Journal of Agricultural Science; Vol. 9, No. 7; 2017
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Proximate Composition, Amino and Fatty Acid Profiles and Element Compositions of Four Different *Moringa* Species

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Received: March 15, 2017 Accepted: May 20, 2017 Online Published: June 15, 2017

doi:10.5539/jas.v9n7p46 URL: https://doi.org/10.5539/jas.v9n7p46

Abstract

Several species of trees belong to the genus *Moringa,* but only one, *Moringa oleifera* (Lam.), has been intensively studied. No data has been published so far on the nutritional properties of *M. stenopetala*, *M. drouhardii* or *M. hildebrandtii*. In this study, kernels and leaves of *M. oleifera*, *M. stenopetala*, *M. drouhardii* and *M. hildebrandtii* have been analysed for their protein, fat, amino acid, fatty acid and macro- and microelements and discussed in relation to the known nutritional requirements of a young child. This study suggests that *Moringa* leaves, especially those of *M. oleifera*, are a suitable source of amino acids, vitamins and several elements but not for lipids and fatty acids. *Moringa* kernels are less suited as vegetable but are a suitable source for oils with *M. oleifera* seeds showing the best kernel to shell ratio.

Keywords: *Moringa* spp., leaf, kernel, nutrient composition

1. Introduction

The family Moringaceae is monogeneric, with medium sized trees belonging to 13 species of the genus *Moringa* (Leone et al., 2015). Most of those species are indigenous to Africa (11 species: *Moringa arborea* (Verdc.), *M. rivae* (Chiov.), *M. borziana* (Mattei), *M. pygmaea* (Verdc.), *M. longituba* (Engl.), *M. stenopetala*, *M. ruspoliana* (Engl.), *M. ovalifolia* (Dinter & A. Berger), *M. drouhardii*, *M. hildebrandtii* and *M. peregrina* (Fiori)) while the remaining two species are indigenous to Asia (*M. concanensis* (Nimmo ex Dalzell & Gibson) and *M. oleifera*) (Leone et al., 2015). The most widely known and studied species is *M. oleifera,* which has more records of various kinds of research (*e.g.* animal and human nutrition, phytotherapeutic treatment of various diseases, water purification, antioxidants, antidiabetic, bioactive secondary plant compounds) in scientific databases than of all the other 12 species combined.

Certainly one of the most important and investigated properties of *M. oleifera* is the ability of the seed powder to coagulate and flocculate suspended solids, including bacteria or other potential pathogens. The bioactive compound has been found to be a protein (5 kDa) which reduces suspended solids and bacteria in water by 1.1 – 4 log units (Gassenschmidt, Jany, Tauscher, & Niebergall, 1995; Ghebremichael, Gunaratna, Henriksson, Brumer, & Dalhammar, 2005).

Due to this highly interesting and beneficial property, which was described in the 1980s by the German developmental aid service GTZ (Jahn, 1986), the tree has been introduced and established in almost every tropical and subtropical country (Anwar, Latif, Ashraf, & Gilani, 2007; Leone et al., 2015). Dissemination has been facilitated by *Moringa oleifera* growing in almost all types of soils, except stiff, heavy clays, although it does not tolerate stagnate water or frequent flooding.

Other properties, which are especially relevant for nutrition and medicine, were only recognized and studied later. It has been found that all parts of *M. oleifera* can be used, which has led to one of its nicknames—"the miracle tree". For medicinal purposes, all parts of the plant (roots, leaves, seeds, bark, gum and flower) have been used to treat a multitude of diseases and deficiencies (Anwar et al., 2007). For nutritional purposes, the leaves can be used as food for humans (Thurber & Fahey, 2009) and as feed for animals, including fishes such as Nile tilapia (*Oreochromis niloticus* L.) (Afuang, Siddhuraju, & Becker, 2003; Richter, Siddhuraju, & Becker, 2003), common carp (*Cyprinus carpio* L.) (Yuangsoi & Masumoto, 2012), African catfish (*Clarias gariepinus* Burchell)

