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Proximate, physical and chemical composition of leaves and seeds of Moringa (*Moringa oleifera*) from Central Malawi: A potential for increasing animal food supply in the 21st century

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The nutritive composition of Moringa (*Moringa oleifera* Lam) leaves and seeds were evaluated for their possible inclusion in livestock feed formulation because of the limited availability of conventional protein concentrates like soybean (*Glycine max)* seeds. Moringa seeds contained 50.70 g kernels and 19.03 g hulls per 100 seeds representing 72.71 and 27.29% as a fraction of the whole seed, respectively. The 100 seeds contained 28.48 and 20.71% oil as a fraction of kernels and seeds, respectively. Moringa leaves had 22.60±0.17% crude protein, 11.24±0.17% ash, 13.40± 0.25% crude fat, 8.07±0.17% crude fiber and 44.69±0.41% carbohydrates. The seeds revealed 28.56±0.41% crude protein, 5.37±0.11% ash, 34.92±0.17% crude fat, 7.90±0.27% crude fiber and 23.27±0.65% carbohydrates. Raw kernel recorded 37.86±0.38% crude protein, 4.60±0.13% ash, 41.18±0.06% crude fat, 4.80±0.23% crude fiber and 11.55±0.37% carbohydrate whereas roasted kernel registered 38.25±0.32% crude protein, 5.36±0.19% ash, 41.06±0.14% crude fat, 6.55±0.34% crude fiber and 8.78±0.60% carbohydrate. Raw kernel meal registered the highest calculated gross energy of 5.6±0.0 Mcal/kg DM and metabolisable energy of 4.4±0.0 Mcal/kg DM, compared to seed and leaves meals. The calculated fatty acid (g/kg DM) was the highest (329.5±0.5) in raw kernel compared to 107.2±2.0 in leaves, 279.3±1.4 in seed and 328.5±1.1 in roasted kernel meal. Titratable acidity (as oleic acid) ranged from 0.36±0.0 at pH 6.42±0.0 to 3.8±0.0 at pH 6.35±0.0 for raw kernel and leaves meal, respectively. Phosphorus concentration (mg/100 g DM) ranged from 427.6±0.0 to 873.9±0.0 for leaves and raw kernel meals. This research indicated that both seeds and leaves are rich in nutrients and could be potential replacements of conventional livestock feed ingredients to ease the feed/food crises in Malawi.

Key words: Moringa (*Moringa oleifera*), raw kernel, roasted kernel, crude protein, livestock production, Malawi.

INTRODUCTION

Global demand for livestock products is expected to increase due to escalating population growth, emerging economies and urbanization by 2050 (Thornton, 2010). Human population is expected to reach 9.6 billion with that of developing countries, Malawi inclusive, increasing five times by 2050. Human population in emerging worlds

would rise to 8.2 billion by 2050 reaching 9.6 billion by the 21st century (UNPD, 2012). The escalating human population coupled with urbanization and improved income may increase demand for food of animal origin such as meat (Thornton, 2010; Thewis and Galis, 2012) to 12 million metric tons (MMT) from 5 MMT in the duration of 17 years by 2020 in sub-Saharan Africa (SSA) (Delgado et al., 1999). The exploding demand for animal products will surge global livestock production (Thornton, 2010) with a consequent annual and total global increase of cereal animal feed to 292 and 928 MMT from 1993 to 2020 (Delgado et al., 1998; Delgado et al., 1999). Milk and meat consumption is universally projected to reach 880 and 452 MMT with that of developing countries projected to be 326 and 585 MMT by 2050 (FAO, 2006). Annual cereal consumption as animal feed in SSA by 2020 is estimated to be 4 MMT representing a 2.3% growth rate (Delgado et al., 1998) surging prices of cereals and legumes such as maize (*Zea mays* L.) and soybean (*Glycine max*) (Thornton, 2010; Thewis and Galis, 2012).

Furthermore, global warming is expected to both positively and negatively affect the production of crops resulting in 10 to 20% crop yields reduction in the tropics and sub-tropics by 2050 (Jones and Thornton, 2003). Cereal production, in SSA, would decline by 3.2% due to global warming resulting in 4.0% increase in maize price by 2050 (Ringler et al., 2010). Maize productivity which is a staple food for many SSA countries, Malawi inclusive, may decline by 10% (Hellin et al., 2012) and 22% (Schlenker and Lobell, 2010) reaching an average price of 4.0% by 2050 (Ringler et al., 2010). The scarcity and high prices of cereals and grain legumes like maize and soybean would be expected to increase animal products prices (Thewis and Galis, 2012).

