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Black mahlab (*Monechma ciliatum* L.) seeds: processing effects on chemical composition and nutritional value

Abdalbasit Adam Mariod[1,]*, Eshraga Mustafa Abdalrahman[2], Mahdi Abbas Shakak[2]

[1] University of Jeddah, Alkamil, Saudi Arabia

[2] Sudan University of Science and Technology, Khartoum, Sudan

* e-mail: basitmariod58@gmail.com; aalnadif@uj.edu.sa

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Abstract:
Introduction. *Monechma ciliatum* L. seeds are rich in proteins, carbohydrates, oils and mineral contents. Researchers have focused on new production development but there is no available data on the impact of processing techniques on the quality of the seeds. Our study aimed to investigate the impact of boiling, roasting, and germination on the composition and nutritional value of *Monechma ciliatum* (black mahlab) seeds.
Study objects and methods. We analyzed 7 kg of black mahlab seeds purchased from the local market. We applied standard methods used in boiling, roasting, and germination techniques. Proximate analyses were performed using the methods of the Association of Official Analytical Chemists. Minerals were analyzed by inductively coupled plasma-mass spectrometry (ICP-MS), and fatty acids were determined by gas chromatography. Tocopherols and amino acids in processed seeds were determined by high-performance liquid chromatography.
Results and discussion. The results showed that the proximate compositions of untreated, boiled, roasted, and germinated mahlab seeds were affected by boiling, roasting, and germination techniques. Most of the nutritional values were enhanced by all the treatments. In particular, all the processing techniques increased the protein content. Boiling and roasting increased the fat content, while boiling and germination increased the fiber content. Tocopherols were higher only in the germinated samples. Amino acids were increased by all the techniques. Minerals were affected by all the techniques, except for Na, which was higher in the germinated sample.
Conclusion. Boiling, roasting, and germination enhanced significantly the chemical composition of *Monechma ciliatum* seeds, which make them a value ingredient to develop new food products.

Keywords: *Monechma ciliatum*, boiling, roasting, germination, tocopherols, fatty acids, amino acids, minerals

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INTRODUCTION

Plants are generally considered an important source of nutrients and food supplements since they are rich in nutritive components essential for humans and animals. Growing scientific evidence that supports their health benefits has led to an increase in plant-based foods and diets [1]. Seeds, which are key components of several plant-based diets, are recognized as having a wide range of potential health benefits. Replacing energy-dense foods with high protein seeds has been shown to have beneficial effects on the prevention and management of obesity and related disorders, such as cardiovascular disease, diabetes and the metabolic syndrome. A great number of people in the world depend on conventional plants to obtain remedies as pharmaceuticals. Medicinal plants are not only used as an alternative to traditional treatment if it does not exist, but they also provide an excellent source of bioactive natural products [2].

Acanthaceae is a tropical and subtropical family of dicotyledonous flowering plants rich in nutritional and medicinal components. It includes 346 genera and around 4300 species distributed across temperate regions, mostly in Indonesia, Malaysia, Africa, Brazil, and Central America. Some species have colorful flower petals and are used as a source of natural dyes. Chemically, *Acanthaceae* plants contain important secondary metabolites such as glycosides, flavonoids, alkaloids, triterpenoids, fatty acid methyl esters, and fatty acids. These compounds play an important role in many biological reactions and work against many lethal diseases [3]. Most of the *Acanthaceae* species have high therapeutic applications due to their alkaloid contents [4]. Their leaves and seeds are used to treat bronchial diseases, flu, and ulcers, as well as to relieve poisonous insect and snake bites, dry cough, and diarrhea [5].

Monechma Hochst., closely related to *Justicia* L., is an *Acanthaceae* genus that contains about 60 species mostly found in tropical and sub-tropical regions, particularly in South Africa. *Monechma* plants are well adapted to harsh environments. As reported by Darbyshire and Goyder, twelve species are recorded in Angola, two of which have recently been added to *Monechma* [6]. Although these two species are morphologically similar, especially in flower and fruit morphology, there is some morphological evidence to support their separation. In particular, there are notable differences in inflorescence form.

