohydrate, total digestible nutrients (TDN), digestible energy (DE), metabolisable energy (ME), calcium (Ca), phosphorus (P), sodium (Na), potassium (K), magnesium (Mg), manganese (Mn), iron (Fe), zinc (Zn), copper (Cu) and water soluble tannins using the procedures of the Association of the Official Agricultural Chemists (AgriLASA, 1993; AOAC, 2006; Cunniff, 1996).

Protein content was determined using a combustion method in a CHN628 machine. Approximately 0.1 g of a sample was weighed into a foil cup and placed in a CHN628 Leco Machine. Samples were burned at 950^{o}C in the presence of oxygen, and then the released gases were separated by helium. The released nitrogen was measured in a thermal conductivity cell and the results were automatically captured and the readings were seen on the screen. The protein percentage was calculated by multiplying the reported nitrogen by 6.25. Disodium ethylenediaminetetraacetate (EDTA) was used for quality control during analysis (AgriLASA, 1993; AOAC, 2006).

Crude fiber was determined using Weende method (AgriLASA, 1993), in which a FIWE Raw Fiber Extractor was used. A ground sample of approximately 1 g was weighed in glass crucibles, inserted into the extractor to which 150 mL of diluted and preheated sulfuric acid (H_2SO_4) was added, followed by 4 drops of antifoam agent (n-octanol) and boiled for 30 minutes. Afterwards, filtering of the remaining reagent was done and washed 3 times with de-ionized hot water. Thereafter, 150 mL of sodium hydroxide was added followed by 4 drops of n-octanol and the mixture was boiled for another 30 minutes. Then, the reagent was filtered out and washed 3 times with de-ionized hot water. The remaining residues were dried at 105^{o}C for five hours in a conventional oven, cooled in a desiccator and weighed to obtain the crude fiber contents. The percentage crude fiber was calculated as follows:

$$\text{Crude Fiber (\%)} = \frac{(F1 - F2)}{F0} \times 100 \quad (1)$$

where F0, F1 and F2 represent the weights of sample, crude fiber plus ash content and ash, respectively. Ash content was determined by placing dried residues from crude fiber in a muffle furnace at a temperature of 550^{o}C for 5 hours, cooled in a desiccator and weighed to obtain the ash (AgriLASA, 1993; AOAC, 2006).

Acid detergent fiber (ADF) was determined using Weende method (AgriLASA, 1993), in which a FIWE Raw Fiber Extractor was used. A ground sample of approximately 1 g was weighed in glass crucible, inserted into the extractor to which 100 mL of cetyltrimethylammonium bromide technical grade ($C_{19}H_{42}BrN$) and sulfuric acid (H_2SO_4) with 4 drops of n-octanol were added and then left to boil for one hour. Afterwards, filtering of the remaining reagent was done and it was washed 3 times with de-ionized hot water. The remaining residues were dried at 105^{o}C to constant weight in a conventional oven, cooled in a desiccator and weighed to obtain the acid detergent fibers. The ADF was calculated using the formula:

$$\text{ADF } \% = \frac{W_r}{W_s} \times 100 \quad (2)$$

where W_r is the weight of the residue after heating and W_s is the weight of the sample (AgriLASA, 1993; AOAC, 2006).

Neutral detergent fiber (NDF) was also determined using Weende method (AgriLASA, 1993) in which a FIWE Raw Fiber Extractor was used. A ground sample of approximately 1g was weighed in glass crucible, inserted into the extractor machine, then 100 mL of sodium borate decahydrate ($Na_2B_4O_{7\cdot10}H_2O$), disodium ethylenediaminetetraacetate (EDTA, $C_{10}H_{14}Na_2O_{8),}$ sodium lauryl sulfate neutral ($C_{12}H_{25}NaO_4S$),

2-ethoxyethanol (Ethylene glycol monoethyl ether, cellosolve, $C_4H_{10}O_2$), and disodium phosphate anhydrous (Na_2HPO_4) with 4 drops of n-octanol (antifoam agent) added. The mixture was allowed to boil for one hour and the boiled mixture was filtered and then washed 3 times with de-ionized hot water. Afterwards, the washed residue was dried at 105°C to constant weight in a conventional oven, cooled in a desiccator and weighed to obtain the neutral detergent fiber. The NDF was calculated using the equation (2) as for ADF.

The moisture from a sample is driven off by the use of heat, and the weight loss is used to calculate the moisture content (AgriLASA, 1993). The moisture content was determined by heating the samples in a vacuum oven at a temperature of 105°C to constant weight and cooled in a desiccator as described by Sanchez et al. (2006). Then the weights lost from the heated samples were used to calculate the moisture content as

$$\text{Moisture (\%)} = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \quad (3)$$

where W_1 is the dish (without lid) weight, W_2 is the sample plus dish and W_3 is the sample plus dish after drying (AgriLASA, 1993).