Therefore, seeds and leaves of tropical and sub-Saharan plants could be investigated for the possibility of their inclusion in feed formulation to meet up with demand for animal products of the global surging population, urbanization and improved income. One of these tropical and SSA plants is Moringa (*Moringa oleifera* Lam). Moringa grows well in both acidic and alkaline soils and is drought resistant (Mughal et al., 1999). Moringa tree grows in humid and hot, dry tropical and subtropical regions (Sultana et al., 2015). It grows from about 5 to 15 m (Somali et al., 1984) with slender and droopy branches (Siddhuraju and Becker, 2003). *M. oleifera* is a fast growing tree with feathery foliage and innate leaves (Rolof et al., 2009). Moringa leaves, pods and seed are used as vegetables and oil extraction, respectively (Rebecca et al., 2006). It is reported that Moringa leaves have 23.61% crude protein (Abou-Elezz et al., 2011) and 4.50±0.10% crude fat observed in Nigeria (Offor et al., 2014). *M. oleifera* seeds contain 300 g/kg crude protein (Madubuike et al., 2015) and 348 g/kg oil (Anwar and Rashid, 2007). Research has been conducted to study the effects of Moringa leaf meal on the growth of layer chicks, productivity of layers and growth of broiler chicks (Olugbemi et al., 2010; Abou-Elezz et al., 2011; Melesse, 2011).

However, there is a paucity of information on the nutritive value of seeds and leaves of *M. oleifera* cultivated in Malawi for its inclusion in livestock feed formulation. Therefore, this study was conducted to analyze the proximate and chemical composition of *M. oleifera* seeds and leaves meal with an objective of addressing food/feed crisis in Malawi.

MATERIALS AND METHODS

M. oleifera sampling and sample preparation

M. oleifera L. leaves and seeds were collected from Mr. Goodson Dawa's house, who resides in the area surrounding Bunda in Lilongwe district. The leaves and seeds were sundried at temperatures above 37°C for 36 and 8 h, respectively (Brennand, 1994; Ahmed, 2013) and some of the seeds were dehulled for further analyses of kernels (Figure 1). Some of the kernels were roasted in the oven, at 130°C for 30 min (Adeyeye, 2010), to evaluate heat effects on the nutrient contents. The sundried leaves, raw kernels, roasted kernels and seeds were ground through a 1 mm sieve using a Thomas-WILEY model 4 Laboratory Mill before analyzing the chemical properties.

Moringa physical characteristics determination

The seeds were evaluated for weight and oil content whereby 100 seeds were randomly selected, thoroughly cleaned and weighed on a JP-2000 electronic balance to the nearest 0.01 g. The 100 clean seeds were dehulled and the kernels and hulls were weighed on the same JP-2000 electronic balance. *M. oleifera* dimensional axes were measured by an electronic digital Vernier Caliper with an accuracy of 0.02 mm. The arithmetic (Da) mean, geometric (Dg) mean and sphericity (Ø) of the kernel were calculated using the following equations (Mohsenin, 1986).

$$Da = L + W + T / 3 \quad (1)$$

$$Dg = (LWT)^{\frac{1}{3}} \quad (2)$$

$$\emptyset = (LWT)^{\frac{1}{3}}/L \quad (3)$$

where L is the length of the kernel, W is the width of the kernel, T is the thickness of the kernel, and Ø is the sphericity of the kernel.

Chemical determination

The ground samples were used to analyze for proximate

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Figure 1. A: *Moringa oleifera* seeds, B: *Moringa oleifera* hulls, C: *Moringa oleifera* kernels.

composition: dry matter (DM), ash, crude protein, crude fat and crude fiber using AOAC (1996) methods. Chemical analyses like titratable acidity as oleic acid, pH and phosphorus (P) were also analyzed from the ground samples.