Monechma ciliatum is a species with unique biochemicals and phytochemicals that make it traditionally useful for many African communities, especially in rural areas. It shows significant antibacterial activity against *Bacillus subtilis*, *Staphylococcus aereus*, *Escherichia coli*, and *Pseudomonas aeraginosa*, compared to well-known antibiotics, as well as antifungal activity against *Cladosporium cucumerinum* and *Candida albicans* [7]. Studies on their seed extracts, seedcakes, and leaves reveal great contents of nutrients with antioxidant, antimicrobial and medicinal properties [8].

M. ciliatum mainly grows in tropical regions. It is found in the west and southwest of Sudan where it is well known and traditionally used. Owing to its small brownish black seeds, this species is referred to as black mahlab, or El-Mahlab El-Aswad, in Sudan. In one of our earlier works, we reported its richness in fat and other essential nutrients, as well as many benefits in traditional treatments and cosmetic uses [9]. According to that study, the protein content of the *M. ciliatum* seed was 21%, with 783.3 mg/g N as total amino acid. The main fatty acids in *M. ciliatum* fat were oleic (47.3%), linoleic (31.4%), stearic (16.0%), and palmitic (4.5%). The content of tocopherols was 45.2 mg/100 g. Boiling, roasting, and germination are traditional methods generally used to improve the nutritional properties of seeds. Studies of the impact of cooking on the nutrient contents in several seeds revealed changes in their chemical composition and nutritional components.

In another work, we studied the effect of introducing mahlab seed flour as a vegetarian food supplement on kisra (Sudanese bread made of sorghum flour) [10]. Mahlab seeds were subjected to three industrial treatments, namely boiling, roasting, and germination. The processed mahlab seed flour was added to sorghum flour and after the necessary fermentation, four samples of supplemented kisra were made. We performed proximal chemical analysis and evaluated the sensory parameters of the samples against those of conventional sorghum kisra. The results showed that the use of *M. ciliatum* seed flour as a supplement to sorghum kisra significantly improved its nutritional value. We also found that all the panelists gave 10% higher scores to sorghum kisra supplemented with roasted *M. ciliatum* seed flour, compared to the other samples.

Mbah *et al*. reported an increase in protein, fiber, iron, and zinc contents in Morenga seeds as a result of boiling and roasting. In another study, processing techniques such as boiling, roasting, soaking, and blanching significantly ($P < 0.05$) reduced tyrosine and cystine contents in black gram (*Vigna mungo*), but increased histidine [11, 12]. We also reported that boiling and roasting increased fat and protein contents and decreased moisture, carbohydrate, and fiber contents in safflower seeds [13]. We found that these processing methods had an insignificant effect on fatty acids, while Ghazzawi and Ismail showed that roasting and frying of nuts had a positive effect on the fatty acids profile and antioxidant activity [14].

Roasted watermelon seeds have fewer benefits and a lower nutritional value compared to raw seeds. They are heated at about 160 degrees Celsius for only 15 min in order to give them a delicious roasting flavor without causing them to burn and lose their nutritional value [15]. A study published in 2014 indicated that roasting sesame seeds and their subsequent fermentation enhanced their nutrient content after they were ground to a fine powder [16]. Sesame roasting and peeling decreased the content of phytates and oxalate, the compounds that affect digestion and reduce protein absorption in the intestine. Therefore, it is preferable to eat peeled and roasted sesame.

Muangrat *et al*. studied the effect of heat and time of roasting and microwave treatment on the contents of acids, free fatty acids, and iodine, as well as the saponification and peroxide number of black sesame seed oil [17]. They found that the microwave-roasted oil samples showed higher antioxidant activity due to a greater content of total phenols, sesamol, and sesamolin. This indicates that both roasting and microwave treatment are suitable methods to achieve better quality for black sesame oil products [17].

Germination is an effective technique used to improve the nutritional content of legume seeds. It decreases their fat content and increases minerals and fatty acids, thus producing healthy nutrients with bioactive components [18]. Ren *et al*. found that germination provided brown rice with considerable amounts of beneficial nutrients and bioactive compounds [19]. Due to the high cost of animal protein, researchers conduct studies on plants as an affordable source of protein. Including plant protein in the daily diet can prevent malnutrition among poor people, especially in developing countries. Sranacharoenpong *et al*. reported increasing numbers of stunted children in Africa. Stunting, or impaired growth, is caused by poor nutrition [20]. Since *M. ciliatum* seeds are rich in protein, fat, minerals, and other nutrients, they could be used to prevent this condition. These seeds are very hard to mill so they are traditionally soaked in water before milling. We aimed to study the impact of boiling, roasting, and germination processes on the composition and nutritional contents of *M. ciliatum* seeds.

