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ORIGINAL PAPER

Characterization of the Seed Oil and Meal from *Monechma ciliatum* and *Prunus mahaleb* Seeds

Abdalbasit Adam Mariod · Kawthar Mahmoud Aseel · Ali Abdalgadir Mustafa · Siddig Ibrahim Abdel-Wahab

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Abstract The oil and meal from *Monechma ciliatum* (black mahlab) and *Prunus mahaleb* (white mahlab) seeds were characterized for their physicochemical properties. The oil content was found to be 30.95 and 13.15% in white and black mahlab seeds, respectively. The refractive indices of white mahlab oil (WMO) and black mahlab oil (BMO) were 1.475 and 1.470, and specific gravities were 0.8511 and 0.8167 g/cm^3, respectively. Saponification values were 184.23 and 180.3 mg KOH/g, peroxide values were 2.54 and 4.43 meq/kg, and unsaponifiable matter was 0.92 and 0.66%, respectively. The major fatty acids were palmitic 4.5%, stearic 16.0%, oleic 47.3%, and linoleic 31.4% in BMO, while in WMO they were palmitic 5.7%, oleic 45.0%, and linoleic acid 47.0%. A moderate amount of tocopherols were found at 45.2 and 28.5 mg/100 g in BMO and WMO, respectively. Protein content was found to be 21% in black and 28% in white mahlab seeds. The total amount of amino acids in black and white mahlab seeds was found to be 783.3 and 1,223.2 mg/g N, respectively. The concentration (on ppm dry-weight basis) of major elements (Ca, K, and Mg) and of minor elements (Al, Pb Ni, Mn, Cu, Cr, Co, and Fe) was also determined in the meals.

Keywords Amino acid · Fatty acid · ICP-MS · Mineral elements · *Monechma ciliatum* · Physicochemical properties · *Prunus mahlab*

A. A. Mariod (✉)
Laboratory of Molecular Biomedicine,
Institute of Bioscience, Universiti Putra Malaysia,
43400 Serdang, Selangor, Malaysia
e-mail: basitmariod@yahoo.com

A. A. Mariod · K. M. Aseel
Food Science and Technology Department,
College of Agricultural Studies,
Sudan University of Science and Technology,
P.O. Box 71, Khartoum North, Sudan

A. A. Mustafa
Department of Plant Protection,
Faculty of Agriculture, Universiti Putra Malaysia,
43400 Serdang, Selangor, Malaysia

S. I. Abdel-Wahab
UPM-MAKNA Cancer Research Laboratory,
Institute of Bioscience, University Putra Malaysia,
43400 Serdang, Selangor, Malaysia

Introduction

Recently, researchers all over the world have been looking to discover new sources of oils. In Sudan many studies have been done looking at the utilization of wild plants as a source of unconventional oil and their maximum utilities as antioxidants [1–3]. One of these wild plants, considered among the plants of the future, is black mahlab (*Monechma ciliatum*), which is well known in Sudan and belongs to the family Acanthaceae. Black mahlab is an annual glabrous herb, 30–65 cm high [4], with simple leaves measuring about 4–7 × 1–2 cm [5]. Black mahlab (*Monechma ciliatum*) is a famous medicinal plant in western Sudan, especially in the Nuba Mountains and Gabel Mara area. The seeds are used as an effective laxative and contain a fixed oil that emits a sweet and pleasant odor. Its further used in traditional Sudanese fragrances, lotions, and other cosmetics used for wedding preparation and childbirth [6]. In Botswana, *Monechma ciliatum* was believed to play an important role as a medicine for the remedy of general body pain, liver, and bowel trouble (diarrhea), as well as sterility in women [7]. The plant is used to induce labor and menses in Nigeria. It is also reported that the dried leaves

are powdered and burnt as an inhalation for colds [8]. In Sudan, the dried entire plant is used for diarrhea, vomiting, and as a scent preparation. The seed oil content is 11.6% with iodine value of 69 and saponification value of 175.16; the fatty acid composition is 20.2, 17.3, and 17.9% for oleic, linoleic, and arachidic acid, respectively [9, 10]. Previous study by Uguru and others [5] showed that the hot methanol extract of the leaves of *M. ciliatum* has potent oxytocic property in vivo and in vitro, thus justifying its use in traditional medicine.