Determination of dry matter content using oven drying method

Dry matter was determined by drying the samples in a laboratory drying oven at 105°C for 5 h. The crucibles were thoroughly washed, dried in the oven, cooled in a desiccator and weighed. 2.5 g of the sample was weighed into the crucible and dried to constant weight. The dry matter in percentage was calculated as the fraction of the original dry weight multiplied by 100 (AOAC, 1996).

Determination of ash content using muffle furnace

Ash content was determined by igniting 2.5 g of the samples, weighed in crucibles, in the muffle furnace at 550°C for 2 h. The amount of ash content in percentage was calculated as follows (AOAC, 1990):

$$\% \, Ash = \left[{}^{Wa \, - Wt}/_{Wo \, - Wt} \right] \times 100 \quad (4)$$

where W_0 is the weight of crucible and sample before igniting the sample, W_a is the weight of crucible and ash and W_t is the weight of crucible only.

Determination of crude protein using micro-Kjeldahl method

Nitrogen (N) content of the samples was analyzed by using micro-Kjeldahl method and the N content was converted to CP by multiplying by 6.25. The method involves digestion of the samples in concentrated (98%) sulphuric acid, distillation of the digests into weak acids (4% boric acid) and titration of the distillates with 0.1 M hydrochloric (HCl) acid using mixed indicator (Methyl and Bromocresol green) as an indicator (AOAC, 1990).

Determination of crude fat content

Crude fat was analyzed by extracting 2.5 g of the sample weighed in porous extraction thimbles by using petroleum ether in a soxhlet apparatus for 16 h. The soxhlet apparatus was equipped with a water cooled condenser fitted above the 250 ml flat bottomed flask containing petroleum ether as fat solvent. The solvent was boiled at 40°C and fat content was calculated as a percentage of the dry weight of the sample (AOAC, 1996).

Determination of crude fiber content

Crude fiber was determined by boiling 2.0 g of the samples in 200 ml of weak sulphuric acid (1.25%) and sodium hydroxide (1.25%), with few drops of anti-foaming agents being added, for 30 min. The residues were filtered and washed three times with hot water, then washed with 95% ethanol and dried at 105°C for 5 h to constant weight. The dried residues were ignited in a muffle furnace at 550°C for 2 h. The crude fiber in grams was calculated as the difference between the weight of the residues and ash and converted as a fraction of the sample weight in percentages (AOAC, 1990).

Determination of carbohydrate content by difference

Carbohydrates were calculated by difference using the following formulae (AOAC, 1990):

$$100 \, \% - (CP \, \% + CF \, \% + Crude \; fat \, \% + Ash \, \%) \quad (5)$$

Determination of titratable acidity

Titratable acidity (TA) was determined by dissolving 2.0 g of the sample in 100 ml of distilled water which was titrated with 0.1 M NaOH using phenolphthalein as an indicator. TA was calculated per 100 g of the sample and was converted to oleic acid per 100 g DM sample by multiplying by the molecular mass of 0.282 g as follows (AOAC, 1999, 1996):

$$TA \; (g \; 100^{-1} \; g \;) = \left[{}^{V_{NaOH} \; \times M_{NaOH} \; \times 0.282}/_{2.0} \right] \times 100 \quad (6)$$

where V_{NaoH} and M_{NaoH} are volume (titre volume) and molarity of sodium hydroxide, respectively.

Determination of pH using pH meter

In determination of pH, 2.0 g of the sample was dissolved in 100 ml of distilled water and the pH was measured by using GLP pH meter at 25°C (AOAC, 1999).

Table 1. Physical characteristics of *Moringa oleifera* Lam seed.

Parameter	Value
Weight of whole seed (kernel + shells) g/100 seeds	69.73
Weight of kernels g/100 seeds	50.7
Kernel fraction (% of whole seed)	72.71
Shell fraction (% of whole seed)	27.29
Oil fraction (%w/w of kernel)	28.48
Oil fraction (%w/w of seed)	20.71

