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ORIGINAL PAPER

# Effect of germination and roasting on oil profile of *Moringa oleifera* and *Moringa peregrina* seeds

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## Abstract

Roasting and germination effect on fatty acids, tocopherols and triacylglycerols of *Moringa oleifera* and by *Moringa peregrina* seeds oils were investigated. Significant differences were indicated between both species. Oil content and oleic acid were higher in *Moringa peregrina* (51.22 and 70.76%) than *Moringa oleifera* (36.90 and 65.78%), while *Moringa oleifera* had higher tocopherols content than *Moringa peregrina* (28.8 and 11.45 mg/100 g), respectively. Triolein was the most abundant triacylglycerol in *Moringa oleifera* and *Moringa peregrina* seeds oils accounting for 38.28 and 34.32%, respectively. An increase had occurred in total unsaturated fatty acids and oil content, while total saturated fatty acids decreased in both species after germination. Triolein increased and α, β, γ and δ-tocopherols amounts decreased after germination in *Moringa oleifera* seed oil, while in *Moringa peregrina* seed oil no significant differences were reported. Roasting led to an increase in behenic, stearic and arachidic, while palmitic acid decreased in both species. The best treatment in roasting was 150 ºC for 20 min which reported the highest amount of oleic acid (66.92 and 72.54%) and the lowest content of elaidic acid (0.10 and 0.13%) in *Moringa oleifera* and *Moringa peregrina* seeds oils, respectively.

**Keywords** *Moringa oleifera* · *Moringa peregrina* · Roasting · Germination · Fatty acids · Tocopherols

## Introduction

In recent years people using herbal medicines has increased in many parts of the world. These medicinal herbs are used in treating many diseases in addition to the few side effects which they have compared to medications.

*Moringa oleifera* (MO) and *Moringa peregrina* (MP) are the most common species in Moringaceae family. MO is a deciduous tree occasionally growing up from 10–15 m in height. It has huge rootstock and a single main trunk with an open, wide and umbrella shaped crown [1]. The weight of the seed is 0.3 g and the kernel represents about 70–75% of the weight [2]. The dried seeds are round or triangular in shape and surround by a light woody shell with three papery wings [3, 4]. MO produces three thousands kg seed from 1 hectare, that can produce 1200 kg edible oil, while soybean which produces 350–400 kg oil from 1 hectare [5]. A single tree of MP may produce up to 1,000 pods per year and length of the pods may vary from 20 to 40 cm. Each pod contains 8–15 ovoid, un-winged, triangular seeds [6]. MO is highly used in different places of Africa and Asia, for its nutritious leaves, flowers, pods and oilseed.

MO seeds contain about 31.3 and 28.8% for protein and fat, respectively [7], and it is rich in essential amino acids especially leaves which are rare in daily diets [8, 9] so many countries use it as a food [10]. It is available at all times of the year. Also, all of its parts can be used as food for humans and animals [11]. Leaves (young and mature) and flowers are consumed as greens or in salads, soups and sauces [1]. It has an effect as antiepileptic, antipyretic, anti-inflammatory, antiulcer and antitumor agent [10, 12–14].

*Moringa peregrina* (MP) is a very good source of antioxidants like, tocopherols, carotenoids, vitamin C, flavonoids, and phenolic compounds [15, 16]. The plant grows in a large geographical area Red Sea, Arabia and Northeast Africa [17].

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*Moringa oleifera* (MO) seed oil is characterized by containing a large amount of unsaturated fatty acids, especially oleic. It is also distinguished as being stable against rancidity because it contains a small content of linoleic acid [18]. Triolein (OOO) is the predominant triacylglycerol in moringa oil reaching 36.7% [7].

Food processing improves flavor, shelf life, nutritional value and other benefits. Among several known methods for improving the acceptability of food materials for human consumption, cooking perhaps is the most popular. Heat is used in traditional cooking process to kill the microorganisms that cause diseases, making food safe and healthy [19].