Fat content was determined using the Solvent Extractor Machine (VELP SICIENTIFICA). About 3 g of sample was weighed in the extraction thimbles and hooked in the Solvent Extractor Machine. Beakers were weighed with boiling stone in each of them and 60 mL of petroleum ether was added and then was put in the extractor machine in which the extraction thimbles were submerged. The tap was open for condensation and the machine knot was moved to level one (immersion) and boiled at 110°C temperature for an hour, then the knot was moved to level two (washing) for another hour boiling and finally the knot was moved to level three (recover) for the last one hour boiling. The boiling stone was used to create a calm boiling process. After boiling, the beakers with recovered samples were placed in a conventional oven at 105°C temperature to dry for 30 minutes. Subsequently, beakers were removed and placed in a desiccator, cooled, weighed and the fat content was calculated as

$$\text{Crude fat (\%)} = \frac{MFR - MF}{m} \times 100 \quad (4)$$

where m, MF and MFR represent mass of sample used, mass of flask, and mass of flask with extracted reside, all in grams, respectively (AgriLASA, 1993; AOAC, 2006).

Mineral analysis was determined by the Atomic Emission Spectroscopy (AES) method using Inductively Coupled Plasma (ICP) instrument. The elements Ca, P, Na, K, Mg, Mn, Fe, Zn and Cu were analysed. This analytical method allows the isolation of minerals from organic matter prior to the analysis by first ashing samples. The ashed samples were digested consecutively by hydrochloric and nitric acids to decompose them. The digested samples were filtered before being diluted with de-ionized water. The sample diluents were injected into ICP-MS instrument for analysis and gave the concentration of individual minerals.

Water soluble tannins were determined using in house method of aqueous extraction followed by colorimetric determination (Folin and Ciocalteu's phenol regent). Non-structural carbohydrates were determined using calculated differences. Total digestible nutrients, digestible energy and metabolisable energy were also determined by calculation (AOAC, 2006; Galyean, 2010).

2.5 Data Analysis

One-sample t-test analysis was used for *M. oleifera* and *M. ovalifolia* nutrient composition data analysis in which the means of *M. oleifera* were compared with the means of *M. ovalifolia* using Statistical Package for Social Sciences (SPSS® version 23). Means of blocks were derived using Microsoft Office Excel® program that compared the nutrient composition of *M. oleifera* and *M. ovalifolia*.

3. Results

The results of this study include the proximate and mineral compositions of *M. oleifera* and *M. ovalifolia* leaves. The results for moisture, ash, fat, CP, CF, ADF, NDF, Ca, P, K, Na, Mg were presented in percent dry weight (% DW) because they found in large quantities, while Cu, Fe, Mn and Zn are reported in parts per million (ppm) since they are found in small quantities as suggested by Hochmuth, Maynard, Vavrina, Hanlon, and Simonne (2015). Total digestible nutrients are expressed in g/100 g, both digestible energy and metabolisable energy in MJ/kg, while water soluble tannins are in g/100g. All analytical results in the tables are presented 'as is'.

3.1 Nutrient Compositions of M. oleifera and M. ovalifolia

Table 1 shows the proximate and mineral composition of *M. oleifera* and *M. ovalifolia* leaves using *M. ovalifolia* means as test values against *M. oleifera* in a one-sample t-test analysis. Moisture content, fat, CP, CF, ADF and

NDF parameters were used as proximate composition while Ca, P, F, Mg, Na were used as macro-nutrients; Cu, Fe, Mn and Zn were used as micro-nutrients. Statistically, *M. oleifera* proximate nutrient values were significantly different ($P < 0.05$) in moisture, ash, CP and CF from *M. ovalifolia*, but there were no significant differences ($P > 0.05$) in fat, ADF and NDF. This means that fat, ADF and NDF nutrient values are similar in both *Moringa* species. For mineral composition, *M. oleifera* was significantly different ($P < 0.05$) from *M. ovalifolia* in K, Mg, Cu and Zn content; but, there were no differences in Ca, Na, P, Fe and Mn values. This implies that both *Moringa* species have similar content of Ca, Na, P, Fe and Mn in their leaf tissues. The differences in mineral nutrient values can be attributed to the higher ash content of *M. ovalifolia* as compared to *M. oleifera* because, it is an approximation of the total mineral (inorganic) portion of the feed sample as defined by (Tisch, 2006). Table 2 indicates the level of TDN, DE, ME and tannins contents in *M. oleifera* and *M. ovalifolia* leaves in which the total mean and standard error of the mean (SEM) were considered.

Table 1. Comparison of *M. oleifera* and *M. ovalifolia* leaves proximate and mineral composition (g/100g)

Nutrient	Mean		Std.	Std. Error	t	
(% in DW)	*M. ovalifolia*	*M. oleifera*	Deviation	Mean		P-values
Moisture	6.2	6.025	0.191	0.068	-2.588	0.036
Ash	11.32	10.653	0.391	0.138	-4.822	0.002
Fat	5.795	6.608	1.569	0.555	1.465	0.186
CP	28.68	30.988	0.908	0.321	7.189	0.000
CF	8.458	8.115	0.410	0.145	-2.366	0.050
ADF	11.78	10.961	1.469	0.519	-1.576	0.159
NDF	13.92	12.835	3.047	1.077	-1.007	0.347
Macro-nutrients (% in DW)						
Ca	1.711	1.206	0.857	0.303	-1.667	0.139
P	0.368	0.265	0.195	0.069	-1.502	0.177
K	0.796	0.578	0.309	0.109	-1.992	0.087
Mg	0.182	0.074	0.045	0.016	-6.787	0.000
Na	0.224	0.656	1.372	0.485	0.891	0.402
Macro-nutrients (ppm)						
Cu	13.1	15.093	1.965	0.694	2.870	0.024
Fe	174.7	177.105	11.168	3.948	0.609	0.562
Mn	0.001	0.358	0.857	0.357	1.000	0.351
Zn	13.51	20.499	0.195	0.746	9.373	0.000

Results are presented 'as is'.