Phosphorus determination using UV- Vis spectrophotometer

Phosphorus was determined by weighing 1.0 g of each sample in porcelain crucibles which were ignited in a muffle furnace at 550°C to constant weight. The ash was dissolved in 3 ml of 3 M hydrochloric (HCl) acid, filtered and diluted to the 100 ml mark in a volumetric flask (Ogungbenle and Atere, 2014). 1 ml of the diluted filtrate was pipette into a 20 ml vials, 2 ml of ammonium molybdate-ascorbic was added and diluted to 10 ml with distilled water. Standards were prepared by pipetting 0.0, 0.2, 0.3, 0.4 and 0.5 ml of the stock solution into the 20 ml vial, 2 ml of ammonium molybdate-ascorbic solution was added and was diluted to 10 ml with distilled water. The absorbance of the solutions were measured after 1 h of color development and absorbance was measured at 860 nm wavelength using DR 5000 WAGTECH projects ultra-violet visible spectrophotometer (AOAC, 2005; Habib et al., 2015).

Fatty acid calculation

Calculated fatty acid in mass per kg of the sample was computed by multiplying crude fat values by a factor of 0.8 (Aremu et al., 2013).

Gross energy calculation

Gross energy (GE) in kJ/100 g DM was calculated by multiplying the values of CP, crude fat and carbohydrate by the factors of 17, 37 and 16 kJ/100 g DM, respectively (Dalziel, 1955; Osborne and Voogt, 1978). The calculated GE (kJ/100 g) was converted to kcal/100 g DM by dividing by a factor of 4.184 (Butcher et al., 2006) and the Kcal/100 g DM was converted to Mcal/100 g DM dividing by 1000 and finally Mcal/100 g was converted to Mcal/kg DM by multiplying by a factor of 10.

Metabolisable energy calculation

Metabolisable energy (ME) in MJ/kg DM was calculated by using the regression equation of Ellis (1981):

$$ME\ (MJ\ kg^{-1}) = 1.549 + 0.0102\text{CP} + 0.0275\text{Oil (crude fat)} + 0.0148\ \text{Carbohydrate} - 0.0034\text{CF} \quad (7)$$

where CP = crude protein, CF = crude fiber. The calculated ME in MJ/kg DM was then converted to Mcal/kg DM by dividing by a factor of 4.184 (Butcher et al., 2006).

Chemical data statistical analysis

Laboratory chemical analyses were done in triplicate and the mean value of each chemical parameter was calculated using Microsoft excel. The data was statistically analyzed by using analysis of variance (ANOVA) in Microsoft Excel ToolPak. Two sample T-test with unequal variances was used to compare mean values and significance was accepted at $P \leq 0.05$ level.

RESULTS AND DISCUSSION

Physical characteristics of seeds and kernels

The physical characteristics of *M. oleifera* seeds and kernels are shown in Tables 1 and 2. 100 *M. oleifera* seeds weighed 69.73 g. The 100 seeds contained 50.70 g kernels and 19.03 g hulls representing 72.71 and 27.29% as a fraction of the whole seed, respectively. In Tanzania, the same amount of *M. oleifera* seeds weighed about 29.6 to 30.2 g with 72.5 and 27.5% representing the fractions of kernels and hulls, respectively (Proyecto, 1996) which was in close correlation with results reported in this study. The physical characterization revealed that 100 g of Moringa seeds and kernels contained 20.71 and 28.48 g of oil, respectively.

The oil content in seeds observed in this study was lower than 38.33±0.65 g oil per 100 g of seeds observed in *Moringa peregrina* (Salaheldeen et al., 2014). The variations in the oil content between *M. oleifera* and *M. peregrina* species could be attributed to species and climatic conditions of the area of their cultivation (Yang et al., 2006).

M. oleifera physical parameters are significant in designing oil expellers, harvesting, processing and transportation machines (Ajav and Fakayode, 2013; Adesina et al., 2013). Moringa kernel length, width and thickness were 7.39±0.40, 6.92±0.47 mm and 6.16±0.56 mm, respectively. The arithmetic and geometric mean diameters were 6.82±0.35 and 6.79±0.35 mm with sphericity mean percentage of 92.08±3.88 mm. Moringa seed kernels have been reported to be 9.22±0.76 mm long, 8.43±0.59 mm wide and 7.42±0.85 mm thick (Adesina et al., 2013). The arithmetic and geometric means of Moringa seeds have been reported to be 7.56±0.87 and 7.49±0.88 mm with mean sphericity value of 88.8±5.2% (Ajav and Fakayode, 2013). The sphericity value of92.08±3.88 mm was comparably similar to 90.37±5.69 mm (Adesina et al., 2013) reported in Nigeria. The proximate composition of *M. oleifera* L. leaves, seed, raw kernel and roasted kernel meals in percentages are shown in Table 3. The results revealed that Moringa products are good sources of crude protein, crude fat, crude fiber and minerals in the form of ash.