Many researchers studied roasting and germination effect on chemical composition and anti-nutritional factors in moringa. Chinma et al. [20] reported that germination caused an increase in the protein, ash contents and the water and oil absorption capacities, while fat, carbohydrate, crude fiber contents, protein solubility, foaming capacity and gel consistency decreased. Mbah et al. [21] studied the effect of roasting of moringa seed on nutrient and anti-nutrients and reported that roasting led to an increase in the fiber, vitamin A, protein, iron and zinc content and decreased tannin level while the saponin, phytate and oxalate levels increased. Different findings were obtained by Ijarotimi et al. [22] who reported a decrease in phytate and saponins after moringa seeds germination while an increase was observed in protein amount and energy value in comparison with the raw seeds. To our knowledge, this is the first work to study roasting and germination effect on the oil profile of *Moringa oleifera* (MO) and *Moringa peregrina* (MP).

## Materials and methods

### Materials

Dried moringa pods were provided from Agricultural Research Center, Kafrelcheikh City (Sakha), Egypt, in summer 2017. The samples were analyzed in summer 2017.

### Chemicals

Petroleum ether (40–60 ºC analytical grade > 98%), heptane, tocopherols standards, sodium methylate, sodium hydrogen sulphate (monohydrate, extra pure) and tert-butyl methyl ether (HPLC grade) were purchased from Merck (Darmstadt, Germany). Standard fatty acid methyl esters were obtained from Restek (Bad Homburg, Germany).

### Samples preparation

Moringa seeds were removed from the pods and the coat was removed from the seeds.

### Germination of moringa seeds

The method of Chinma et al. [23] was adopted for the germination of moringa seeds. In brief, for 12 h, the seeds were put in tap water (the soaking water was changed every 2 h to prevent fermentation) at 25 ± 2 ºC. After soaking, the seeds were drained, put on a jute bag, covered with a wet cotton cloth and left for 72 h to germinate. Every 12 h, water was sprayed to make germination process easy. Germinated seeds were dried at 60 ºC in an air-dry oven and grinded using a mill (IKA, model A11 BS000, Germany). Samples were stored at – 18 ºC for 24 h until use.

### Roasting of moringa seeds

Whole moringa seeds and kernels were roasted according to Mbah et al. [21] with some modification. Three different temperatures (100, 150 and 200 ºC) were used for 10 and 20 min. After the end of roasting process, samples were grinded using a mill (IKA, model A11 BS000, Germany). The roasted powder were stored at – 18 ºC for 24 h until use.

### Oil extraction

Oil content was determined with method DGF, B-I-5–12 [24] using a Twisselmann apparatus. In brief, five gram of the dried seeds were grounded in a mill (IKA, model A11 BS000, Germany) and extracted using 75 mL petroleum ether in a Twisselmann apparatus for 6 h at 70 ºC. The solvent was eliminated by a rotary evaporator (model RV 10 C S93, IKA-Werke GmbH & Co. KG, Stauffen, Germany) at 40 °C and 25 Torr. Solvent residue was evaporated by stream of nitrogen.

### Determination of fatty acid composition in the seed oil

Method DGF-C-VI 10–13 [24] was used to determine the fatty acid compositon in the seed oil together with method DGF-C-VI 11d-98 [24]. The oil sample (one drop) was put in a tube and dissolved in n-heptane (1 mL). Sodium methylate (50 mg) was added to the tube and agitated for 60 s at 25 ± 2 ºC. Centrifugation was used (3000 xg for 5 min) after adding 100 µL of water to the tubes and carefully the lower aqueous phase was removed. HCL (1 mol with methyl orange (Merck, Darmstadt, Germany)) (50 µL) was added and the lower phase was eliminated after shortly mixing the solution. After adding sodium hydrogen sulphate (20 mg) (monohydrate, extra pure) the tube was centrifuged 3000 × *g* for 5 min. The top phase (*n*-heptane) was taken to a vial for injection in GC (HP5890, Agilent Tech.

GmbH & Co. KG, Waldbronn, Germany) with CP-Sil 88 a capillary column, (100 m length, 0.25 mm ID, 0.2 µm film thickness). The temperature program was prepared as follows: from 155 °C to 220 °C (1.5 °C/min) and then 10 min in isotherm; injector 250 °C; detector 250 °C; carrier gas 36 mL/min hydrogen; gas flow is 1.1 mL/min; split ratio 1:50; detector gas 30 mL/min hydrogen; 300 mL/min air and 30 mL/min nitrogen; the injection volume was 1 µL; Flame Ionisation Detector (FID) has been used as a detector. The peak areas were computed by the integration software, and percentages of fatty acid methyl esters (FAME) were obtained as weight percent by direct internal normalization.