(Hlophe & Moyo, 2014), and poultry (Abbas, 2013). The flowers, fruits and immature pods are also used as vegetables: primarily in India, Pakistan, The Philippines, Hawaii and large parts of Africa (Anwar et al., 2007). *Moringa oleifera* leaf meal powder is increasingly recognized as a lifesaving nutritious food supplement; especially in countries where large parts of the population are undernourished. However, well-documented, clinical studies are still lacking (Thurber & Fahey, 2009; Scheinert, 2015). The frequently reported nutritional benefits of leaf powder include that it has a relatively high protein content, ranging between 250 g/kg dry matter (DM) (Richter et al., 2003) and 321 g/kg of DM (Hlophe & Moyo, 2014); optimal amino acid make up; and high amounts of vitamins, such as vitamin C and α-tocopherol. Pro-vitamin A, in the form of ß-carotenes, can reach up to, and sometimes exceed, 1000 mg/kg DM in *M. oleifera* (Babu, 2000; Nambiar & Seshadri, 2001; Leone et al., 2015). Furthermore, it is rich in minerals such as calcium, potassium and iron (Makkar & Becker, 1996; Afuang et al., 2003). The seeds contain even more protein, which has been reported to be as high as 367 g/kg DM in untreated kernels (Makkar & Becker, 1997) and 600 g/kg DM in defatted kernel meal (Makkar & Becker, 1997; Ben Salem & Makkar, 2009). The seeds of *M. oleifera* are rich in oil (417 g/kg DM) (Makkar & Becker, 1997), which is widely known as Ben oil, and is edible, very rancidity resistant (Fahey, 2005) and usually similar to olive oil in its fatty acid profile (Ben Salem & Makkar, 2009). In addition to the nutritional value of *M. oleifera* oil, a number of medicinal properties have been reported for *M. oleifera* seeds (Anwar et al., 2007). *Moringa oleifera* leaves and kernels may contain some secondary plant compounds such as total phenols, tannins, saponins and phytate in varying concentrations (Makkar & Becker, 1996, 1997).

In contrast to the extensive body of published knowledge on the properties of *M. oleifera*, information on the other *Moringa* species, such as *M. stenopetala*, *M. drouhardii* and *M. hildebrandtii* is scarce. To begin to address this knowledge gap, we report nutritive values (proximate composition, amino and fatty acid profiles and mineral trace element and heavy metal compositions for seeds and leaves of *M. stenopetala*, *M. drouhardii* and *M. hildebrandtii*: each from one origin and compare them to values from leaves and seeds of *M. oleifera* from various locations. These values are in the end discussed in the context of the known nutritional requirements of a young child. The aim was to identify and report the suitability of the seeds or leaves from the different *Moringa* species and origins as nutritious and potentially locally grown food.

2. Material and Methods

2.1 Plant Material

Seed and leaf material from four different *Moringa* species were collected from Nicaragua, India, Ethiopia, Malawi, Israel, Madagascar, Thailand, Uganda and Gran Canary. *M. hildebrandtii* originally came from Madagascar and were grown in the Canary Islands. The harvesting time for the seeds was when the pots cut open, which ensures comparability. At each location, mixed samples representing 4-6 subsamples for leaves and seeds were taken.

2.2 Seed Characteristics

For each species, single seed mass (SSM), single kernel mass (SKM), seed hull mass (SHM) and ratio of kernel to seed mass (KSR) were determined by weighing 10 seeds and the respective kernels and hulls.

2.3 Chemical Analysis

The collected leaf and seed samples were immediately dried in a force drying oven at 45 °C. Small soft twigs were separated from the leaves before milling to 1 mm size. Seeds were de-shelled manually. Before analysis both leaves and kernels were dried to constant weight in a drying oven at 105 °C.

All analyses were carried out in duplicate. Dry matter (DM), crude protein (CP), crude lipids (CL) and amino acids (AA) were determined according to EC 152/2009 III sections A (DM), C (CP), H (CL), F (AA except Tryptophan) and G (Tryptophan). Fatty acids (FA) were determined using the trimethylsulfoniumhydroxid method (P23-5-008, the former DIN EN ISO 12966-3). The AA are presented as the percentage of crude protein and the FA are presented as the percentage of crude lipids. Fatty acid determination was not carried out for the leaves because their lipid content was generally very low (below 4%). All reported chemical data refer to dry matter unless stated otherwise.

Macro elements (Ca, P, Mg, Na, K), micro elements (Fe, Mn, Mo, Se, Co, Cu, Zn, As, B, Si, V), harmful elements (Ag, Al, Ba, Cd, Ni, Pb) and all other elements (Cr, Ge, Li, Sb, Sn, Sr) were determined by inductively coupled plasma optical emission spectrometry after microwave digestion (SAS-PA-01137). Dry matter, CP, CL, AA and FA were determined at the State Institute for Agricultural Chemistry of the University of Hohenheim, while the elemental analysis was conducted by SALUS Haus GmbH & Co KG Analytischer Service (Bruckmühl, Germany).

Leaf vitamins were determined in one sample of leaves from Malawi only. Determination was conducted by the commercial laboratory "ifp Institut für Produktqualität GmbH" (Berlin, Germany) according to the methods as stated in Table 8.

2.4 Statistics

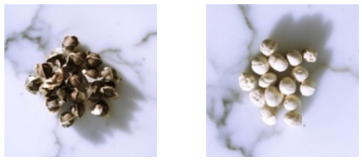
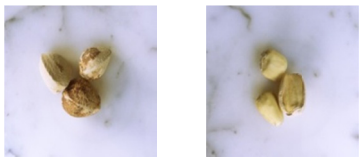
The comparison between the seed and kernel morphometrics was conducted using SPSS Version 10.0. Levene's test was applied to test for homoscedasticity and the Kolmogorov-Smirnov test was applied to test for normal distribution of data. Due to lack of homoscedasticity and normal distribution, the nonparametric Kruskal-Wallis-H test was used to test for differences between the groups. In case where significant differences were found, the Mann-Whitney-U test was used to test the strength of the significance. The probability level for significance was set to 5%.