Moringa dry matter content

Moringa leaves meal dry matter (DM) content was lower ($P < 0.05$) than that of seed, raw kernel and roasted kernel meals. The DM content in leaves meal was in agreement with 94.0, 93.07 and 93.09% for early, mid

Table 2. Physical characteristics of *Moringa oleifera* Lam seed kernels.

Physical property	N	Minimum	Maximum	Mean
Length (mm)	100	6.54	8.26	7.39±0.40
Width (mm)	100	5.98	8.11	6.92±0.47
Thickness (mm)	100	4.80	7.42	6.16±0.56
Arithmetic mean diameter (mm)	100	5.96	7.62	6.82±0.35
Geometric mean diameter (mm)	100	5.90	7.61	6.79±0.35
Sphericity mean %	100	81.99	98.65	92.08±3.88

Table 3. Proximate composition of *Moringa oleifera* L.

Sample	DM (%)	CP (%)	Ash (%)	Crude fat (%)	CF (%)	Carbohydrate (%)
Leaves	93.78±0.07^{a}	22.60±0.17^{a}	11.24±0.15^{a}	13.40±025^{a}	8.07±0.17^{a}	44.69±0.41^{a}
Seed	96.86±0.30^{b}	28.54±0.41^{b}	5.37±0.11^{b}	34.91±0.16^{b}	7.90±0.27^{a}	23.27±0.65^{b}
Raw kernel	97.40±0.43^{b}	37.86±0.38^{c}	4.60±0.13^{c}	41.18±0.06^{b}	4.80±0.23^{b}	11.55±0.37^{c}
Roasted Kernel	99.72±0.07^{c}	38.25±0.32^{d}	5.36± 0.19^{b}	41.06±0.14^{b}	6.55±0.34^{c}	8.78±0.60^{d}

DM: Dry matter, CP: crude protein, CF: crude fibre. For each parameter, means with same superscript were not significantly different (P>0.05).

and late maturity stage Moringa leaves observed in the previous study (Bamishaiye et al., 2011), whereas the DM value for seed meal was lower than 97.40±0.43% for raw kernel meal in this study.

Ash content

The total ash content (% DM) ranged from 4.60±0.13 to 11.24±0.17% for raw kernel and leaves meal, respectively. In this study, ash content for leaves meal was almost twice (P< 0.05) that of seed, raw kernel and roasted kernel meals, respectively. The ash content for seed meal of 5.37±0.11% was comparable to 4.5% for oil extracted seed meal (Abbas, 2013) and 5.06±0.03% (Barakat and Ghazal, 2016) reported in Sudan and Egypt but higher than 4.10±0.14% from another study in Nigeria (Abiodun et al., 2012). Moringa leaves meal ash value of 11.24±0.15% was higher than 5.7, 8.00 and 9.25% for early, mid and late maturity stage leaves observed in Nigeria (Bamishaiye et al., 2011). The ash values for leaves meal, seed meal, raw kernel and roasted kernel meals were higher than those of pigeon peas (*Cajanus cajan*) (3.2%) observed in Sudan (Eltayeb et al., 2010) and 4.6 and 4.0% for NRC-35 and JS446 genotype *G. max* L. seeds (Jain and Jain, 2010). The high mineral ash content observed from *Moringa* species growing in Malawi means the leaves and seed meal could be used in formulating livestock feed for body tissues functioning and health.

Crude protein content

Crude protein values ranged from 22.60±0.17 to 38.25±0.32% for leaves and roasted kernel meals, respectively. The raw and roasted kernel meals, in this study, had the highest (P<0.05) crude protein content compared to leaves meal and seed meal. The crude protein content for seed meal of 28.54±0.41% was lower than 31.65±1.20% obtained in another study (Anwar and Rashid, 2007) but closely similar to 28.04±0.67% (Abiodun et al., 2012) and 30.06% (Madubuike et al., 2015) observed in another study in Nigeria. Moringa leaves meal revealed crude protein value of 22.67±0.09% which was closely similar to 23.61% (Abou-Elezz et al., 2011) and 24.20±0.90% (Offor et al., 2014) observed in previous studies. However, this value was lower than 26.5% (Kakengi el al., 2003) and 27.4% (Olugbemi et al., 2010) but higher than 10.71±0.81% (Amabye and Gebrihiwot, 2015) observed in Ethiopia.