STUDY OBJECTS AND METHODS

Monechma ciliatum L. seeds (7 kg) were purchased from a local market. The seeds were hand-sorted to remove broken seeds and foreign materials. Then, they were well cleaned with running tap water twice and stored in white/clear reclosable self-seal zip lock polyethylene bags (2.36”×3.94”, 4 Mil thick) at 25°C.

Boiling of *M. ciliatum* seeds. 600 g of *M. ciliatum* seeds was put into three 1.0 L beakers, 200 g in each. Water was added at a ratio of 1:4 and boiled to 100°C for 40 min on a magnetic stirrer hot plate until the seeds were cooked. The seeds were drained and dried in a 50°C vacuum oven and then ground to 0.5–0.8 mm particles in a grinder (Moulinex, Japan). Finally, they were put into white/clear reclosable self-seal zip lock polyethylene bags (2.36”×3.94”, 4 Mil thick) and stored in a refrigerator at 0–5°C at a relative humidity of 55–65% for analysis.

Roasting of *M. ciliatum* seeds. 500 g of washed and dried *M. ciliatum* seeds were arranged in 3 aluminum foil dishes and then put in an electric air oven, as described by Chirinos *et al.* with some modifications [21]. The seeds were roasted at 180°C for 20 min. The roasted seeds were left to cool to 25°C and then were ground to 0.5–0.8 mm particles in an electric grinder (Moulinex, Japan). They were stored in a refrigerator at 0–5°C at a relative humidity of 55–65% for analysis.

Germination of *M. ciliatum* seeds. In line with the method described by de Jesus *et al.*, 500 g of *M. ciliatum* seeds were soaked in 2500 mL of 0.7 g/L sodium hypochlorite solution for 30 min at 25°C [22]. Then, the seeds were well washed with running tap water twice, drained, and soaked in deionized water for 5 h. After that, they were kept between two layers of cotton cloth for 72 h at room temperature (25°C). The germinated seeds were dried in an air oven at 60°C till constant weight. Then, they were ground to 0.5–0.8 mm particles in an electric grinder (Moulinex, Japan) and stored in a refrigerator at 0–5°C at a relative humidity of 55–65% for further use. The control samples were only ground to 0.5–0.8 mm particles in an electric grinder (Moulinex, Japan) and stored in the same conditions.

Proximate chemical analysis. Moisture, crude fat, crude fiber, and ash were analyzed using the methods of the Association of Official Analytical Chemists [23]. Total nitrogen was analyzed by the micro-Kjeldahl method, with nitrogen converted to protein using the factor of 6.25. The carbohydrate content was calculated by subtracting the sum of fat, protein moisture, fiber, and ash from 100.

Mineral determination. 0.03 Ag ground sample was put in a microwave vessel containing 5.0 mL of HNO_3 and 2 mL of H_2O_2 (Suprapur, Merck). Then, it was heated to 205°C for 15 min to obtain a finely digested mixture. The mixture was left to cool to 25°C and a colorless solution was obtained. The solution was analyzed by inductively coupled plasma-mass spectrometry (ICP-MS) according to the method described by Ngigi and Muraguri with some modifications [24].

Fatty acid composition. Test seeds (15.0 g) were ground and their oil was separated in a Soxhlet extractor (Gerhardt), as indicated by the American Oil Chemists Society [25]. The removed oil was methylated and changed over to fatty acid methyl esters. Then, it was analyzed on a Shimadzu GC-2010 gas chromatograph with a DB-23 column (60 m×0.25 mm ID, 0.25 μm film thickness). The injector, column, and indicator temperatures were 230, 190, and 240°C, respectively. The split proportion was 80:1. Helium (1.0 mL/min) was used as a transporter gas.

Determination of tocopherols. A solution of 250 mg of black mahlab seeds oil in 25 mL n-heptane was used for the high performance liquid chromatography (HPLC). The HPLC analysis was conducted using a low-pressure gradient system fitted with an L-6000 pump, an F-1000 fluorescence spectrophotometer (detector wavelengths of 295 nm and 330 nm for excitation and emission, respectively), and a D-2500 integration system (Merck-Hitachi). 20 μL samples were injected by a 655-A40 autosampler onto a 25 cm×4.6 mm ID Diol phase HPLC column (Merck, Darmstadt, Germany) at a flow rate of 1.3 mL/min. The mobile phase was n-heptane/tert, butyl methyl ether (99+1, v/v) [26].