White mahlab (*Prunus mahaleb*) is a deciduous tree, 1–2 m high, with many spreading branches; the bark is smooth and mahogany red. The leaves, which are up to 6 cm long, are bright green, shiny, oval, and finely toothed [11]. The white mahlab tree is a member of Rosaceae family, subfamily Prunoideae. The kernels of white mahlab seem to contain only small amounts of cyanogenic glycosides, but coumarin derivatives have been found. From the seeds, a fixed oil can be extracted that contains unusual conjugated linolenic fatty acid [12]. In Sudan, white mahlab is used in wedding preparations by crushing the seeds to manufacture traditional fragrances and lotions such as Dilka, Khumrra, and Darira. Also eating soaked white mahlab seeds is a remedy used for diarrhea in children. White mahlab is collected in Turkey and exported on a large scale. It is used in Turkey as a tonic or an antidiabetic in folk medicine and as a flavoring agent in making pies and candies. The white mahlab kernels form an important source of protein (30.98%) and fatty oil (40.40%). Its oil is also valuable in the preparation of lacquers and varnishes [12].

Monechma ciliatum still grows as a wild plant in different areas in western Sudan states. No research data on its commercial production and its oil composition are available.

Amino acid composition and protein digestibility measurements are considered necessary to predict accurately the protein quality of foods for human diets [13]. The widespread availability of vegetable oils around the world has resulted in the development of other oil-bearing plant species being neglected [14]. This study investigates the physicochemical and compositional properties including amino acids, minerals, trace elements, and fatty acids of seeds of the two mahlab plants, and a sensory evaluation of the oils obtained from these seeds is performed.

Materials and Methods

Samples, Solvents, and Reagents

All solvents used were of analytical grade. *n*-Hexane, methanol, chloroform, and petroleum ether were obtained from Prime for Scientific Services, Khartoum, Sudan. HCl, NaOH, HNO_3, and H_2O_2 were Suprapur grade (Merck, Darmstadt, Germany).

Dried seeds of white and black mahlab were collected from a local market in Khartoum North, Sudan, then blended to obtain homogeneous samples, and pulverized before representative samples were taken for chemical analysis. For determination of the oven-dry weight, samples were dried at 105 °C for 24 h. Moisture and volatile matter in the samples were determined following a previously described method [15].

Proximate Chemical Analysis

Moisture, lipid, ash, and crude-fiber contents were determined following the standard methods of the Association of Official Analytical Chemists [16]. The organic nitrogen content was quantified by the Kjeldahl method, and an estimate of the crude protein content was calculated by multiplication of the organic nitrogen content by a factor of 6.25 [17]. The two different samples were analyzed in triplicate. Total carbohydrate content was calculated from the difference, applying the formula:

$$100\% - (\% \text{ protein} + \% \text{ lipid} + \%\text{ash} + \%\text{fiber})$$

Mineral Analysis

Two replicate aliquots (500 mg) from each of the dried, powdered plant specimens were weighed, then wet-ashed by refluxing overnight with 15 mL of concentrated HNO_3 and 2.0 mL of 70% $HClO_4$ at 150 °C. The samples were dried at 120 °C, and the residues were dissolved in 10 mL of 4.0 N HNO_3-1% $HClO_4$ solution. The mineral content of each sample solution was determined by an Agilent Technologies 7500c inductively coupled plasma mass spectrometry (ICP-MS) system (Agilent Technologies, Wilmington, DE). Wavelengths used for the tested minerals were aluminum (Al) 396.152, calcium (Ca) 393.366, cadmium (Cd) 226.502, chromium (Cr) 206.149, cobalt (Co) 238.892, copper (Cu) 224.700, iron (Fe) 239.562, lead (Pb) 220.353, magnesium (Mg) 279.553, manganese (Mn) 257.610, nickel (Ni) 221.647, potassium (K) 766.490, and zinc (Zn) 213.856. The mineral contents of the samples were quantified against standard solutions of known concentrations, which were analyzed concurrently.