The crude protein content for leaves meal was higher than 21.0% for *C. cajan* reported in Sudan (Eltayeb et al., 2010) but lower than 24.70±0.10 and 26.10±0.09% for cow pea and lentil (Iqbal et al., 2005). The crude protein values for seed meal were higher than that of cowpea and lentil (Iqbal et al., 2005) but closely similar to 32.18 and 32.81% for NRC-37 and JS-335 genotype *G. max* seed (Jain and Jain, 2010).

Raw kernel meal crude protein value of 37.86±0.38% was closely similar to 38.25±0.32% for roasted kernel meal in this study. Crude protein value for raw kernel meal was closely similar to 36.7% observed in another study in Sudan (Abbas, 2013) but lower than 51.8% observed in Sudan (Ochi et al., 2015). Both raw and roasted kernel meals had higher crude protein values than 36.6±0.70% for soybean (*G. max* L.) seed (Siulapwa and Mwambungu, 2014). The differences in crude protein values from those reported in previous studies could be

due to agro-climatic conditions of cultivation, Moringa trees ages and differences in the stage of maturity of the leaves and seeds. Mature leaves and seeds tend to contain higher crude protein values than young ones (Yang et al., 2006).

Crude fat content

Crude fat ranged from 13.40±0.25 to 41.18±0.06% for leaves and raw kernel meal, respectively. The roasted and raw kernel meals had comparably similar crude fat values which were higher than that of seed and leaves meals ($P<0.05$), respectively. The crude fat value of 13.40±0.25% for the leaves meal was higher than 4.50±0.10% observed in Nigeria (Offor et al., 2014). The crude fat content for raw kernel meal of 41.18±0.06% was closely similar to 41.7% reported in Sudan. The seed meal crude fat value of 34.92±0.17% was closely similar to 34.80% observed in Sudan (Anwar and Rashid, 2007) but lower than 40.0% reported in Nigeria (Aja et al., 2013). The variations in crude fat content could be attributed to the cultivated variety, climatic conditions and maturity stage (Yang et al., 2006). The observed crude fat values were all higher than that of *C. cajan* (4.8±0.07%), chickpea (*Cicer arietinum*, 5.2±0.01%) and lentils (*Lens culinaris*, 3.2±0.06%) (Iqbal et al., 2005). The high crude fat content in *M. oleifera* leaves, seed and kernel means that they could be used in livestock feed formulation as a source of lipids besides contributing to the energy value of the feed.

Crude fiber content

Crude fiber values ranged from 4.80±0.23 to 8.07±0.17% with seed meal recording the highest ($P<0.05$) and raw kernel meal the lowest value ($P<0.05$). The crude fiber content observed in seed meal was higher than 5.00±0.0% (Adegbe et al., 2016) and lower than 9.94% (Madubuike et al., 2015), 10.92±0.52%, 12.16±0.26% and 11.05±0.61% (Barakat and Ghazal, 2016) observed in Egypt but closely in agreement with 7.73±0.35% (Abiodun et al., 2012) and 6.84±0.42% (Siyanbola et al., 2015) for Moringa seed meal analyzed in Nigeria. Moringa leaves meal crude fiber value was lower than 17.3±0.20% reported in another study (Offor et al., 2014) but closely similar to 8.20±0.01% (Bamishaiye et al., 2011) and 8.51% (Melesse, 2011) for mid stage Moringa leaves grown in Nigeria and observed in Ethiopia. The observed crude fiber values were higher than 3.25 and 3.55% for NRC-37 and JS-335 genotype *G. max* seeds (Jain and Jain, 2010).