Amino acid composition. A 200 mg sample was digested with 5.0 mL 6N HCL in a hydrolysis tube. The solution was incubated at 11°C for 24 h and filtered through filter paper. Then, 200 mL of the filtered solution was evaporated at 140°C for about an hour and 1.0 mL of a diluted buffer was added to the dried sample. The amino acid composition of the hydrolyzed sample was determined on an S 433 automatic amino acid analyzer (Sykam, Germany) [9].

Statistical analysis. The analyses were performed in triplicate. The mean values and standard deviation (mean ± SD) were determined by Duncan’s test ($P < 0.05$). The measurable analysis of variance (ANOVA) was applied on all the values using a Statgrafics® Statistical Graphics System (version 18.1.12).

RESULTS AND DISCUSSION

The weight of a hundred or thousand seeds is an important characteristic of the seeds’ fullness and maturity. It also indicates the amount of flour from the seeds [27]. In our study, the average length of *Monechma ciliatum* seeds was about 4.0 mm and 100 seeds weighed about 3.0 g.

Proximate chemical composition of boiled, roasted, and germinated *M. ciliatum* seeds. The seeds' chemical composition is very important because they contain many nutrients and growth materials that affect germination. Seeds are considered a basic source of food. For example, Chia (*Salvia hispanica*) seeds are used as ingredients or supplements in many foodstuffs such as baked products, muesli, dairy drinks, fruit smoothies, or salads. They are also used as thickeners in soups and sauces [28]. The proximate compositions of untreated black mahlab boiled black mahlab, roasted black mahlab, and germinated black mahlab seeds are presented in Table l.

Moisture content. The seed's moisture, which is usually expressed as a percentage on a wet weight basis, is an important indicator that affects the seed's quality and shelf-life. In our study, the moisture content of untreated black mahlab seeds was 9.43%, while boiling, roasting, and germination decreased it to 6.91, 6.41, and 9.41%, respectively. This finding was consistent with the one we made in our earlier study, namely a decrease in the moisture of crude safflower seeds after roasting and boiling [29]. Hatamian *et al*., who studied chia seeds, also found a diminished moisture content after roasting [30].

Fat content. The fat contents of untreated and treated black mahlab seeds are shown in Table 1. The untreated black mahlab seed flour had a fat content of 11.65%, which was lower than 14.66% for untreated black mahlab and 12.39% for boiled black mahlab, but higher than 11.30% for germinated black mahlab. As we can see, boiling and roasting increased the fat content, while germination had an insignificant effect on this indicator. This result disagreed with Onyeike and Oguike, who showed that crude fat was highest in raw groundnut seeds and lowest in boiled groundnut seeds [31].

Protein content. Proteins are essential nutrients for the human body. They are the basic units of body tissue and can also serve as an energy source. Proteins provide as much energy density as sugars. Most importantly for nutrition is that protein contains amino acids [32]. The protein contents of untreated and treated black mahlab seeds are shown in Table 1. We found that all the processing methods increased the protein content. Amounting to 22.29% in untreated black mahlab, it increased to 23.89, 22.90, and 24.34% in boiled, roasted, and germinated black mahlab, respectively. Thus, boiling and germination contributed to a higher protein content, unlike roasting. This finding was consistent with that in our earlier study, where the germination of black cumin increased both the oil and the protein contents, while other constituents decreased [29]. In a study by Olanipekun *et al*., the flour from processed kidney bean seeds had a significantly higher protein content than that of the raw seeds [33]. Cargo-Froom *et al*. reported that boiling and roasting enhanced the pulses' protein content, availability, and digestibility, as well as the content of essential amino acids [34]. Similarly, Mbah *et al*. showed that boiling and roasting increased the protein content in Moringa seeds [11]. The higher protein content in the processed seeds might be due to the increase of proteolytic enzymes activity which hydrolyzed proteins to their amino acids during processing.