Table 2. Total digestible nutrients, digestible energy, metabolisable energy and Tannins contents in *M. oleifera and M. ovalifolia*

Nutrients (g/100 g)	*M. oleifera*	*M. ovalifolia*	Total Mean	SEM
Total digestible nutrients	67	62	64.5	4.419
Digestible energy	12	12	12	0.000
Metabolisable energy	11	10	10.5	0.177
Tannins (tannic acid)	3.9	4.4	4.15	0.044

Results are presented 'as is'.

3.2 Comparison of M. oleifera Nutritional Compositions within Blocks

Table 3 shows the proximate and mineral composition of *M. oleifera* leaves in which blocks B2, B3 and B4 means were compared with the control block (B1) mean. *Moringa oleifera* seedlings were transplanted in four blocks with four treatment levels: B1 (0 g), block2 (100 g), block3 (200 g) and block4 (300 g) of superphosphate fertilizer with a P content of 83 g/kg (Wonder superphosphate granular, AGRO-SERVE (Pty) Ltd., Bryanston, South Africa and nitrogen fertilizer with an N content of 280 g/kg (Limestone Ammonium Nitrate - LAN), WONDER HORTICULTURAL PRODUCTS (Pty) Ltd., Silverton, South Africa for roots and leaves development. The one sample t-test analysis result revealed no significant differences ($P > 0.05$) within blocks in moisture content, ash, fat, CP, CF and ADF, except NDF that was statistically different ($P < 0.05$) between control and other blocks, which might be attributed to *M. oleifera*'s high level of NDF without fertilizers. Also, there were no significant differences ($P > 0.05$) in Ca, K, Mg, P, Cu and Mn content between the control block

and other blocks, except for Na, Fe and Zn which were significantly different ($P < 0.05$) in mineral values.

Table 3. Comparison of proximate and mineral composition of *M. oleifera* leaves in different treatments (g/100g)

Nutrients (% in DW)	Mean		Std. Deviation	Std. Error Mean	t	P-values
	Control block	Fertilized blocks				
Moisture	5.975	6.042	0.227	0.131	0.509	0.661
Ash	10.775	10.612	0.439	0.253	-0.644	0.585
Fat	5.695	6.912	1.303	0.752	1.617	0.247
CP	30.95	31.000	0.265	0.153	0.327	0.775
CF	8.15	8.103	0.215	0.124	-0.377	0.743
ADF	10.055	11.263	1.656	0.956	1.264	0.334
NDF	15.725	11.872	1.340	0.774	-4.980	0.038
Macro-nutrients (% in DW)						
Ca	1.419	1.135	0.404	0.233	-1.219	0.347
P	0.2865	0.257	0.153	0.088	0.069	0.951
K	0.5705	0.581	0.254	0.147	0.857	0.482
Mg	0.0615	0.078	0.033	0.019	-35.371	0.001
Na	2.1125	0.171	0.095	0.055	-0.330	0.773
Micro-nutrients (ppm)						
Cu	14.585	15.263	1.469	0.848	0.799	0.508
Fe	181.722	175.566	3.523	2.034	-3.026	0.094
Mn	0.001	0.477	0.825	0.476	1.000	0.423
Zn	18.957	21.013	1.207	0.697	-1.219	0.098

Results are presented 'as is'.

Table 4 shows the comparison of proximate and mineral compositions of *M. oleifera* blocks (B1, B2, B3 and B4) in which B1 served as a negative control (i.e. without fertilizer). The results for proximate composition show that CP was the highest followed by NDF, ADF and ash while the moisture, fat and CF nutrient values were < 9% in all blocks. The results revealed that Fe had the highest values among the minerals followed by Zn and Cu while Ca, K, Mg, Na, P and Mn were < 3% in values for all blocks.

Table 4. Comparison of proximate and mineral compositions of *M. oleifera* leaves (g/100g) within blocks

Nutrients (% in DW)	Block 1	Block 2	Block 3	Block 4
Moisture	5.975	6.185	5.78	6.16
Ash	10.775	11.07	10.195	10.57
Fat	5.695	6.11	8.415	6.21
CP	30.95	31.1	30.7	31.2
CF	8.15	8.03	8.345	7.935
ADF	10.055	10.305	13.175	10.31
NDF	15.725	13.415	11.2	11
Macro-nutrients (% in DW)				
Ca	1.419	1.304	1.427	0.674
P	0.287	0.425	0.222	0.125
K	0.571	0.762	0.69	0.291
Mg	0.062	0.116	0.054	0.065
Na	2.113	0.205	0.245	0.064
Micro-nutrients (ppm)				
Cu	14.59	16.89	14.86	14.04
Fe	181.722	175.8	171.932	178.966
Mn	<0.001	<0.001	1.43	<0.001
Zn	18.957	19.986	20.71	22.343

Results are presented 'as is'.