Carbohydrates content

Carbohydrate values ranged from 8.78±0.60 to 44.69±0.41% for roasted kernel and leaves meals, respectively (Table 3). The leaves had the highest ($P<0.05$) carbohydrate values compared to seed, raw kernel and roasted kernel meals. The carbohydrate value for seed meal was higher than 12.44±0.53% (Siyanbola et al., 2015), 3.93% (Madubuike et al., 2015) and 10.59±0.22% for Moringa flour (Abiodun et al., 2012) and lower than 56.42±0.72% (Orhevba et al., 2013) but closely similar to 20.03±1.56, 19.0±0.65 and 20.29±3.15% for *M. oleifera* seeds analyzed in Egypt (Barakat and Ghazal, 2016). Moringa raw kernel meal carbohydrate value of 11.55±0.37% was lower than 15.5% observed in Sudan (Ochi et al., 2015).

Moringa leaves meal carbohydrate value of 44.69±0.41% was lower than 64.87±0.18% (Adeyemi et al., 2014) and 57.61±2.19% (Amabye and Gebrehiwot, 2015) observed in Nigeria and Ethiopia but closely in agreement with 45.71% (Olugbemi et al., 2010). The differences in the nutrient values observed in this study and those of other previous studies with respect to region of growth could be attributed to environmental climate, soil fertility and plants strain (Chadare et al., 2009; Osman, 2004). The high nutrient content in *M. oleifera* means that it could be another source of protein, fat and minerals in livestock feed formulation in Malawi to ease the feed/food crisis and improve livestock production because of the lower cost of *M. oleifera* than that of conventional feeds like *G. max* meal. The crude fiber and carbohydrate values observed in this study would facilitate easy movement of food/feed bolus besides lowering constipation in the livestock intestines if they were included in feed formulation (Wasagu et al., 2013).

Energy and chemical content

The energy and chemical composition values of *M. oleifera* leaves, seed, raw kernel and roasted kernel meals are shown in Table 4.

Gross energy content

The calculated gross energy (GE) values in Mcal/kg DM ranged from 3.8±0.0 to 5.6±0.0 for leaves meal and raw kernel meal, respectively. Moringa raw kernel meal had 5.6±0.0 higher ($P<0.05$) gross energy value than 5.5±0.0, 5.1±0.0 and 3.8±0.0 for roasted kernel, seed and leaves meal, respectively. The gross energy value for leaves meal was higher than 3.0 observed in Tanzania (Olugbemi et al., 2010), but lower than 4.5 reported in Mexico (Abou-Elezz et al., 2011). However, the gross energy value for leaves meal was in close agreement with 3.7±0.04 (Amabye and Gebrehiwot, 2015). The gross energy for seed meal of 5.1.0±0.0 was closely similar to 4.5±0.4 observed in Egypt (Barakat and Ghazal, 2016). Moringa raw kernel meal and roasted kernel meal gross energy values were in close agreement

Table 4. Chemical composition of *Moringa oleifera* L.

Sample	Gross energy (Mca/kg DM)	ME (Mca/kg DM)	Fatty acids (g/kg DM)	pH	Titratable acidity (g/100 g oleic acid)	Phosphorus (mg/100 g DM)
Leaves	3.8±0.0[a]	3.3±0.0[a]	107.2±2.0[a]	6.35±0.0[a]	3.8±0.0[a]	427.6±33.9[a]
Seed	5.1±0.0[b]	4.1±0.0[b]	279.3±1.4[b]	6.26±0.0[b]	1.7±0.0[b]	599.5±4.5[b]
Raw kernel meal	5.6±0.0[c]	4.4±0.0[c]	329.5±0.5[c]	6.42±0.0[c]	0.4±0.0[c]	873.8±6.9[c]
Roasted kernel meal	5.5±0.0[d]	4.3±0.0[c]	328.5±1.1[c]	5.44±0.0[d]	1.2±0.0[d]	754.1±23.0[d]

ME: Metabolisable energy. For each parameter, means with same superscript were not significantly different (P>0.05).

with 6.4 observed in Khartoum, Sudan.