Oil Extraction and Determination

The seeds were milled gently in a blender (Braun Multimix System 200, with Multimix deluxe grinder, MXK4 Germany), and oil was extracted by Soxhlet apparatus using petroleum ether 40–60 °C and determined following a previously described method [15]. The oil content was determined as a percentage of the extracted oil to the

sample weight (w/w). The samples were analyzed in triplicate, then mean and standard deviation were calculated. The extracted oil was stored in a cold room (4 °C) in a dark glass bottle under nitrogen blanket for further analysis.

Oil Physicochemical Analysis

Free fatty acids (FFA), iodine value (IV), saponification number (SN), peroxide value (PV), unsaponifiable matter, color, and refractive index (RI) were measured following a previously described method [15]. Color was determined using Lovibond Tintometer, Lovibond model E (Bicasa), supplied by Griffin and Georgy, England, and refractive index was determined using an Abbe bench refractometer (model 46-315, England) with the temperature maintained at 30 °C. The analysis was done for the freshly extracted oils. The samples were analyzed in triplicate, then mean and standard deviation were calculated.

Fatty Acid Composition by Gas Liquid Chromatography

The fatty acid compositions of the seed oils were determined by gas liquid chromatography (GLC). The oils were converted to their corresponding methyl esters following a previously described method [15]. BF_3/methanol reagent (14% boron trifluoride) was used for methylation. GLC analysis of the fatty acid methyl esters (FAME) was performed using a Hewlett-Packard HP-5890 Series II gas chromatograph (GLC) coupled to a flame ionization detector (FID) equipped with an Ultra 2 capillary column (25 m × 0.32 mm × 0.5 μm, 5% biphenyl and 95% dimethyl polysiloxane; Hewlett-Packard, Waldron, Germany), a split injector (split ratio 88:1), and an FID. The column temperature program was 5 min at 150 °C, 10 °C/min to 275 °C, and 10 min at 275 °C. The injector temperature was 250 °C with a split ratio of 88:1. The carrier gas was hydrogen at a flow rate of 1.6 mL/min. The detector temperature was 280 °C with air and hydrogen flow rates of 460 and 33 mL/min, respectively. The fatty acid peaks were identified by comparing the retention times with those of a mixture of standard FAMEs (Sigma Chemicals, Deisenhofen, Germany). Each FAME sample was analyzed in duplicate.

Tocopherol

For determination of tocopherols, a solution of 250 mg of *Monechma ciliatum* and *Prunus mahaleb* oils in 25 mL *n*-heptane was directly used for the HPLC. The HPLC analysis was conducted using a Merck–Hitachi (Tokyo, Japan) low-pressure gradient system fitted with an L-6000 pump, a Merck–Hitachi F-1000 fluorescence spectrophotometer (detector wavelengths for excitation 295 nm, for emission 330 nm), and a D-2500 integration system. The samples (20 μL each) were injected by a Merck 655-A40 autosampler onto a Diol phase HPLC column (25 cm × 4.6 mm i.d.) (Merck) using a flow rate of 1.3 mL/min. The mobile phase used was *n*-heptane/methy tert-butyl ether (MTBE) (99:1, v/v) [18].

Amino Acid Composition by Amino Acid Analyzer

Preparation of Hydrolysate Sample

The content of dry matter and total N were determined according to procedures described by [16]. The content of amino acids (except for tryptophan) in defatted mahlab seeds was determined using Amino Acid Analyzer (L-8900 Hitachi-hitech, Japan) under the experimental conditions recommended for protein hydrolysates. Samples containing 5.0 mg of protein were acid hydrolyzed with 1.0 mL of 6 N HCl in vacuum-sealed hydrolysis vials at 110 °C for 22 h. The ninhydrine was added to the HCl as an internal standard. Hydrolysates were suitable for analysis of all amino acids. The tubes were cooled after hydrolysis, opened, and placed in a desiccator containing NaOH pellets under vacuum until dry (5–6 days). The residue was then dissolved in a suitable volume of a sample dilution Na–S buffer, pH 2.2 (Beckman Instr.), filtered through a millipore membrane (0.22-μm pore size) and analyzed for amino acids by ion-exchange chromatography in a Beckman (model 7300) instrument, equipped with an automatic integrator. Nitrogen in amino acids was determined by multiplying the concentration of individual amino acids by corresponding factors calculated from the percentage N of each amino acid [19]. The ammonia content was included in the calculation of protein nitrogen retrieval, as it comes from the degradation of some amino acids during acid hydrolysis [20, 21]. The ammonia nitrogen content was calculated by multiplying the ammonia content by 0.824 (N = 82.4% NH_3).