The comparison of manured *M. oleifera* leaf proximate and mineral compositions from four locations of Namibia which are the Neudamm (NEU.) cultivated field, Neudamm Campus, Rundu (Kaisosi) and Windhoek City is found in Table 5. The Neudamm Field is an agronomic field about 1.5 km outside the Neudamm Campus

where moringa was cultivated; Neudamm Campus has three old *M. oleifera* trees; Kaisosi is a location in Rundu Town about 750 km from Windhoek, the capital city of Namibia. Statistically, there were no significant differences ($P > 0.05$) in *M. oleifera* leaves nutrient values among locations.

Table 5. Proximate and mineral compositions of *M. oleifera* leaves from four locations of Namibia (g/100g)

Nutrients (% DM)	NEU. Field	NEU. Trees	Rundu (Kaisosi)	Windhoek
Moisture	5.975	6.16	6.11	6.3
Ash	10.775	13.55	10.64	15.5
Fat	5.695	5.81	5.64	4.45
CP	30.95	21.9	27.2	29
CF	8.15	9.73	7.76	8.15
ADF	10.055	13.88	8.91	8.7
NDF	15.725	14.77	16.39	15.52
Macro-nutrients (% DM)				
Ca	1.758	0.83	1.918	1.419
P	0.315	0.31	0.379	2.1125
K	0.701	1.755	0.783	0.2865
Mg	0.165	0.645	0.141	0.5705
Na	0.129	0.05	0.152	0.0615
Micro-nutrients (ppm)				
Cu	12.371	9.4	10.512	14.585
Fe	182.97	150.5	196.843	181.722
Mn	<0.001	76.5	<0.001	<0.001
Zn	20.711	20.5	10.596	18.957

Results are presented 'as is'.

Tables 8 presents a comparison of *M. oleifera* leaves proximate and mineral compositions from four regions of Sub-Saharan Africa; namely, Central (Chad), East (Ethiopia), South (Namibia), and West (Nigeria). The data from the three countries were adopted from reports by Melesse (2011) from Ethiopia, Ogbe and Affifu (2012) from Nigeria and Mbailao, Mianpereum and Albert (2014) from Chad, while the data on Namibia were from the Neudamm Experimental Farm *Moringa* orchard.

Table 8. Comparative proximate and mineral composition of *M. oleifera* leaves from different African regions (g/100 g DW)

Nutrients (% in DW)	Chad	Ethiopia	Namibia	Nigeria
Moisture	20.92 (DM)	---	6.16	3.21
Ash	6.73	13.2	13.55	7.93
Fat	2.34	6.73	5.81	2.11
CP	32.06	28.9	21.9	17.01
CF	8.07	8.51	9.73	7.09
ADF	---	12.1	13.88	---
NDF	---	16.7	14.77	---
Macro-nutrients (% in DW)				
Ca	1.23	2.62	0.83	1.91
P	0.32	0.43	0.31	30.15
K	1.73	2	1.755	0.79
Mg	0.39	0.56	0.645	0.38
Na	0.08	0.03	0.05	192.95
Micro-nutrients (ppm)				
Cu	9.07	---	9.4	6.18
Fe	97.12	---	150.5	107.48
Mn	29.33	---	76.5	81.65
Zn	29.14	---	20.5	60.06

Sources: Melesse (2011), Ogbe and Affifu (2012) and Mbailao *et al*. (2014); Results are presented 'as is'.

3.3 Comparison of M. ovalifolia Nutrient Compositions at Treatment Levels

The comparison of *M. ovalifolia* leaf proximate and mineral composition within blocks using the control block in a one-sample t-test is found Table 9. Just as *M. oleifera*, *M. ovalifolia* was transplanted in four blocks in which block1 was the control (0 g), and block2 (100 g), block3 (200 g) and block4 (300 g) - the experimental blocks for phosphorus and nitrogen fertilizers application (See Table 3). There were no significant differences ($P > 0.05$) in moisture, ash, fat, CP, ADF and NDF contents between the control (block1) and the experimental blocks (block2, block3 and block4); except for CF which showed a different ($P < 0.05$) between the control block and experimental blocks. Similarly, there were no significant differences ($P > 0.05$) in Ca, K, Mg, P, Cu and Mn mineral composition within blocks, except for Na, Fe and Zn that showed different ($P < 0.05$) between the control block and experimental blocks.