Metabolizable energy content

Metabolizable energy (ME), in Mcal/kg DM, ranged from 3.3±0.0 to 4.4±0.0 with raw kernel meal recording the highest and leaves meal the lowest values. Moringa raw and roasted kernel meals had 4.4±0.0 and 4.3±0.0 ME values higher (P< 0.05) than 3.3±0.0 and 4.1±0.0 for leaves meal and seed meal in this study. However, ME value for leaves meal was closely similar to 3.0 (Olugbemi et al., 2012) reported in Tanzania but higher than 2.2 observed in another study in Ethiopia (Melesse, 2011). The ME value for seed meal was higher than 1.8 observed in another study for Indian oil extracted seeds analyzed in Tunisia (Salem and Makkar, 2008). Moringa raw kernel meal ME value was higher than 3.4 reported by Ochi et al. (2015). ME values observed in this study were relatively higher than 2.7 for *G. max* L. (Siulapwa and Mwambugu, 2014) observed in Zambia. The relative high GE and ME values for kernel meals followed by seed meal indicated that *M. oleifera* products are concentrated sources of energy for livestock production and Moringa seeds and leaves could be potential alternatives of conventional livestock feed ingredients in Malawi.

Chemical composition

pH values

The pH values ranged from 5.44±0.0 to 6.42±0.0 for Moringa roasted kernel and raw kernel meal, respectively. The seed meal pH of 6.26±0.0 indicated that *M. oleifera* seeds are more acidic (P<0.05) than leaves and raw kernel meals with pH values of 6.35±0.0 and 6.42±0.0 in this study. The study indicated that roasted kernel meal had the highest acid content with relative to Moringa leaves, seeds and raw kernel meals.

Titratable acidity values

Titratable acidity, in g/100 g DM (as oleic acid), ranged from 0.36±0.0 to 3.8±0.0 for raw kernel and leaves meals, respectively. The titratable acidity of leaves meal of 3.8±0.0 was the highest (P<0.05) followed by seed meal, roasted kernel meal and raw kernel meal, respectively.

Fatty acids content

Calculated fatty acid, in g/kg DM, ranged from 107.2±2.0 to 329.5±0.5 for Moringa leaves and raw kernel meals, respectively. Moringa raw kernel meal had the highest (P<0.05) fatty acid followed by roasted kernel, seed and leaves meals, respectively.

Phosphorus content

Phosphorus (P) content, in mg/100 g DM, ranged from 427.6±0.0 to 873.9±0.0 for leaves and raw kernel meals respectively (Table 4). Moringa raw kernel meal had the highest (P<0.05) phosphorus content compared to leaves, seed and roasted kernel meals in that sequence. The seed meal revealed phosphorus content of 599.5±0.0 whereas roasted kernel meal registered a value of 754.1±0.0. The leaves meal phosphorus content of 427.6±0.0 was almost twice higher than 240 (Abou-Elezz et al., 2011) reported in previous studies but closely correlated to 430 (Melesse, 2011) analyzed in Ethiopia. Seed meal revealed phosphorus content of 599.5±0.0 lower than 738.15±9.71, 753.31±3.31 and 705.27±10.82 observed in Egypt (Barakat and Ghazal, 2016) but higher than 619 (Kawo et al., 2009) reported in Nigeria. Phosphorus content in raw kernel meal was 873.9±0.0 higher than 535 (Ochi et al., 2015) and 754.1±0.0 for roasted kernel meal observed in this study. Leaves and seed meals phosphorus values were lower than 960±1.0 for *G. max* L. (Siulapwa and Mwambugu, 2014). However, raw and roasted kernel meal phosphorus content was comparable to 960±1.0 for *G. max* L. (Siulapwa and Mwambugu, 2014) observed in Zambia.

Conclusion

The results showed that the species of *M. oleifera* grown

in central Malawi have nutritional potential for inclusion in animal feed because the leaves and seeds contained a high concentration of nutrients in the form of crude protein, crude fat, crude fiber, nitrogen free extracts, and total minerals and energy compared to conventional feed ingredients. Moringa kernels have higher concentration of nutrients than the whole seeds and leaves. The presence of more mineral elements in *M. oleifera* leaves and seed than in conventional feed ingredients such as *G. max* and *C. cajan* means Moringa products are suitable for livestock and human consumption. Therefore, smallholder livestock farmers in Malawi could be encouraged to use Moringa seeds and leaves in livestock feed formulation.

However, in the future Moringa plant samples from different districts in Malawi should be collected for *in vivo* digestibility trials to investigate the effect of including Moringa products in livestock feeds on growth, weight gain and productivity.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest

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