3. Results

3.1 Seed and Kernel Morphometrics

Of the four different species tested, the seeds of *M. oleifera* were by far the lightest with an average SSM of 0.32 g., while the average SSM of *M. stenopetala* was 1.09 g. The seeds of *M. hildebrandtii*, (average SSM = 3.82 g) and *M. drouhardii* (average SSM = 3.14 g) were not statistically different from each other and were around ten times as heavy as the seeds of *M. oleifera* (Table 1). A similar result could be seen for the average SHM and SKM which was also lowest for *M. oleifera* and highest for *M. hildebrandtii* with no significant difference between *M. drouhardii* and *M. hildebrandtii*. The kernel to shell ratio, however, was highest for *M. oleifera*, where the kernel was more than three times the mass of the shell. In the other *Moringa* species, the kernel to shell ratio was significantly lower and in *M. drouhardii* and *M. hildebrandtii* the shell mass was very similar to the kernel mass (Table 1).

Table 1. Morphometric characteristics of seeds and kernels of four *Moringa* species

Species (origin)	Characteristics				
	Appearance (left whole seed, right kernel)	Single seed mass (SSM) (g)	Seed hull mass (SHM) (g)	Single kernel mass (SKM) (g)	Ratio kernel/shell (KSR)
M. oleifera (Managua, Nicaragua)		0.32±0.06[a]	0.08±0.02[a]	0.24±0.05[a]	3.16±0.50[c]
M. stenopetala (Negev, Israel)		1.09±0.11[b]	0.38±0.05[b]	0.70±0.07[b]	1.85±0.21[b]
M. drouhardii (Toliara, Madagascar)		3.14±0.71[c]	1.47±0.31[c]	1.67±0.55[c]	1.16±0.41[a]
M. hildebrandtii (Gran Canary)		3.87±0.72[c]	1.78±0.39[c]	2.08±0.49[c]	1.20±0.26[a]

Note. N = 10, mean ± standard deviation. Values in the same coloumn with different superscripts are statistically different ($P \leq 0.05$).

3.2 Proximate Compositions

The crude protein content ranged from 188 g/kg (*M. stenopetala*) to 375 g/kg (*M. oleifera*) of the kernels and from 197 g/kg (*M. drouhardii*) to 277 g/kg (*M. oleifera*) of the leaves. The crude lipid content ranged from 227 g/kg (*M. drouhardii*) to 482 g/kg (*M. hildebrandtii*) of the kernels and from 37 g/kg (*M. drouhardii*) to 52 g/kg (*M. hildebrandtii*) of the leaves (Table 2).

Table 2. Overview of the origins of the different *Moringa* spp. leaf and kernel samples and their proximate compositions (g/kg DM)

Plant part	Species	Origin	Water	Crude protein (CP)	Crude lipids (CL)
Leaves	*M. oleifera*	Malawi		277	
Leaves	*M. drouhardii*	Madagascar		197	37
Leaves	*M. hildebrandtii*	Gran Canary		222	52
Kernel	*M. oleifera*	Nicaragua	49	367	374
Kernel	*M. oleifera*	India	48	375	370
Kernel	*M. oleifera*	Ethiopia	61	347	285
Kernel	*M. stenopetala*	Israel	53	188	315
Kernel	*M. drouhardii*	Madagascar			227
Kernel	*M. hildebrandtii*	Gran Canary	41	275	482

3.3 Amino Acid Composition of Leaves and Kernels

The amino acid composition (% of CP) is given in Table 3. There were no striking differences in the composition of the tested *Moringa* varieties. Compared to the AA contents of the leaves, kernel meal is generally relatively poorer in EAA, except for sulphur-containing AA (Methionine and Cysteine). The major non-essential amino acids in kernels and leaves were glutamic and aspartic acid, arginine, proline and glycine (Table 3).

Table 3. Amino acid (AA) profiles of the various *Moringa* spp. leaf and kernel samples (data given as % of CP)