Table 9. Comparative proximate and mineral composition of *M. ovalifolia* leaves within treatments (g/100 g)

Nutrient (% in DW)	Blocks Means		Std. Deviation	Std. Error Mean	t	P-values
	Control	Fertilized				
Moisture	6.37	6.143	0.29687	0.17140	-1.322	0.317
Ash	12.61	10.887	1.35463	0.78210	-2.203	0.158
Fat	6.17	5.670	1.03793	0.59925	-0.834	0.492
CP	31.5	27.733	3.6074	2.0827	-1.809	0.212
CF	10.08	7.917	1.18095	0.68182	-3.173	0.087
ADF	12.87	11.410	1.24852	0.72083	-2.025	0.180
NDF	16.72	12.980	2.84317	1.64150	-2.278	0.150
Macro-nutrients (% in DW)						
Ca	1.541	1.768	0.172	0.099	2.288	0.149
P	0.362	0.370	0.092	0.053	1.736	0.225
K	0.735	0.816	0.080	0.047	-3.897	0.060
Mg	0.274	0.151	0.055	0.031	1.192	0.356
Na	0.141	0.251	0.160	0.093	0.158	0.889
Micro-nutrients (ppm)						
Cu	15.112	12.427	3.194	1.844	-1.456	0.283
Fe	184.834	171.368	26.748	15.443	-0.872	0.475
Mn	0.001	0.001	0.000	0.000	1.961	0.189
Zn	12.65	13.798	1.0137	0.585	2.288	0.149

Results are presented 'as is'.

Table 10 compares the proximate and mineral composition of *M. ovalifolia* leaves within blocks as the nitrogen and phosphorus fertilizers were applied. The same experimental design was used as in the case of *M. oleifera* (see Table 3).

Table 10. Comparative proximate and mineral composition of *M. ovalifolia* leaves within treatments (g/100g)

Nutrients	B1	B2	B3	B4
Moisture (% in DW)	6.37	6.47	5.89	6.07
Ash	12.61	12.45	10.06	10.15
Fat	6.17	4.5	6.48	6.03
CP	31.5	24	31.2	28
CF	10.08	9.16	7.78	6.81
ADF	12.87	10.75	12.85	10.63
NDF	16.72	16.12	10.58	12.24
Macro-nutrients (% in DW)				
Ca	1.541	1.57	1.878	1.856
P	0.362	0.265	0.415	0.431
K	0.735	0.723	0.869	0.856
Mg	0.274	0.201	0.093	0.16
Na	0.141	0.171	0.147	0.436
Micro-nutrients (ppm)				
Cu	15.112	8.947	15.224	13.111
Fe	184.83	151.71	201.83	160.57
Mn	<0.001	<0.001	<0.001	<0.001
Zn	12.65	12.681	14.052	14.66

Results are presented 'as is'.

4. Discussion

4.1 Nutrient Composition of M. oleifera and M. ovalifolia

The CP levels were the highest in both *M. oleifera* and *M. ovalifolia* than other parameters in the proximate compositions, followed by NDF, ADF, ash, CF, fat and moisture (See Table 1), which concurs with Fagwalawa, Yahaya and Umar (2014) report that CP was highest in their proximate composition study with *M. oleifera*. Among the two species, *M. oleifera* had higher overall mean value in CP (30.988%) than *M. ovalifolia* (28.68%). Crude protein in both *Moringa* species in this research was higher than 27.1% and 18.49% as reported by Fuglie (2001) and Mutiara, Estiasih and Sriwahyuni (2013), respectively for *M. oleifera*. On the other hand, Fagwalawa *et al*. (2014) reported higher CP (43.53%) value of *M. oleifera* leaves than the current study values. According to Mpofu (2004), CP content of less than 7% is known to limit forage intake and small ruminants performance, which normally occurs during dry months leading to the search for alternative protein sources. The CP content in the both *Moringa* species ranges from 28.86 to 30.988%; thus, making all these species good alternative sources for protein supplements. However, *M. ovalifolia* had higher content of NDF (13.92%), ADF (11.78%) and ash (11.32%) than *M. oleifera*, which makes *M. ovalifolia* a better energy and mineral source. Tisch (2006) explained that structural carbohydrate, measured as NDF, constitute the cell wall of a plant and includes the fiber fractions of cellulose, hemicellulose, lignin and neutral detergent fiber insoluble protein (NDFIP). When a feedstuff's ADF is high, it will be of low digestibility to animals. On the other hand, the nutrient values obtained were higher than those obtained in Nigeria for *M. oleifera* leaves by Ogbe and Affifu (2011). Moisture content of 6.2% and 6.025% in *M. ovalifolia* and *M. oleifera* respectively was lower than the 7.5% reported by Fuglie (2001). Moisture (6.98%) and Fat (4.19%) of *M. oleifera* as reported by Romuald *et al*. (2016) are in agreement with the present study result, but CP (25.8%) was much lower than that reported by Fagwalawa *et al*. in 2014 (43.53%). On the other hand, in the report by Fayomi *et al*. (2014) ash (4.48%), CP (15.93%) values were much lower compared to the values obtained in the current study report, while CF (11.84% against 8.458% and 8.115%) was higher.