Expression of Results

The composition of amino acids was expressed as milligrams per gram of N to estimate the quality of the protein in mahlab defatted seeds using the amino acid score pattern where amino acid ratio = (mg of an essential amino acid in 1.0 g of test protein/mg of the same amino acid in 1.0 g of reference protein × 100). Nine essential amino acids were calculated by using a previously described method [13], where egg protein was used as reference protein.

Sensory Evaluation

Panelists were chosen to taste the two mahlab oils for characterization of their organoleptic properties (color, flavor, and taste). Oil samples were presented to the panelists in clear glasses at room temperature and in duplicate. The sensory analysis used was described in detail by Min [22]. Sensory qualities of the two oils were evaluated using a hedonic scale of 1–10, where 1 indicated the poorest flavor, color, and taste quality and 10 the highest organoleptic quality. The numerical results were then subjected to statistical analysis.

Statistical Analysis

The analyses were performed with three replicates. The mean values and standard deviation (mean ± SD) were calculated and tested using the Student's *t*-test ($P < 0.05$). Statistical analysis of variance (ANOVA) was performed on all values using the statistical program Statgrafics Statistical Graphics System version 4.0 [23].

Results and Discussion

Proximate Chemical Analysis

The proximate composition of the two mahlab seeds is given in Table 1. The two samples showed significant differences ($P \leq 0.05$) in all the analyzed constituents of the proximate composition except moisture content. The white mahlab seeds showed higher levels of lipid and protein content of 30.95 and 28.0 g/100 g, respectively, while black mahlab showed higher levels of fibers and carbohydrates content at 24.4 and 32.6 g/100 g, respectively. The results of oil content showed that white mahlab seed has a higher amount of oil (30.9 g/100 g) than the black mahlab seed (13.2 g/100 g). In 1981 Ayoub and Babiker [9] reported an oil content of 11.6% for black mahalb, which was higher than that reported in this study. Yücel [24] studied the seeds of *Prunus mahaleb*, and he found that the oil content ranged from 4.7 to 18.5 g/100 g, while Johansson et al. [25] mentioned that oil contents of *Prunus mahaleb* ranged from 12 to 16 g/100 g. The oil content of *Prunus mahaleb* in this study was higher than that found in these other studies.

Table 1 Proximate composition of two mahlab seeds[a]

Constituents (g/100 g)	WMO	BMO
Moisture	6.2 ± 0.2	6.0 ± 0.3
Lipid	30.9 ± 0.6*	13.2 ± 0.5
Protein	28.0 ± 0.4*	21.0 ± 0.3
Ash	2.1 ± 0.2*	2.8 ± 0.1
Fiber	18.7 ± 0.5*	24.4 ± 0.6
Carbohydrates	14.1 ± 0.7*	32.6 ± 0.8

WMO White mahlab oil, *BMO* black mahlab oil

*$P < 0.05$

[a] All determinations were carried out in triplicate and mean value ± standard deviation (SD) are reported

Oil Physicochemical Properties

The physicochemical properties of the two mahlab seed oils are shown in Table 2. Compared with Codex standards for crude vegetable oils [26], the white mahalab oil showed higher values for specific gravity, refractive index, acid value, peroxide value, saponification value, and unsaponifiable matter. Ayoub and Babiker [9] reported a lower saponification value (175.16) and a lower refractive index (1.4730) for black mahlab oil in comparison with the results in this study.