Species		*M. oleifera*	*M. drouhardii*	*M. hildebrandtii*	*M. oleifera*			*M. stenopetala*	*M. hildebrandtii*
Plant part		Leaves	Leaves	Leaves	Kernel	Kernel	Kernel	Kernel	Kernel
Origin		Malawi	Madagascar	Gran Canary	Nicaragua	India	Ethiopia	Israel	Gran Canary
Essential AA									
Methionine	Met	1.66	1.67	1.31	1.93	1.92	1.82	1.70	1.93
Valine	Val	4.69	5.00	4.01	3.49	3.31	3.43	3.78	3.16
Isoleucine	Ile	4.01	4.22	3.24	2.97	3.01	2.74	3.09	2.98
Leucine	Leu	7.65	7.71	6.08	5.42	5.39	5.53	5.48	5.56
Phenylalanine	Phe	6.28	5.16	4.37	4.14	4.05	3.86	4.15	4.40
Histidine	His	2.35	2.34	2.25	2.40	2.35	2.51	2.61	2.40
Lysine	Lys	5.20	5.26	4.46	1.66	1.55	2.39	1.86	1.82
Threonine	Thr	4.26	4.32	4.05	2.48	2.37	2.82	2.77	2.65
Tryptophan	Trp	2.06	1.93	1.80	0.90	0.93	0.95	0.96	0.87
Non-essential AA									
Cystine	Cys	1.34	1.56	1.67	4.09	4.13	3.69	3.51	3.85
Aspartic acid	Asp	9.46	9.95	13.6	4.44	4.32	5.50	5.05	4.29
Proline	Pro	4.91	4.69	4.01	5.89	6.08	6.46	5.27	5.82
Serine	Ser	4.48	4.27	5.23	2.97	2.91	2.80	3.03	3.05
Tyrosine	Tyr	3.14	3.07	2.57	1.72	1.63	1.64	1.54	1.49
Glutamic acid	Glu	13.8	10.8	11.7	21.1	20.9	19.9	20.4	19.2
Glycine	Gly	4.69	4.84	4.50	5.20	4.85	4.55	5.21	4.65
Alanine	Ala	5.67	5.42	4.41	3.84	3.76	3.37	3.88	3.35
Arginine	Arg	5.52	5.36	4.55	15.0	14.9	13.3	12.1	14.3

3.4 Fatty Acids

The fatty acid profiles, which were only analysed in lipids extracted from the kernels, were relatively low in variation. In all species, the single most important FA was the monounsaturated oleic acid (C18:1n-9), which made up between 66 and almost 75% of the total crude lipids, followed by the saturated palmitic (C16:0) and stearic acids (C18:0). Behenic acid (22:0) is characteristic for *Moringa* oil and ranged from 2.3% in *M. drouhardii* to 5.58% in seeds of *M. oleifera* from India. The total unsaturated fatty acids (UFA) were slightly lower in *M. oleifera* and *M. hildebrandtii* than in *M. stenopetala* and *M. drouhardii* (around 73% and 76% of CL, respectively) (Table 4). Only two poly-unsaturated fatty acids (PUFA) were determined in the analyses: the cis variants of linoleic acid (C18:2 n-6c) and linolenic acid (C18:3 n-3c). Both PUFAs were found to be less concentrated in kernels of *M. drouhardii* than in all other samples.

Table 4. Fatty acid profiles of the various *Moringa* spp. kernel samples (data given as % of CL)

Species		*M. oleifera*			*M. stenopetala*	*M. drouhardii*	*M. hildebrandtii*
Plant part		Kernel	Kernel	Kernel	Kernel	Kernel	Kernel
Origin		Nicaragua	India	Ethiopia	Israel	Madagascar	Gran Canary
caproic acid	C6:0	0.01	0.01	0.01	0.01	-	0.01
caprylic acid	C8:0	0.05	0.04	0.03	0.05	-	0.05
capric acid	C10:0	0.01	0.01	0.01	-	-	0.01
lauric acid	C12:0	0.03	0.03	0.03	0.02	0.01	0.02
myristic acid	C14:0	0.20	0.20	0.17	0.16	0.07	0.13
pentadecyclic acid	C15:0	0.04	0.04	0.03	0.04	0.01	0.03
palmitic acid	C16:0	10.5	9.66	8.87	11.8	8.93	12.2
palmitoleic acid	C16:1	1.57	1.45	0.37	1.83	0.26	0.45
margaric acid	C17:0	0.14	0.15	0.14	0.16	0.10	0.14
stearic acid	C18:0	6.61	7.05	8.21	5.81	8.33	9.15
oleic acid	C18:1n-9	66.5	66.8	69.5	71.1	74.8	70.0
linoleic acid	C18:2n-6c	2.97	2.48	1.97	2.50	0.62	1.89
linolenic acid	C18:3n-3c	0.25	0.21	0.11	0.10	0.07	0.08
arachidic acid	C20:0	2.72	3.26	3.42	1.86	2.92	2.58
eicosenoic acid	C20:1	1.81	2.07	1.64	1.35	0.72	0.70
behenic acid	C22:0	5.48	5.58	3.93	2.77	2.30	2.16
lignocerine acid	C24:0	0.98	0.95	1.45	0.51	0.71	0.46
Σ saturated fatty acids	Σ SFA	26.8	26.9	26.3	23.2	23.4	26.9
Σ unsaturated fatty acids	Σ UFA	73.2	73.1	73.6	76.8	76.5	73.1

3.5 Elemental Analysis

Calcium (> 20 g/kg DM), phosphorous and potassium were the major macroelements in leaves although *M. oleifera* leaves from India were rather low in calcium (11 g/kg DM). Potassium and phosphorous were the dominant macroelements in the kernels but kernels seemed to have generally lower levels of macroelements than the leaves (Table 5). Iron and silicon were the main microelements in both kernels and leaves in terms of quantity (Table 6). Of the harmful elements, aluminium was dominant with contents as high as 614 µg/kg DM (*M. oleifera* leaves from Uganda) and 862 µg/kg DM (*M. oleifera* leaves from Malawi) (Table 7).