Fiber content. Dietary fiber includes parts of plant food that the body cannot digest or absorb. Unlike other food components (fats, proteins, or carbohydrates), which the body breaks down and absorbs, fiber passes relatively well through the stomach, small intestine, and colon, and then out of the body [35]. The fiber content in untreated and treated black mahlab seeds is shown in Table 1. As we can see, it reached 9.2, 10.1, 9.0, and 9.9% in untreated, boiled, roasted, and germinated black mahlab, respectively. It was slightly affected by roasting and germination and increased by boiling. This result agreed with Mbah *et al*. who reported that boiling and roasting increased the fiber content in Moringa seeds [11]. However, it was opposed to our earlier finding that roasting and boiling decreased the fiber content in safflower [13].

Carbohydrate content. Carbohydrates are a group of organic compounds that include sugars, starches, and fibers that provide the body with energy. During digestion, carbohydrates are converted into glucose sugar. The pancreas secretes insulin to help glucose sugar enter the cells in the brain and muscles and provide them with the energy needed to perform various functions. The excess of glucose sugar is stored in the liver in the form of glycogen to be used when needed [36]. The carbohydrate contents of untreated and treated black mahlab seeds are shown in Table 1. As we can see, the total available carbohydrates in untreated, boiled, roasted, and germinated black mahlab amounted to 43.60, 40.89, 45.62, and 41.39%, respectively. The carbohydrate content was the highest in roasted black mahlab followed by untreated, germinated, and boiled black mahlab. Our findings agreed with those of Onyeike and Oguike, who reported that boiling and

Table 1 Approximate chemical analysis of raw, boiled, roasted, and germinated *Monechma ciliatuim* seeds, %

Sample	Moisture	Fat, %	Carbohydrate, %	Protein, %	Fiber, %	Ash, %
Untreated mahlab	9.43 ± 0.03^{b}	11.56 ± 0.37^{a}	43.60 ± 0.70^{a}	22.29 ± 0.23^{a}	9.20 ± 0.22^{a}	3.92 ± 0.10^{a}
Boiled mahlab	6.91 ± 0.01^{a}	14.66 ± 0.31^{c}	40.89 ± 0.50^{b}	23.89 ± 0.29^{b}	10.11 ± 0.14^{b}	3.54 ± 0.10^{a}
Roasted mahlab	6.14 ± 0.11^{a}	12.39 ± 0.25^{b}	45.62 ± 0.70^{c}	22.90 ± 0.13^{a}	9.00 ± 0.23^{a}	3.95 ± 0.20^{a}
Germinated mahlab	9.41 ± 0.30^{b}	11.30 ± 0.08^{a}	41.39 ± 0.20^{d}	24.34 ± 0.17^{b}	9.90 ± 0.29^{a}	3.66 ± 0.10^{a}

Values are means of triplicate determinations. ^{a,b,c,d}Means in the same column followed by the same superscript are not significantly different at $P < 0.05$

frying increased the total carbohydrate content in groundnuts [31]. This indicates that *M. ciliatuim* flour is a good source of energy for consumers.

Ash content. The ash contents in untreated and treated black mahlab seeds are shown in Table 1. The ash content in untreated black mahlab was 3.92%. Insignificantly affected by all processing techniques, it amounted to 3.95, 3.66, and 3.45% in roasted, germinated, and boiled black mahlab, respectively.

Mineral content in boiled, roasted, and germinated *M. ciliatum* seeds. The mineral compositions of untreated, boiled, roasted, and germinated black mahlab seeds are presented in Table 2. The concentrations of major and trace elements in the untreated seeds were significantly ($P < 0.05$) higher than in the processed seeds. Table 2 shows how boiling, roasting, and germination affected sodium, calcium, potassium, copper, iron, zinc, magnesium, manganese, selenium, and phosphorus contents in *M. ciliatum* seeds. As we can see, the three processing treatments varied in their effects on the mineral contents.

The sodium (Na) content in untreated black mahlab was 264.1 mg/kg. This value insignificantly decreased to 251.6 mg/kg in untreated black mahlab, significantly decreased to 227.4 mg/kg in roasted black mahlab, and insignificantly increased to 270.7 mg/kg in germinated black mahlab.

The calcium (Ca) content in untreated black mahlab was 4911 mg/kg. After treatment, it significantly decreased to 4158.5, 4666.3, and 3880.3 mg/kg in boiled, roasted, and germinated black mahlab, respectively. The roasted sample had the highest content of calcium.