From Table 2 it is instructive to note that the refractive indices for the white mahlab seed oil (1.475) and black mahlab seed oil (1.470) fall within the same range of 1.467–1.477 for grapeseed oil. The acid values for WMO and BMO of 7.8 and 7.3 mg KOH/g, respectively, were higher than the Codex standards for sunflower and ground nut oils, whilst the peroxide values for the WMO of 2.54 meq/Kg oil and for the BMO of 4.43 meq O_2/Kg oil were less than that recorded for sunflower and ground nut oils in Codex standards. The percent unsaponifiable matter, shown in Table 2 for white mahlab (0.99%) and black

Table 2 Physicochemical properties of white and black mahlab seed oil[a]

Physicochemical parameters	WMO	BMO
Oil content (%, w/w)	30.95 ± 0.01*	13.15 ± 0.8
Specific gravity	0.8511 ± 0.01*	0.8167 ± 0.02
Refractive index	1.475 ± 0.004*	1.470 ± 0.008
FFA%	3.93 ± 0.01	3.65 ± 0.8
Acid value (mg KOH/g)	7.86 ± 0.01	7.30 ± 0.08
Peroxide value (meq O_2/kg oil)	2.54 ± 0.01*	4.43 ± 0.8
Saponification value (mg KOH/g oil)	184.2 ± 0.01*	180.3 ± 0.01
Unsaponifiable matter (%, w/w)	0.92 ± 0.01*	0.66 ± 0.008

WMO White mahlab oil, *BMO* black mahlab oil

*$P < 0.05$

[a] All determinations were carried out in triplicate and mean values ± standard deviation (SD) are reported

mahlab (0.66%) seed oils, was less than that recorded for sunflower and ground nut oils in Codex standards [26].

Sensory Evaluation of Black and White Mahlab Oil

Table 3 shows the results of the sensory evaluation for white and black mahlab oils. WMO oil scored more than 8 as overall score thus classifying the oil as better in color, odor, and taste. There was a significant difference ($P \leq 0.05$) between the average scores for color, odor, and taste in the two mahlab oils, and white mahlab oil seemed to be preferred by the panelists.

Fatty Acid Composition

The fatty acid composition determined by GLC of the black and white mahlab oils is illustrated in Table 4. The major fatty acids in white mahlab seed oil were oleic (45.0%), linoleic (47.0%), and palmitic (5.7%). This result was higher than that reported by Yücel [24], who reported 35.4, 28.5, and 4.6% for oleic, linoleic, and palmitic, respectively, in white mahlab seed oil. The major fatty acids in black mahlab seed oil were oleic (47.3%), linoleic (31.4%), stearic (16.0%), and palmitic (4.5%). This were higher than reported by Ayoub and Babiker [9] who reported 20.2, 17.3, and 12.5% for oleic, linoleic, and palmitic acids, respectively. They also reported 17.9% for arachidic acid, which was surprisingly not found in this study. The percentage of unsaturated fatty acids in white mahlab oil was 92.1%, while it was 79.9% in black mahlab oil. White mahlab oil was very rich in both oleic and linoleic acid, while black mahlab oil was rich in oleic acid only.

Table 3 Sensory evaluation analysis of two mahlab oils

Sample	Color	Odor	Taste
WMO	8.7*	8.5*	8.0*
BMO	7.4	7.5	7.5

WMO White mahlab oil, *BMO* black mahlab oil

*$P \leq 0.05$

Table 4 Fatty acid (FA) composition (%) of the two mahlab oils

FA (%)	WMO	BMO
Lauric C12:0	Trace[a]	Trace
Myristic C14:0	Trace	0.1 ± 0.01
Palmitic C16:0	5.7 ± 0.02	4.5 ± 0.1
Stearic C18:0	1.3 ± 0.3	16.0 ± 0.2
Oleic C18:1	45.0 ± 0.5	47.3 ± 0.4
Linoleic C18:2	47.0 ± 0.5	31.4 ± 0.2
Linolenic C18:3	0.1 ± 0.02	0.1 ± 0.02
SFA	7.0	20.6
MUFA	45.0	47.3
PUFA	47.1	31.5
Total lipid (% dry wet)	30.95	13.15

WMO White mahlab oil, *BMO* black mahlab oil, *SFA* saturated fatty acids, *MUFA* monounsaturated fatty acids, *PUFA* polyunsaturated fatty acids

[a] Trace less than 0.1%

Table 5 Tocopherol compositions (mg/100 g oil) of BMO and WMO

Sample	BMO	WMO
α-T	12.3 ± 0.2*	1.4 ± 0.2
γ-T	31.3 ± 0.4*	20.7 ± 0.3
δ-T	1.6 ± 0.1*	6.4 ± 0.3
Total	45.2 ± 0.6*	28.5 ± 0.5