The mineral composition of *M. oleifera* and *M. ovalifolia* leaves analysis comprised of Ca, P, F, Mg, Na, Cu, Fe, Mn and Zn and was divided into macro-nutrients and micro-nutrients (See Table 1). Macro-minerals are needed in relatively larger amount in an animal diet while the micro-minerals (trace elements) are needed in very small amount in diets (Jurgens, Bregendahl, Coverdale, & Hansen, 2012). Iron had the highest mean value of 174.7 ppm and 177.10475 ppm followed by Zn (13.51 ppm and 20.49887 ppm) and Cu (13.1 ppm and 15.09338 ppm) with Mn (0.001 ppm and 0.358 ppm) being the lowest for *M. oleifera* and *M. ovalifolia* correspondingly. Iron (28.2) and Cu (0.57) values reported by Fuglie (2001) were lower than the values found in this study (see Table 1). However, Ca, K, Mg and P were higher than those in the current study. For macro-nutrients, Ca (1.711% for *M. ovalifolia* and 1.206% for *M. oleifera*) was higher while P, K, Mg and Na were all < 1% for both species. An elemental composition of *M. oleifera* leaves from Chad reported by Mbailao *et al*. (2014) found similar values to the current study of Na (0.08%), K (1.73%), Ca (1.23%), Mg (0.39%), P (0.32%), Fe (97.12 ppm), Mn (29.33 ppm), Zn (19.14 ppm) and Cu (9.07 ppm), except for Fe and Cu which were much lower compared to the current findings (see Table 1). However, Mn was higher than what was found in that previous work.

M. oleifera leaves had higher TDN content (67%) and ME content (11 MJ/kg) while DE (12 MJ/kg) was equal in both species of *Moringa* (See Table 2), which is higher than 9.2 MJ/kg of ME from an extracted *M. oleifera* leaves reported by Makkar and Becker (1996). Total digestible nutrient had the highest total mean and standard error of the mean (SEM) (64.5% and 4.419% respectively), followed by DE mean (12% MJ/kg) with zero SEM, ME mean and SEM contents (10.5% and 0.177%, respectively). Tannins (tannic acid) content was higher in *M. ovalifolia* leaves (4.4%) than in *M. oleifera* leaves (3.9%) with a total mean of 4.15%, and SEM of 0.044%. The tannins results of this study concurred with the condensed tannins result (3.2%) of *M. oleifera* leaves analysed by Moyo, Masika, Hugo and Muchenje (2010). In addition, Ojiako (2014) study on the quantitative analysis of phytochemical compounds present in the leaf extract of *M. oleifera* shows 8.22% tannins content, which is higher than the values found in this research.

4.2 Comparison of M. oleifera Leaves Nutritional Composition

The proximate composition *M. oleifera* leaves harvested from four blocks (See Table 3) showed that the means of moisture (6.042%), fat (6.912%), ADF (11.263%) and CP (31%) nutrient values were higher for block2, block3 and block4 in comparison to the control block (block1), and reveals a progressive increment as the level of applied fertilizers increased. Contrary, CF (6.15%), ash (10.775%) and NDF (15.725%) were higher in the control block, an indication that *M. oleifera* naturally contains high CF, ash and NDF and hence does not require fertilizer application as discussed by Fuglie (2001). Crude fiber in this study was lower than 11.84% reported by

Fayomi *et al*. (2014); however, CP and ash were higher in this study than what they reported (15.93% and 4.89% against 31% and 10.775%). The moisture and ash contents 6.98% and 8.35% reported by Romuald et al. (2016) from Ivory Coast concur with the results of this study but the CP they reported was lower (25.81% against 31%). For the mineral composition as seen in Table 3, the means of Mg (0.078%), Mn (0.477 ppm), K (0.581%), Cu (15.263 ppm), and Zn (21.01 ppm) nutrient values were higher for blocks where fertilizers were applied in comparison to the control block. Phosphorus (0.2865%), Ca (1.419%), Na (2.1125%) and Fe (181.722%) were higher in the control block, which is an indication that *M. oleifera* naturally contains high levels of P, Ca, Na and Fe. The other hand, the soil readily contains P, Ca and Na that might have been taken by the trees of the control block although Fe was not determined as seen in Table11.

Table 11. Soil nutrients and properties of the moringa orchard

Type of analysis	Units	Sample collection depths	
		0-30 cm depth	30-60 cm depth
pH		7.22	7.67
Electrical Conductivity or Soluble Salts (EC)	uS/cm	80	87
Organic Matter (OM)	%	0.87	0.65
Nitrogen	%		
Phosphorus (P)	ppm	24.60	12.30
Potassium (K)	ppm	295	384
Calcium (Ca)	ppm	572	586
Magnesium (Mg)	ppm	95	107
Sodium (Na)	ppm	5	8
Carbonate (CO_3^{2-})	estimate	None	None
Texture	---	Loamy sand	Loamy sand
Sand	%	84.2	82.1
Silt	%	8.2	9.7
Clay	%	7.6	8.1