### Determination of triacylglycerol profile in the seed oil

The triacylglycerol profile in the seed oil was determined by gas chromatography according to method DGF-C-VI 14–08 [24]. In brief, 50 to 100 mg of the melted sample were solved in 10 mL iso-octane and 1 µL was injected by an autosampler onto a RTX-65 column (30 m length, 0.32 mm ID, 0.1 µm film thickness) (Resteck GmbH, Bad Homburg, Germany) using an Agilent 6890 GC-System combined with an Agilent 7683B injector (Agilent, Technologies Deutschland GmbH & Co. KG, Waldbronn, Germany). A Flame Ionisation Detector (FID) was used as a detector.

Further parameters were as follows: hydrogen as carrier gas, split ratio 1:40, injection and detection temperature adjusted to 380 °C, temperature program, 300 °C to 360 °C at 2 °C/min, then 10 min isotherm. Peaks were identified by comparison with triacylglycerol composition of other fats and data from literature.

### Determination of tocopherol content in the seed oil

For identification and determination of tocopherols in the seed oil, method DGF-F-II 4a-00 [24] was used. 150 mg of oil were dissolved in *n*-heptane (1 mL) followed by two stages of filtration, the first one with a syringe filter of 1.0 µm and the second of 0.45 µm. After filtration the sample was directly injected to the HPLC. The HPLC analysis was conducted using a Merck-Hitachi low-pressure gradient system, fitted with pump (L-6000), a Merck-Hitachi F-1000 fluorescence spectrophotometer, and a ChemStation integration system. The samples (20 µL) were injected by an autosampler (Merck 655-A40). A Diol phase HPLC column (25 cm length × 4.6 mm internal diameter with 5 µm particle size, Merck, Darmstadt, Germany) was used with *n*-heptane and tert-butyl methyl ether (99 + 1, v/v) as a mobile phase. The system was operated at a flow rate of 1.3 mL/min.

### Statistical analysis

The data were statistically analyzed by software of SPSS (Version 16.0, SPSS Inc., Chicago, IL) to test the variance by one-way analysis of variance (ANOVA) method [25].

## Results and discussion

### Effect of germination on oil yield

Figure 1 shows the amount of oil after germination of two species. Germination led to an increase in oil yield in MO from 39.2 to 42.4% and in MP from 54.2 to 55.6%. This observation is similar to the findings by Frank et al. [26] and Mariod et al. [27], who observed an increase in the oil level of germinated fluted pumpkin seeds and black cumin seeds, respectively. Also, Shi et al. [28] reported that soybean seeds germination caused an increase in oil amount during first three days (the period of our study) after that it decreased. On the contrary, different results were found during sesame seeds germination [29].

### Effect of germination on fatty acid composition in the seed oil

Total unsaturated fatty acids of raw MP was higher than in MO (Fig. 2). Oleic acid reached 70.76% in MP, while in MO the amount was 65.78%. Vaccenic acid was higher in MO and MO had higher total saturated fatty acids than MP but stearic and palmitic were higher in MP.

Özcan et al. [30] reported that stearic acid was higher in MP than in MO while behenic acid was higher in MO than in MP which were similar to our results. Palmitic