Table 5. Macroelements of the various *Moringa* spp. leaf and kernel samples (g/kg DM)

Plant part	Species	Origin	Ca	P	Mg	K	Na
Leaves	*M. oleifera*	Nicaragua	20.8	3.36	3.69	18.8	0.70
Leaves	*M. oleifera*	India	11.0	6.32	3.73	29.6	0.67
Leaves	*M. oleifera*	Malawi	22.2	3.70	8.79	13.5	0.60
Leaves	*M. oleifera*	Thailand	23.7	3.07	3.68	19.3	0.45
Leaves	*M. oleifera*	Uganda	21.6	2.59	4.20	17.3	0.29
Leaves	*M. drouhardii*	Madagascar	11.9	2.19	9.06	12.3	9.78
Leaves	*M. hildebrandtii*	Gran Canary	15.7	4.66	4.90	19.5	5.04
Kernel	*M. oleifera*	Ethiopia	2.53	8.28	4.15	11.3	0.04
Kernel	*M. stenopetala*	Israel	1.45	3.62	2.37	5.64	0.49
Kernel	*M. drouhardii*	Madagascar	0.75	3.55	1.83	7.84	0.15
Kernel	*M. hildebrandtii*	Gran Canary	0.87	8.03	2.79	9.03	0.06

Table 6. Microelements of the various *Moringa* spp. leaf and kernel samples (mg/kg DM)

Plant part	Species	Origin	Fe	Zn	Mn	Mo	Co	Se	Si	Cu	B	As	V
Leaves	*M. oleifera*	Nicaragua	229	20.7	71.4	1.30	0.083	2.85	343	5.37	32.2	< 0.734	0.276
Leaves	*M. oleifera*	India	132	30.1	16.7	0.518	0.080	1.57	248	5.89	29.1	< 0.721	0.136
Leaves	*M. oleifera*	Malawi	1239	21.7	76.9	4.53	0.860	27.7	279	8.21	64.6	< 0.725	3.64
Leaves	*M. oleifera*	Thailand	132	21.0	79.4	1.13	0.081	0.978	260	6.59	52.4	< 0.726	0.204
Leaves	*M. oleifera*	Uganda	581	17.7	116	1.27	0.437	2.27	286	5.79	57.4	< 0.717	1.21
Leaves	*M. drouhardii*	Madagascar	138	12.2	79	1.46	< 0.082	< 0.653	389	4.23	126	< 0.816	0.215
Leaves	*M. hildebrandtii*	Gran Canary	350	21.8	80.5	1.6	0.248	< 0.645	192	2.52	62.7	< 0.806	0.733
Kernel	*M. oleifera*	Ethiopia	123	34.2	17.7	< 0.241	0.081	< 0.644	124	4.91	7.93	< 0.804	0.189
Kernel	*M. stenopetala*	Israel	21.2	21.7	9.16	< 0.238	< 0.08	< 0.636	9.73	3.01	6.14	< 0.795	< 0.08
Kernel	*M. drouhardii*	Madagascar	39.7	14.7	5.34	0.283	< 0.081	< 0.645	33.5	3.56	7.35	< 0.806	< 0.081
Kernel	*M. hildebrandtii*	Gran Canary	24.1	27	5.11	< 0.243	< 0.081	0.796	5.38	3.91	6.31	< 0.809	< 0.081

Table 7. Potentially essential and toxic heavy metals and minerals of the various *Moringa* spp. leaf and kernel samples (mg/kg DM)