Among the four blocks (See Table 4), CP values were almost the same [B3 (30.7), B1 (31.1), B2 (31.1) and B4 (31.2)], which indicates that *M. oleifera* needs little or no inorganic fertilizers to maintain its protein content level. NDF had a declining increase in values as the fertilizer levels increased. This means that the more levels of fertilizers one applies, the lower nutrients it yields. For ADF, block3 had the highest nutrient value (13.175%) which was followed by B4 (10.31%), B2 (10.305%) and B1 (10.055%) respectively. The highest Ash value was found in B2 (11.07), followed by B1 (10.775%), B4 (10.57%) and B3 (10.195%). Ash is the total mineral content of plants or animals (Jurgens *et al*., 2012). The control (B1) had the highest value of Fe (181.7215 ppm), followed by B4 (178.9855 ppm), B2 (175.8% ppm) and B3 (171.932 ppm), consecutively. This implies that *M. oleifera* naturally contains Fe in large quantity and fertilizer application may have little or no effect at all. Interestingly, Zn as the second highest mineral component, increased in values as the levels of fertilizers increased according to blocks, that is, B1 (18.957 ppm), B2 (19.986 ppm), B3 (20.71 ppm) and B4 (22.3425 ppm). This means that an increase in fertilizer levels resulted in an increment in Zn values. Just as Fe, Cu increased randomly in that B2 (16.891 ppm), B3 (14.8595 ppm), B1 (14.585 ppm) and B4 (14.038 ppm). Minerals make up only a relatively small amount of the diet of animals. Nevertheless, they are vital to the animals' diet, their supplementation is required in most situations for high-producing animals (Church, 1991).

The comparison of manured *M. oleifera* leaf proximate composition from four locations of Namibia as shown in Table 5 included parameters such as moisture, ash, fat, CP, CF, ADF and NDF. The Neudamm cultivated field *M. oleifera* leaves had the highest nutrient values in NDF (14.77%) and CP (30.95%), followed by leaves harvested from Neudamm Campus trees in fat (6.81%), CF (9.73%) and NDF (13.88%); leaves from Windhoek City had higher values of moisture (6.3%) and second in CP (29%), while leaves from Rundu (Kaisosi) had the highest content only in NDF (16.39%). For the minerals considered in Table 5, Fe, Zn, Cu and Mn had higher values, and Neudamm Campus trees had the highest Fe (196.843 ppm), followed by those from Rundu, Kaisosi (182.97 ppm), from Neudamm cultivated field (181.7215 ppm) and from Windhoek City (150.5). The highest values for Cu were found in Windhoek City leaves (14.585 ppm), Neudamm cultivated field leaves (12.371 ppm), Rundu, Kaisosi leaves (10.512 ppm) with Neudamm Campus leaves being the lowest (9.4 ppm). Concerning Zn values, Neudamm Campus leaves had 10.596 ppm, Neudamm cultivated field leaves - 18.957 ppm, Windhoek City leaves - 20.5 ppm and Rundu Kaisosi leaves - 20.711 ppm. Minerals such as Ca, P, K, Mg, Na and Mn were very

low in values. On the contrary, *M. oleifera* leaves from Windhoek City had higher Mn values (76.5 ppm) as an outlier while leaves from other locations had < 0.001 ppm Mn values. *Moringa oleifera* leaves from trees found in the four locations of Namibia have quite similar nutrient profiles, which means that location has very little or no impact on moringa nutrient contents.

Moringa oleifera tree is native to India but has been planted around the world and is naturalized in many countries and has very high concentration of nutrients (Fuglie, 2001; Sanchez et al., 2006; Prince, 2007), of which Africa is no exception. The comparison of *M. oleifera* leaves proximate compositions from the four regions of sub-Saharan Africa as seen in Table 8 indicates that moisture ranges from 3.21% to 6.16% with leaves from Nigeria having less moisture percentage than those from Namibia while leaves from Chad had 20.92% moisture content. Leaves from Namibia and Ethiopia had the highest content of ash (13.55% and 13.2% respectively) with those from Chad having the lowest moisture content (6.73%). Leaves from Ethiopia and Namibia had the highest content of fat (6.73% and 5.81% respectively) with those from Chad and Nigeria having 2.11% and 2.34% fat content. Leaves from Chad and Ethiopia had higher CP (32.06% and 28.9%) while those from Namibia and Nigeria had lower CP content (21.9% and 17.01%). Leave crude fiber had similar content across the four regions and was ranging from 7.09% to 9.73% with leaves from Namibia having the highest content and Nigeria, the lowest. Leaves from Namibia had higher contents in ADF (13.88%) and NDF (14.77%) than those from Ethiopia (8.49% and 11.40% for ADF and NDF, respectively). These results were reported by Melesse (2011) from Ethiopia, Ogbe and Affifu (2011) from Nigeria and Mbailao *et al*. (2014) from Chad. Leaves from Namibia had the best in most nutritional values except for fat and CP for which Ethiopia and Chad had higher contents correspondingly. Among the four representative nations, Nigeria had the lowest proximate nutritional values.

Moring oleifera leaves macro-nutrients (Ca, P, K, Mg and Na) and micronutrients (Cu, Fe, Mn and Zn) for the four regions of Africa are found in Table 8. Moringa leaves from Nigeria had the highest content of macro-nutrients such as Ca (1.91%), P (30.15%) and Na (192.95%), while leaves from Chad, Ethiopia and Namibia had quite similar values. Concerning micro-nutrient contents, leaves from Nigeria also had the highest values of Mn (81.65 ppm) and Zn (60.06 ppm); leaves from Namibia had the highest content of Fe (150.5 ppm). On the other hand, leaves from Chad and Namibia had the higher values of Cu (9.07 ppm and 9.4 ppm) respectively, while those from Nigeria had the lowest Cu values. However, moringa leaves from Ethiopia were not analysed for micro-nutrients and therefore had unknown contents of micro-nutrients. The slight differences in mineral composition might be attributed to soil-nutrient compositions at production sites as discussed by Grusak (2001). Interestingly, *M. oleifera* maintains its nutritional values almost at the same level despite regional ecological differences among the four countries.