The potassium (K) content in untreated black mahlab was 7812.7 mg/kg. After treatment, it decreased significantly to 4787.6 mg/kg in boiled black mahlab and insignificantly to 7702.6 and 7140.0 mg/kg in roasted and germinated black mahlab, respectively. The roasted *M. ciliatum* seeds had the highest content of potassium.

The copper (Cu) content in untreated black mahlab was 12.40 mg/kg. It did not change significantly after the treatments, amounting to 12.11, 11.53, and 11.73 mg/kg in boiled, roasted, and germinated black mahlab, respectively.

The iron (Fe) content in untreated black mahlab was 166.5 mg/kg. After treatment, it significantly decreased to 59.2 and 89.6 mg/kg in boiled and roasted black mahlab, respectively, and insignificantly decreased to 162.2 mg/kg in germinated black mahlab.

The zinc (Zn) content in untreated black mahlab was 23.66 mg/kg. After treatment, it significantly decreased to 19.67 and 21.36 mg/kg in boiled and roasted black mahlab, respectively, and insignificantly decreased to 22.88 mg/kg in germinated black mahlab. The germinated sample was the richest in zinc.

The magnesium (Mg) content in untreated black mahlab was 4747.2 mg/kg. After treatment, it significantly decreased to 4387.6 and 4367.3 mg/kg in boiled and germinated black mahlab, respectively. However, roasting had no significant effect on the magnesium content, which amounted to 4747.6 mg/kg in roasted black mahlab.

The manganese (Mn) content in untreated black mahlab was 93.19 mg/kg. This value significantly decreased after treatment, amounting to 66.02, 84.79, and 67.36 mg/kg in boiled, roasted, and germinated black mahlab, respectively. The roasted sample was the richest in manganese.

The selenium (Se) content in untreated black mahlab was 0.56 mg/kg. It did not change significantly after boiling, amounting to 0.54 mg/kg in boiled black mahlab. However, it significantly decreased to 0.26 and 0.41 mg/kg in roasted and germinated black mahlab, respectively.

The phosphorus (P) content in untreated black mahlab was 3059.5 mg/kg. It did not change significantly after germination, amounting to 3002.7 mg/kg in germinated black mahlab. However, it significantly increased to 3118.8 and 3205.8 mg/kg in boiled and roasted black mahlab, respectively. The roasted sample had the highest content of phosphorus.

Thus, the three processing treatments generally decreased the contents of minerals in the raw seeds. Sodium was decreased by boiling and roasting, but increased by germination. Iron and zinc were insignificantly affected by boiling and roasting. Magnesium was not affected by roasting but it was decreased by boiling and germination. Selenium slightly diminished with boiling but significantly diminished after roasting and germination. However, the roasting technique contributed most to the minerals retention, followed by germination and then boiling. This might be due to the fact that minerals leached from the seeds into distilled water at different rates during cooking. This result agreed with Kinge *et al.*, who reported that boiling and roasting of Djansang (*Ricinondron*

Table 2 Effects of boiling, roasting, and germination on the mineral contents (g/kg) in *Monechma ciliatum* seeds

Sample	Na	Ca	K	Cu	Fe	Zn	Mg	Mn	Se	P
Untreated mahlab	264.1^a	4911.2^a	7812.7^a	12.40^a	166.5^a	23.66^a	4747.2^a	93.19^a	0.56^a	3059.5^a
Boiled mahlab	251.6^b	4158.5^b	4787.6^b	12.11^a	59.2^d	19.67^b	4387.6^b	66.02^b	0.54^a	3118.9^b
Roasted mahlab	227.4^c	4666.3^c	7702.6^c	11.53^b	89.6^c	21.36^a	4747.6^a	84.79^c	0.26^b	3205.8^c
Germinated mahlab	270.7^d	3880.3^d	7140.0^d	11.73^b	162.5^b	22.88^a	4367.2^b	67.36^d	0.41^c	3002.7^d

Values are means of triplicate determinations ± S.D. ^{a,b,c,d} Means in the same column followed by the same superscript are not significantly different at $P < 0.05$

heudelotii L.) seeds significantly increased the amount of phosphorous, iron, calcium, and magnesium [37]. Boiling retained those minerals better than roasting. However, the amounts of potassium and sodium were significantly lower in the boiled samples compared to the roasted ones. Their study concluded that the roasting process preserved minerals better than boiling. Our findings were also consistent with the ones we made earlier, namely that the contents of major elements in raw safflower seeds were higher than in the roasted and boiled seeds [13]. According to Table 2, only sodium and phosphorus were significantly increased by germination and roasting, respectively.