WMO White mahlab oil, *BMO* black mahlab oil, *T* tocopherol

*$P < 0.05$

All determinations were carried out in triplicate and mean values ± standard deviation (SD) are reported

Table 6 Total amino acid and ammonia contents (mg/g N) of black and white mahlab seeds[a]

Amino acid	White mahlab seed	Black mahlab seed
Isoleucine	71.2 ± 8	55.0 ± 7
Leucine	116.1 ± 6	90.1 ± 4
Lysine	67.0 ± 10	59.1 ± 9
Cystine	26.1 ± 6	10.0 ± 7
Methionine	22.3 ± 7	17.1 ± 7
Tyrosine	48.0 ± 6	24.0 ± 6
Phenylalanine	69.0 ± 8	54.1 ± 5
Threonine	39.0 ± 7	33.2 ± 6
Valine	83.1 ± 5	67.0 ± 4
Histidine	82.0 ± 5	45.2 ± 5
Total essential amino acids	623.8	454.8
Aspartic acid	138.0 ± 4	92.0 ± 7
Glutamic acid	246.1 ± 6	109.0 ± 9
Serine	42.0 ± 6	30.1 ± 5
Glycine	92.2 ± 8	34.1 ± 7
Alanine	81.1 ± 9	63.3 ± 5
Total non-essential amino acids	599.4	328.5
Ammonia	120.0 ± 4	80.1 ± 5
Total amino acids	1,223.2	783.3

[a] Results (mean ± standard deviation, $n = 3$) represent the real recovery of amino acids after analysis. Concentrations of ammonia correspond to nitrogen recovered from some amino acids destroyed during acid hydrolysis

Table 7 Amino acid score of black and white mahlab protein[a]

Amino acid	Black mahlab		White mahlab	
Amino acid score (mg/g N)	Ranking	Ranking	Amino acid score (mg/g N)	Ranking
His	7.2	3	13.1	–
Ile	8.8	4	11.4	4
Leu	14.4	–	18.6	–
Lys	9.4	–	10.7	3
Met + Cys	4.3	1	7.7	2
Phe + Tyr	12.5	–	18.7	–
Thr	5.3	2	6.2	1

[a] Calculations are based on the amino acid analyses listed in Table 6. Limiting essential amino acids are ranked in order of their decreasing importance in each case

Tocopherol

The tocopherol content of the oil from black and white mahlab seeds is given in Table 5. They had moderate amounts of tocopherols, 45.2 and 28.5 mg/100 g, respectively. The main tocopherol of the two samples was γ-tocopherol, which represented 80.7 and 77.6% of the total, followed by α-tocopherol and δ-tocopherol, which represented 12.3 and 1.6 mg/100 g in BMO and 1.4 and 6.4 mg/100 g in WMO, respectively.

Amino Acid Profile

The amino acid profile of black and white mahlab seed, analyzed by amino acid hydrolysis, is presented in Table 6. The percentage of sulphur-containing amino acids (methionine and cystine) in white mahlab seed was 3.9%, while in black mahlab it was 3.4% of the total amino acids, which was the lower than the other amino acids and was considered a reasonable amount for their important function in the cell processes in the oxidation and reduction system (cystine) and as a methyl donor (methionine) in metabolism. The total amount of the essential amino acids found in white and black mahlab seed was 623.8 and 454.8 mg/g N, respectively. The total aromatic amino acid levels (phenylalanine and tyrosine) found in white and black mahalab were 117.0 and 78.1 mg/g N, respectively. All the essential amino acids with the exception of tryptophan, which was not analyzed, were found to be present at low levels, and the total essential amino acids were found to be lower when compared to that of three different foods: broad bean (2740.0 mg/g N), wheat flour (1960.0 mg/g N), and soy flour (2,630.0 mg/g N) [27]. The total amount of the essential amino acids of white mahlab seed comprised about 50.9% of the total amino acids, which was less than that of black mahlab seed (58.0%).

The chemical score suggested that the first limiting amino acid in black mahlab seed sample was methionine + cystine followed by threonine, histidinen and isoleucine (Table 7). In the white mahlab seed sample, the chemical score suggested that the first limiting amino acids were threonine**,** methionine + cystine, lysine, and isoleucine.