Plant part	Species	Origin	Pb	Cd	Ag	Al	Ba	Ni	Cr	Sn	Li	Ge	Sb	Sr
Leaves	*M. oleifera*	Nicaragua	<0.408	<0.082	<0.163	79.7	37.4	0.681	0.557	<0.652	0.653	<0.489	<0.571	66.9
Leaves	*M. oleifera*	India	<0.400	<0.080	<0.160	65.3	11.9	1.49	0.488	<0.641	0.165	<0.480	<0.560	21.2
Leaves	*M. oleifera*	Malawi	0.59	<0.080	<0.161	862	37.4	3.80	5.15	<0.644	0.987	<0.483	<0.564	126
Leaves	*M. oleifera*	Thailand	<0.403	<0.081	<0.161	88.2	9.44	0.646	0.283	<0.645	2.63	<0.484	<0.565	34.5
Leaves	*M. oleifera*	Uganda	<0.398	<0.080	<0.159	614	73.2	1.56	1.03	<0.637	0.459	<0.478	<0.557	149
Leaves	*M. drouhardii*	Madagascar	<0.408	<0.057	<0.245	80.6	3.18	0.729	0.466	0.676	1.64	<0.49	<0.572	28.4
Leaves	*M. hildebrandtii*	Gran Canary	<0.403	<0.056	<0.272	301	7.07	1.86	0.7	0.605	0.907	<0.484	<0.564	58.6
Kernel	*M. oleifera*	Ethiopia	<0.402	<0.056	<0.241	65.7	2.48	0.886	0.469	0.466	<0.161	<0.483	<0.563	16.8
Kernel	*M. stenopetala*	Israel	<0.397	0.068	<0.238	2.81	<0.08	1.66	0.604	<0.397	<0.159	<0.477	<0.556	24.4
Kernel	*M. drouhardii*	Madagascar	<0.403	<0.056	<0.242	15.4	0.226	1.56	2.08	<0.403	<0.161	<0.484	<0.564	37.1
Kernel	*M. hildebrandtii*	Gran Canary	<0.404	<0.057	<0.243	1.3	0.319	0.741	0.131	0.428	<0.162	<0.485	<0.566	33.3

3.6 Vitamins

Vitamin C (29.2 mg/100 g) and niacin (11 mg/100 g) were the major water soluble vitamins followed by vitamin B2 (2.30 mg/100 g) and pantothenic acid (2.15 mg/100 g). Of the water insoluble vitamins, vitamin E (DL-tocopherol, 44.5 mg/100 g) was the major vitamin followed by β-carotene (8030 µg/100 g) (Table 8).

Table 8. Vitamins measured in the leaves of *M. oleifera* from Malawi

	Unit (on dry matter basis)	Method of analysis	*M. oleifera* leaf meal
Water soluble vitamins			
Biotin	µg/100 g	AOAC certificate 101001	29.5
Folic acid	mg/100 g	AOAC certificate 100903	0.78
Niacin	mg/100 g	VitaFast® ifp	11
Vitamin B1	mg/100 g	VitaFast® ifp	0.27
Pantothenic acid	mg/100 g	AOAC certificate 100904	2.15
Vitamin B2	mg/100 g	AOAC certificate 100902	2.30
Vitamin B6	mg/100 g	VitaFast® ifp	1.15
Vitamin C	mg/100 g	DIN EN 14130	29.2
Water insoluble vitamins			
β-carotene (Vitamin-A precursor)	mg/100 g	DIN EN 12823-2	8.03
Vitamin K1	mg/100 g	DIN EN 14148	0.898
Vitamin E (DL-Tocopherol)	mg/100 g	DIN EN 12822	44.5

4. Discussion

Of the 13 described *Moringa* species, one has been given the vast majority of scientific and public attention. The search term "*Moringa oleifera*", when entered in the Web of Knowledge search (www.webofknowledge.com), yielded 1465 results, while the search term "*Moringa stenopetala*" yielded 61; "*Moringa drouhardii*" yielded 4; and "*Moringa hildebrandtii*" yielded 2 results (search conducted on the 14th of March 2017). The large discrepancy in scientific interest is likely based on several important and advantageous properties of *M. oleifera*; of which the most important and well known is probably the coagulation ability of specific seed proteins (Olsen, 1987; Gassenschmidt et al., 1995; Muyibi & Evison, 1995; Ndabigengesere, Narasiah, & Talbot, 1995; Ndabigengesere & Narasiah, 1998). Other reasons that *M. oleifera* has been the focus of study are the potential utilization of the seeds as a feed additive (Ben Salem & Makkar, 2009; Hlophe & Moyo, 2014; T. P. Singh, P. Singh, & Kumar, 2015) or insecticide (Benelli, 2015); the importance of the leaves for human nutrition (Subadra, Monica, & Dhabhai, 1997; Babu, 2000; Fahey, 2005; Thurber & Fahey, 2009); including its potential use as a human famine food (Sena et al., 1998) and as animal feed (Richter et al., 2003; Negesse, Makkar, & Becker, 2009; Abbas, 2013) and the medical potential of all plant parts (Anwar et al., 2007; Jaeschke, Williams, McGill, Xie, & Ramachandran, 2013); including the antibiotic activity of pods, flowers and leaves (Brilhante et al., 2015).