Fatty acid composition of the oil from boiled, roasted, and germinated *M. ciliatum* seeds. The human body uses essential fatty acids (EFAs) to produce healthy cell membranes and benefit from their multiple biological roles. In particular, they influence the inflammatory cascade, reduce the oxidative stress, and provide neural and cardiovascular protection. A significant factor in various illnesses, fatty acid levels are used to distinguish potential biomarkers for a few pathologies, for example, polycystic ovary condition [38]. Some treatments, such as progressive heating, can influence the arrangement of fatty acids in food [39].

The compositions of fatty acids in untreated and treated *M. ciliatum* seed oils (untreated, boiled, roasted, and germinated black mahlab) determined by gas chromatography are presented in Table 3. As we can see, oleic and linoleic were the major fatty acids. The untreated sample had 68.15% of unsaturated fatty acids and 31.40% of saturated fatty acids. Boiling slightly changed the composition of unsaturated fatty acids and decreased the content of saturated fatty acids to 22.82%. Palmitic acid increased from 6.11% in untreated black mahlab to 31.80 and 21.80% in roasted and germinated black mahlab, respectively. Myristic acid increased from 0.14% in the untreated seeds to 4.46 and 8.43% in roasted and germinated black mahlab, respectively. Oleic and linoleic acids decreased from 44.87 and 16.84% in the untreated samples to 39.21 and 10.26% in roasted black mahlab and to 29.40 and 9.16% in germinated black mahlab, respectively. It was clear that roasting and germination increased the content of saturated fatty acids and decreased that of unsaturated fatty acids. These results disagreed with our previous study, where fatty acids of black cumin seeds did not change with roasting and boiling [29]. Ali *et al.* found that the relative content of polyunsaturated fatty acids decreased while that of saturated fatty acids increased in groundnut seed oil exposed to microwave heating [35]. However, the roasting process slowed down the oxidative deterioration of polyunsaturated fatty acids.

Tocopherol composition of the oil from boiled, roasted, and germinated *M. ciliatum* seeds. Tocopherols are fat-soluble compounds with vitamin E. This is a term for eight different molecules, namely *α*-, *β*-, *γ*-, *δ*-tocopherol, and the corresponding tocotrienols. The activity of vitamin E in humans is related to its antioxidant properties. It is synthesized only in photosynthetic organisms and acts as a protective component. Tocopherol has also been found to be crucial for seed storage and germination [40]. The nutritional benefits of vitamin E (α-tocopherol) and its importance in the daily diet have been well documented. The contents of total tocopherols in treated and untreated *M. ciliatum* seeds oil are shown in Table 3. As we can see, the total tocopherol concentration decreased during boiling and roasting as a result of heating. However, it was significantly increased by germination. In particular, the content of tocopherols in the untreated oil was 0.11 mg/100 g. This amount was affected equally by boiling and roasting,

Table 3 Boiling, roasting, and germination effects on fatty acids (%) and tocopherols (mg/100 g) in *Monechma ciliatum* seed oil

Fatty acids		Untreated mahlab	Boiled mahlab	Roasted mahlab	Germinated mahlab
C12	Lauric	0.859[a]	1.807[b]	2.258[c]	20.427[d]
C14	Myristic	0.140[a]	0.124[a]	4.462[b]	8.433[c]
C16	Palmitic	6.116[a]	6.495[a]	31.804[b]	21.806[c]
C18	Stearic	3.238[a]	3.236[a]	6.135[b]	3.806[a]
C20	Archidic	9.183[a]	9.020[a]	–	–
C22	Behenic	0.839[a]	0.829[a]	–	–
C23	Tricosanoic	7.033[a]	6.626[b]	–	–
C24	Lignoceric	3.994[a]	3.709[a]	–	–
C16:1	Pamitoleic	0.251[a]	0.270[a]	4.083[b]	2.177[c]
C18:1	Oleic	44.878[a]	44.420[a]	39.216[b]	29.408[c]
C18:2	Linoleic	16.480[a]	16.734[a]	10.264[b]	9.159[c]
C20:1	Eicosenoic	6.545[a]	6.453[a]	1.378[b]	0.73[c]
Saturated		31.402[a]	22.826[b]	45.059[c]	54.203[d]
Unsaturated		68.154[a]	67.881[b]	54.941[c]	41.475[d]
Tocopherol		0.11[a]	0.10[a]	0.10[a]	0.18[b]