Mineral Composition

Mineral analyses are essential to guarantee the quality of any food product. ICP-MS allowed us to determine the content of 13 minerals, many of which are required in human diets and others which are considered toxic. Table 8 summarizes the results of these analyses. Concentrations of major elements such as Ca, K, and Mg in white mahlab seeds (133.7, 204.2, and 102.2 ppm) were significantly ($P < 0.05$) higher than black mahlab seeds (100.8, 80.5, and 69.13 ppm). As for calcium, a mineral that is essential to bone structure and function, the white mahlab contained a large amount of this metal in excess of 133.7 ppm, whereas black mahlab seed contained 100.8 ppm, thus

Table 8 Minerals in black mahlab and white mahlab seeds (ppm, wet basis)[a]

Minerals	WMS	BMS
Aluminum (Al)	2.47 ± 0.05*	3.38 ± 0.04
Calcium (Ca)	133.7 ± 0.25*	100.8 ± 0.45
Cadmium (Cd)	0.005 ± 0.01	0.002 ± 0.61
Cobalt (Co)	0.24 ± 0.15	0.21 ± 0.11
Chromium (Cr)	0.34 ± 0.20*	0.18 ± 0.12
Copper (Cu)	0.50 ± 0.70*	0.29 ± 0.25
Iron (Fe)	3.02 ± 0.5	2.90 ± 0.25
Potassium (K)	204.2 ± 1.25*	80.53 ± 1.32
Magnesium (Mg)	102.2 ± 0.80*	69.13 ± 0.75
Manganese (Mn)	0.88 ± 0.25	0.66 ± 0.21
Nickel (Ni)	0.76 ± 0.27*	1.02 ± 0.29
Lead (Pb)	0.15 ± 0.15*	0.02 ± 0.11
Zinc (Zn)	0.52 ± 0.12	0.63 ± 0.73

WMO White mahlab oil, *BMO* black mahlab oil

*$P < 0.05$

[a] Values are means ± standard deviation (SD) of two replicates

providing 16 and 12% of the recommended dietary allowances [28], respectively.

Table 8 also shows the content of potassium in black and white mahlab seeds was 204.2 and 80.53 ppm, respectively. Potassium plays an important role in human physiology, and sufficient amounts of it in the diet protect against heart disease, hypoglycemia, diabetes, obesity, and kidney disease. The content of magnesium in the studied samples (Table 8) was 102.2 and 69.13 ppm for BMS and WMS, thus providing 28.9 and 19.6% of the recommended dietary allowances [28], respectively. The concentrations of minor elements Al, Pb Ni, Mn, Cu, Cr, Co, and Fe levels were found at low levels in the studied samples.

Conclusions

The results reported here show that the seeds of two different species of mahlab plant collected in Sudan were different in their oil content and the physicochemical properties of that oil. Fatty acid composition was determined by GLC, and the major fatty acids were found to be 4.5% palmitic, 16.0% stearic, 47.3% oleic, and 31.4% linoleic in black mahlab oil. In white mahlab, the major fatty acids of the oil were found to be 5.7% palmitic, 45% oleic, and 47% linoleic acid. The amino acid profile of the defatted seeds as analyzed by amino acid analyzer indicated that the total amount of amino acids of black mahalb was 783 mg/g N and that of white mahlab was 1,223 mg/g N. The percentage of essential amino acids was 58.0% in black mahalb and 50.9% in the white mahlab. The results from sensory evaluation analysis of the two mahlab oils revealed that there was a significant difference ($P \leq 0.05$) in the average scores for color, odor, and taste in the two mahlab oils. The white mahlab oil was preferred very much by the panelists. To our knowledge, minerals and amino acids of *Monechma ciliatum* data are not available in the literature.