Generally, it is more common to utilize *Moringa* leaves as food and feed than *Moringa* kernels. The necessary amount of dry matter intake to cover 15% of the respective nutrient demand of a child (Golden, 2009) is calculated for leaves of *M. oleifera*, *M. hildebrandtii* and *M. drouhardii* and presented in Table 9. As a source for protein and essential amino acids (EAA), *M. oleifera* leaves are superior to the leaves of *M. hildebrandtii* and *M. drouhardii*. This is especially the case for isoleucine, phenylalanine + tyrosine, lysine and tryptophan (Tables 3 and 9). A potentially high food value of *M. oleifera* leaf protein as an EAA source can be justified in that the analysed amino acid patterns almost completely satisfied the requirement of a 2-5 year old child. All analysed *Moringa* leaves contained all essential amino acids except lysine in higher concentrations than recommended for the young child (Zarkadas, Yu, & Burrows, 1995). *Moringa* spp. kernels, however, were rather poor in EAA when compared to leaves (Table 3). All *Moringa* kernels were deficient in leucine, phenylalanine, lysine, threonine and tryptophan.

Table 9. Necessary amount of leaf dry matter intake (g) to cover 15% of the daily requirement of a child for the given nutrient of *Moringa* leaves. Requirement values from Golden (2009), with data from FAO where available, otherwise data from other sources (*e.g.* Institute of Medicine, IOM)

Nutrient	Unit	Childs requirement	Species		
			M. oleifera Various[1]	*M. hildebrandtii* Gran Canary	*M. drouhardii* Madagascar
Protein	g	22.3	12.1	15.1	17.4
Methionine + Cysteine	mg	575	10.4	13.1	13.9
Valine	mg	776	8.95	13.1	12.1
Isoleucine	mg	575	7.77	12.0	10.6
Leucine	mg	1245	8.81	13.8	12.6
Phenylalanine + Tyrosine	mg	1125	6.47	11.0	10.7
Histidine	mg	430	9.92	12.9	14.3
Lysine	mg	1190	12.4	18.0	17.7
Threonine	mg	655	8.33	10.9	11.8
Tryptophan	mg	175	4.61	6.56	7.09
Calcium	mg	595	5.13	5.70	7.47
Phosphorous	mg	450	18.8	14.5	30.9
Magnesium	mg	79	2.64	2.42	1.31
Potassium	mg	1099	9.01	8.47	13.4
Sodium	mg	978	293	29.1	15.0
Iron	mg	17.8	9.66	7.63	126
Zinc	mg	12.5	86.3	86.0	86.4
Manganese	mg	1.2	4.30	2.24	19.7
Molybdenum	µg	16.6	2.31	1.56	-
Selenium	µg	17.8	0.98	-	-
Copper	µg	892	21.8	53.1	44.5
Chromium	µg	10.8	2.03	2.31	2.68

Note. [1] Protein and amino acid data where only available for *M. oleifera* leaves from Malawi, values for dry matter intake for macro- and microelements are the mean of *M. oleifera* leaves from Nicaragua, India, Malawi, Thailand and Uganda.

All *Moringa* spp. leaves were excellent sources for the macro-elements calcium and magnesium. As little as 5.0-7.5 and 1.3-2.4 g of dry leaf powder satisfy 15% of a child's daily calcium and magnesium requirement (Tables 5 and 9), respectively. The phosphorous content was lower than the calcium and magnesium content in *M. oleifera* and *M. hildebrandtii*, while phosphorous content was found to be even lower in *M. drouhardii*. For a growing child, calcium and phosphorous are especially important as both are necessary for bone mineralization and thus for sustained growth (FAO, 2001). As a source of iron, only leaves of *M. oleifera* and *M. hildebrandtii* were sufficient. The iron content of *M. drouhardii* leaves was very low and the required leave meal quantity to cover 15% of a child's daily need was extremely high (Table 9). In comparison to other green leafy vegetables (*e.g.* spinach, cauliflower, amaranth), the analysed iron contents in *Moringa* spp. leaves were higher while those of *Moringa* spp. kernels were lower or similar (Singh, Kawatra, & Sehgal, 2001). High amounts of aluminium were measured in *M. hildebrandtii* leaf samples and in *M. oleifera* leaf samples from Malawi and Uganda, which might point to either high aluminium contents in the soils or abrasion in the mills. Wastewater irrigation is usually also a possible source of minerals and heavy metals (Arora et al., 2008) but the plantations from which the samples were collected do not use this type of combined irrigation and fertilization, so this potential source can be excluded. The iron and aluminium content in canola (*Brassica napus* L.) has also been found to vary with the plant's growth stage; showing a negative correlation between mineral content and plant age (Miller-Cebert, Sistani, & Cebert, 2009). Of the other microelements, *M. oleifera* and *M. hildebrandtii* leaves contained concentrations of manganese, chromium and molybdenum that a DM intake of only between 1.56 (molybdenum, *M. hildebrandtii*) and 4.30 g (manganese, *M. oleifera*) per day are sufficient to cover 15% of the daily requirement. Zinc and copper were found in relatively low concentrations, so *Moringa* leaves are not well suited to deliver the recommended daily doses. The selenium concentrations were on average very high in *M. oleifera*

leaves, but the leaves from *M. oleifera* harvested in Malawi showed exceptionally high selenium values (Table 6) while the other samples where considerably lower.