[a,b,c,d] Means in the same row followed by the same superscript are not significantly different at $P < 0.05$

Table 4 Boiling, roasting, and germination effects on amino acids in *Monechma ciliatum* seeds, g/100 g

Amino acid	Untreated mahlab	Boiled mahlab	Roasted mahlab	Germinated mahlab
Aspartic acid	2.294	2.349	2.285	2.514
Serine	1.555	1.665	1.576	1.676
Glumatic acid	2.485	3.679	3.386	3.824
Glycine	1.165	1.224	1.243	1.229
Histidine	0.525	0.559	0.586	0.525
Arginine	2.532	2.930	2.889	2.889
Therionine	1.014	1.111	1.092	1.096
Alanine	1.130	1.207	1.170	1.213
Proline	1.157	1.276	1.198	1.306
Threonine	0.695	0.744	0.743	0.750
Valine	1.215	1.318	1.262	1.354
Methionine	0.300	0.000	0.023	0.000
Lysine	1.386	1.453	1.246	1.462
Isoleucine	1.009	1.123	1.061	1.124
Leucine	1.912	2.130	2.003	2.112
Phenylalanine	1.017	1.124	1.134	1.164
Total	22.291	23.894	22.899	24.336

Values are means ± SD

decreasing to 0.10 mg/100 g in both boiled and roasted black mahlab. Germination, however, increased it to 0.18 mg/100 g. Our results agreed with Junmin *et al.*, who reported that the roasting of sesame seeds at 160°C for 30 min led to a steady decrease in total tocopherols and sesamolin [41].

Amino acid composition in boiled, roasted, and germinated *M. ciliatum* seeds. Table 4 shows the amino acid composition in the treated and untreated *M. ciliatum* seeds. Generally, amino acids increased with boiling, roasting, and germination, except for methionine acid which was decreased by all the treatments. Aspartic acid and lysine were decreased by roasting. Total amino acids in the untreated black mahlab seeds amounted to 22.291 g/100 g. They increased to 23.894, 22.899, and 24.336 g/100 g in the boiled, roasted, and germinated samples, respectively. The roasted sample had the lowest content of total amino acids due to the decrease in aspartic acid and lysine. These results were in agreement with those in our earlier work, where we observed extremely high contents of amino acids in the boiled and roasted safflower seeds, compared to the fresh samples [13]. This finding was also consistent with that of EL-Suhaibani *et al.*, who found that germination and cooking of goat pea (*Securigera securidaca* L.) seeds increased the proportion of essential amino acids [42]. They also reported that soaking and cooking processes increased valine, phenylalanine, isoleucine, and leucine, but reduced methionine and lysine. Our results disagreed with those reported by Nwosu *et al.*, who found that boiling black gram (*Vigna mungo* L.) seeds for 120 min generally decreased the concentration of leucine, lysine, and arginine [12]. Blanching and soaking improved the concentrations of lysine, isoleucine, and histidine, compared to the control samples.

CONCLUSION

Generally, most of the nutritional factors were enhanced by processing treatments. All the treatments increased protein and amino acids. Boiling and roasting increased the fat content, while boiling and germination increased the fiber content. Saturated fatty acids were higher and unsaturated fatty acids were lower in the roasted and germinated samples. Minerals were decreased by all the treatments, except for sodium which increased in the germinated sample. Our results can be applied in large-scale research experiments with *Monechma ciliatum* L. seeds used as a food product, supplement, or ingredient in new products.

CONTRIBUTION

Abdalbasit Adam Mariod conceived and designed the analysis, contributed data and analysis tools, and wrote the paper. Eshraga Mustafa Abdalrahman Mustafa collected the data, performed the analysis, and wrote the paper. Mahdi Abbas Shakak contributed data and analysis tools and wrote the paper.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest related to this article.

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ORCID IDs
Abdalbasit Adam Mariod https://orcid.org/0000-0003-3237-7948
Eshraga Mustafa Abdalrahman https://orcid.org/0000-0002-0892-3286