4.3 Comparison of M. ovalifolia Leaves Nutrient Composition at Treatment Levels

The comparison of *M. ovalifolia* leaf proximate and mineral compositions (See Table 9) revealed that leaves from the control (block1) had higher moisture content (6.37%), ash (12.61%), Fat (6.17%), CP (31.5%), CF (10.08%) ADF (12.87%) and NDF (16.72%) values in comparison to the experimental blocks (block2, block3 and block4). The higher proximate composition of leaves from block1 is a clear indication that *M. ovalifolia* does not need both phosphorus and nitrogen fertilizers to produce quality/nutrient-rich leaf biomass. *Moringa ovalifolia* contains a high level of CP like *M. oleifera* under organic production, which makes it a better alternative feed supplement for animals while avoiding human-livestock conflict and reducing the production/purchase cost. Church (1991) and Tisch (2006) emphasized that protein sources for livestock ration are more expensive than carbohydrate sources and the most costly component of a finished feed. Church (1991) also mentioned that most plant CP sources (beans, alfalfa, coconut, sunflower, and so on) range from 20% to 40+ %, which both *Moringa* species have (CP contents of 31% and 31.5% for *M. oleifera* and *M. ovalifolia* respectively). Between the blocks, Mg (0.078%), Mn (0.477 ppm), K (0.581%), Cu (15.263 ppm), and Zn (21.013 ppm) mineral values were higher in leaves from experimental blocks (blocks 2 to 4) than the values in the leaves from block1(control). However, P (0.2865%), Ca (1.419%), Na (2.1125%) and Fe (181.722 ppm) were higher in block1. These higher mineral values in the leaves of the control block may be attributed to the soil mineral contents (See Table 11).

Moringa ovalifolia seedlings were transplanted in four blocks with four treatment levels: B1 (0 g), block2 (100 g), block3 (200 g) and block4 (300 g) as in the case of *M. oleifera* (See Table 4). The proximate composition (See Table 10) of *M. ovalifolia* leaves at block levels showed that block1 had the highest values in ash (12.61%), CP (31.5%), CF (10.08%), ADF (12.87%) and NDF (16.72%). Leaves from block2 had the second highest content of moisture (6.47%), ash (12.45%), CP (9.16%) and NDF (16.12%); followed by leaves from block3 fat content (6.48%), CF content (7.78%) and ADF content (12.85%), while leaves from block4 had the lowest CF

(7.935%) and NDF (11%) values respectively. The high nutrient values in leaves from block1 is an indication that *M. ovalifolia,* like its counterpart *M. oleifera* is a nutrient-rich plant source with less demand in fertilizers and can serve as a perfect supplement for ruminants. In addition, CF showed declining nutrient values as the fertilizer levels increased (block1 =10.08, block2 = 9.16, block3 = 7.78 and block4 = 6.81). Since leaves from the control block had the highest content of nutrients besides Fat and moisture, it is evident that *M. ovalifolia* can be grown without phosphorus and nitrogen fertilizers and maintain high nutrient content for use as an animal supplement as suggested by Fuglie (2001).

Among minerals as found in Table 10, only Fe, Cu and Zn were found in large quantities while Ca was < 2%; K, Mg, Na and P were < 1% and Mn was < 0.001 ppm for all blocks (B1, B2, B3 and B4). Leaves from block three (B3) had the highest mineral composition with Fe (201.827 ppm) and Cu (15.224 ppm); followed by B1 in which Fe (184.834 ppm) and Cu (15.112 ppm) were the highest micro-nutrients. Leaves from B4 only had the highest content in Zn (14.66 ppm), while those from B2 had the lowest elements. Zinc had increasing values as the fertilizer levels increased: B1 = 12.65%, B2 = 12.681%, B3 =13.052% and B4 = 14.66% respectively. This implies that Zn composition could be dependent on the levels fertilizers.

5. Conclusion

Moringa plant species are nutritious and contain almost all the essential nutrients needed by humans and livestock for growth and development. Substantial amount of macro- and micro-nutrients were found in both *Moringa* species making it fit to be used as feed supplements. Their proximate composition showed desirable nutrients for the formulation of animal feeds. Although there is a possible human-livestock conflict in the use of *M. oleifera*, if adopted by livestock farmers, both *M. oleifera* and *M. ovalifolia* have the potential to eliminate the purchasing of animal feed supplements since they contain all the essential nutrients. This problem can be solved by replacing *M. oleifera* by *M. ovalifolia* (for which there in no competition) as an animal feed supplement. Thus, it will improve livestock production as it will be readily available on the farm for supplementation during winter and drought periods when grasses and browses in rangelands have low nutritional values. *Moringa oleifera* leaves maintain their nutritional values despite the geographical or ecological differences in its cultivation (no data are available for *M. ovalifolia*). Therefore, the cultivation of *Moringa* as a nutrient-rich plant species should be encouraged, and its uses and benefits as a food and/or feed for humans and "livestock improvement".

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