Moringa leaves were found to be not particularly dense in energy as their lipid content was low (37 g/kg DM in *M. hildebrandtii* and 52 g/kg DM in *M drouhardii* leaves). The kernels, however, had high lipid contents well above 300 g/kg DM in *M. oleifera* (Table 2). Kernels of *M. hildebrandtii* were exceptionally rich in lipids while those of *M. drouhardii* were comparatively poor (482 and 227 g/kg DM, respectively). Kernel lipids of all the analysed *Moringa* spp. were rich in oleic-acid which is also the most important mono-unsaturated fatty acid in Western diets but nutritionally less valuable than poly-unsaturated fatty acids (FAO, 2010). The Ben oil extracted from *M. oleifera* kernels is known for a long shelf life and has been used for salads and industrial applications with higher emphasis on the industrial uses (Tsaknis, Lalas, Gergis, Dourtoglou, & Spiliotis, 1999). As a lipid source the kernels of *M. hildebrandtii* would be better suited although their low kernel to shell ratio is less favourable than in *M. oleifera*.

Vitamin A is a fat soluble vitamin that plays an important role in metabolism: primarily for the visual functioning; growth and development; epithelial cellular integrity; immune functioning; and reproduction (FAO, 2001). It is mainly stored in animals and humans in the fat storing cells in the liver as esterified retinyl but carotenoids are also stored in other fat tissues in the body. One important precursor for vitamin A or retinol, is the long chain, lipophilic carotenoid β-carotene. The FAO lists 1 µg β-carotene as being equivalent to 0.167 µg retinol or retinol-equivalents (RE). It is thus the most important and readily available precursor for the important fat-soluble vitamin (FAO, 2001) since the conversion for other carotenoids is 1 µg to 0.084 RE. The amount of β-carotene in the leaves of *M. oleifera* from Malawi was 8.03 mg/100 g DM in our study, which was considerably lower than that reported for *M. oleifera* leaves from India (17.4 mg/100 g DM) (Subadra et al. 1997) or *M. oleifera* leaves of unspecified origin (16.3 mg/100 g DM) (Singh et al., 2001). An adult female between 19 and 65 years of age has a mean vitamin A requirement of 270 µg RE/day (FAO, 2001) corresponding to 1617 µg β-carotene/day or 20.1 g DM of *M. oleifera* leaves from Malawi.

In addition to the macro- and micronutrients that were the focus of this study, *Moringa* leaves and kernels can contain a variety of different bioactive compounds. Phenols, tannins, saponins, phytate (Makkar & Becker, 1996; 1997) of varying concentrations have been described in leaves.

Moringa kernels can contain concentrations of glucosinolates (4-(α-L-rhamnopyranosyloxy)-benzylglucosinolate) as high as 264 mg/g DM in *M. oleifera* and 256 mg/g DM in *M. stenopetala* (Bennett et al., 2003). *Moringa* leaves are seemingly lower in glucosinolate content with concentrations between 5.3 and 70.2 mg/g DM (Bennett et al., 2003). They might be the reason for a described antibacterial and antifungal activity (Fahey, Zalcman, & Talalay, 2001), are believed to play a role in the plant's defence (Redovniković, Glivetić, Delonga, & Vorkapić-Furač, 2009) and have potential uses for medicinal purposes for humans and animals (Bennett et al., 2003; Brilhante et al., 2015).

6. Conclusion

The nutritional patterns of macro- and micronutrients of *Moringa* spp. leaves and kernels highlight them as potential food and feed source in the tropic and sub-tropic regions where they can be grown effectively. In general, the leaves tend to be the more promising plant parts as vegetables for human consumption, especially so for macroelements. Given the different production systems for seeds and kernels on the one hand (older trees, lower leaf to stem ratio) and leaves on the other hand (very young trees, high leaf to stem ratio, short rotation coppice), either old trees for seed and kernel production or young trees for leaf production can be utilized. In terms of nutrient production it seems to be more promising to produce leaves over kernels and leaves of *M. oleifera*, *M. hildebrandtii* and *M. drouhardii* can be considered nutritionally valuable leafy vegetables.

However, for the product to be ready for human consumption, and also suitable as high quality animal feed ingredient, the production must be safe and free of contaminants and pesticide residues. If that goal is accomplished, especially the nutrient content of the leaves but also the kernel of *Moringa* spp., allows them to be considered as a meaningful alternative to combatting malnutrition by being consumed directly by humans or indirectly by utilization as animal feed. Controlled clinical trials are, however, necessary to determine the extent to which *Moringa* can be adopted to combat malnutrition and to evaluate anecdotal knowledge about its beneficial nutritional and medical properties. Our study on macro- and micronutrients helps to close the knowledge gap, although more work is necessary; especially to determine intraspecific variation between different sampling locations versus interspecific variation.

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