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References

1. Mirghani MES, Hussein IH, Dagne E, Bekele T (1996) A comparative study of seed of *Chrozophora brochiana* and *Guizotia abyssinica*. Bull Chem Soc Ethiopia 10:161–164
2. Mirghani MES (1990) Studies on conventional and new sources of vegetable oil in the Sudan. MSc Thesis, University of Gezira, Medani, Sudan
3. Mariod AA (2000) Seeds of *Sclerocarya birrea* oil and protein: quality and product development aspects. MS. Thesis, University of Gazira, Wadmedani, Sudan
4. Andrews EW (1952) The flowering plants of the Anglo-Egyptian Sudan, vol 2. T. Buracle, Arboroach, Scotland
5. Uguru MO, Okwuasaba FK, Ekwenchi MM, Uguru VE (1995) Oxytocic and oestrogenic effects of *Monechma ciliatum* methanol extract in vivo and in vitro in rodents. Phytotherap Res 9:26–29
6. Sharief MT (2002) The effect of sowing date and plant spacing on growth and yield of black mahlab (*Monechma ciliatum*). MSc Thesis, University of Khartoum, Khartoum, Sudan
7. Hedberg I, Stangard F (1989) Traditional medicine plants—traditional medicine in Botswana. Ipeleng, Gaborone
8. Uguru MO, Evans F (2000) Phytochemical and pharmacological studies on *Monechma ciliatum*. J Ethnopharmacol 73:289–292
9. Ayoub SMH, Barbiker AJ (1981) Component fatty acids from the oils of *Monechma ciliatum*. Fitoterapia 52:251–253
10. Burkill NM (1985) The useful plants of West Tropical Africa, 2nd edn. Royal Botanical Gardens, Kew
11. Bown D (1995) Encyclopedia of herbs and their uses. Dorling Kindersley, London
12. Aydin C, Ogut H, Konak M (2002) Some physical properties of Turkish Mahaleb. Biosyst Eng 82(2):231–234
13. FAO/WHO (1991) Protein quality evaluation. Report of the joint FAO/WHO expert consultation. FAO, Rome
14. Mabaleha MB, Mitei YC, Yeboah SO (2007) A comparative study of the properties of selected melon seed oils as potential candidates for development into commercial edible vegetable oils. J Am Oil Chem Soc 84:1–36
15. AOCS (ed) (1993) Official methods and recommended practices of the American Oil Chemists' Society, 5th edn. Official method Cc 13b-45, reapproved (2000). AOCS, Champaign, IL
16. Association of Official Analytical Chemists-AOAC (1990) Official methods of analysis, 15th edn. AOAC, Washington DC
17. Lourenc SO, Barbarino E, De-Paula JC (2002) Amino acid composition, protein content and calculation of nitrogen-to-protein conversion factors for 19 tropical seaweeds. Phycol Res 50:233–241
18. Balz M, Shulte E, Their HP (1992) Trennung von Tocopherol und Tocotrienolen durch HPLC. Fat Sci Technol 94:209–213
19. Sosulski FW, Imafidon GI (1990) Amino acid composition and nitrogen-to-protein conversion factors for animal and plant foods. J Agric Food Chem 38:1351–1356
20. Mossé J (1990) Nitrogen to protein conversion factor for ten cereals and six legumes or oilseeds. A reappraisal of its definition and determination. Variation according to species and to seed protein content. J Agric Food Chem 38:18–24
21. Yeoh HH, Truong VD (1996) Protein contents, amino acid compositions and nitrogen-to-protein conversion factors for cassava roots. J Sci Food Agric 70:51–54
22. Min DB (1983) Analyses of flavor qualities of vegetable oils by gas chromatography I. J Am Oil Chem Soc 80:544–545
23. Statgraphics (1985–1989) Statgraphics statistical graphics systems, v. 4.0. STSC, Rockville, MD
24. Yücel SÖ (2005) Determination of conjugated linolenic acid content of selected oil seeds grown in Turkey. J Am Oil Chem Soc 82:893–897
25. Johansson A, Laakso P, Kallio H (1997) Characterization of seed oils of wild, edible finnish berries. Z Lebensm Unters Forsch A 204:300–307
26. FAO/WHO (2009) Codex alimentarius. Current official standards. http://www.codexalimentarius.net/web/standard_list.jsp Accessed April 2009
27. Mariod AA, Ali AO, Elhussein SA, Hussien IH (2005) *Sclerocarya birrea* seed chemical composition, protein quality and product development. Sudan J Sci Technol 6:184–192
28. Food and Nutrition Board (1989) Recommended dietary allowances, 10th edn. National Academy of Sciences/National Research Council, Washington DC