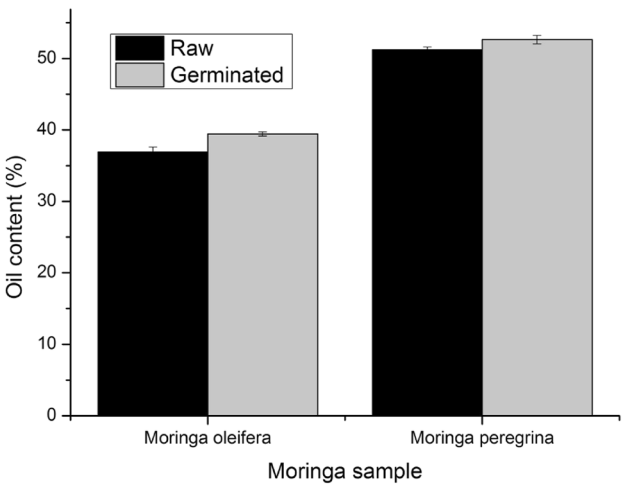


**Fig. 1** Oil contents (%) of raw and germinated *Moringa oleifera* and *Moringa peregrina* seeds

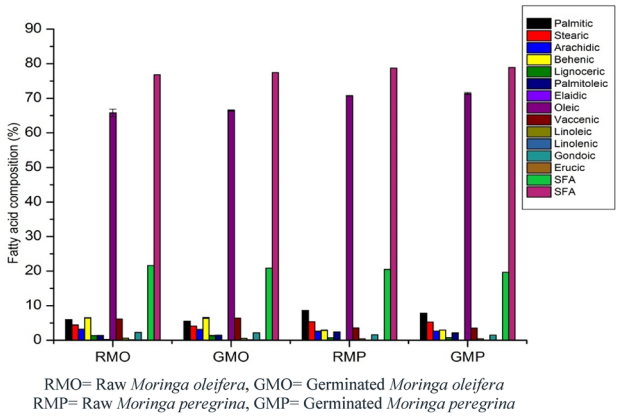


**Fig. 2** Fatty acid composition (%) of raw and germinated *Moringa oleifera* and *Moringa peregrina* seeds oils. *RMO* raw *Moringa oleifera*, *GMO* germinated *Moringa oleifera, RMP* raw *Moringa peregrina*, GMP germinated *Moringa peregrina*

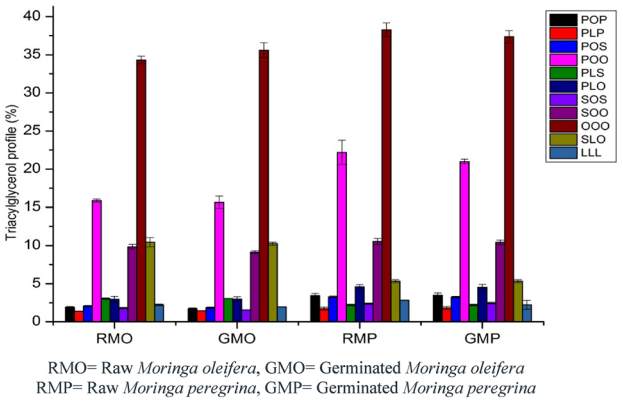


**Fig. 3** Triacylglycerol profile (%) of raw and germinated *Moringa oleifera* and *Moringa peregrina* seeds oils. *RMO* raw *Moringa oleifera*, *GMO* germinated *Moringa oleifera, RMP* raw *Moringa peregrina*, GMP germinated *Moringa peregrina*

acid reached 5.9% in MO which was similar to Abdulkarim et al. [31] (6.1%). Özcan et al. [30] mentioned higher values for palmitic acid than ours in MO and MP. The amount of oleic acid in MO found in the current work was slightly lower than in results published by Abdulkarim et al. [31], Nzikou et al. [32], Tsaknis et al. [33] and Özcan et al. [30], which reached 70.0, 74.9, 73.6 and 73.8 g/100 g, respectively. The reason might be that oleic acid and cis-vaccenic acid come close together in the GC chromatogram which makes it difficult to separate the two fatty acids. Thus, the percentage of oleic acid in some publications includes the percentage of cis-vaccenic acid. The sum of oleic acid and cis-vaccenic acid was presented as oleic acid as 71.2 g/100 g [34]. On the other side Vlahov et al. [3] described MO oil as "oleic-vaccenic acid oil" with 66.9 g/100 g oleic acid and 7.3 g/100 g cis-vaccenic acid, comparable to the current paper. In comparison to other edible oils, MO and MP contained high amounts of behenic acid (6.49 and 2.89%, respectively) while in oils such as rapeseed or sunflower oils only 0.5 to 2.0%, respectively were found and only peanut oil contains up to 4.5 g/100 g [35]. The results for behenic acid found in the current paper were similar to others reported by Abdulkarim et al. [31] (5.40%) and Anwar et al. [36] (7.0%). In comparison with other uncommon vegetable oil, moringa oil had higher amount of oleic acid (65.78 and 70.76% for MO and MP, respectively) than peanut (50.94%), grape seed oil (17.20%) and tomato seed oil (22.48%), while linoleic acid was higher in peanut (35.17%), grape seed (75.02%) and tomato seed (58.47%) than in moringa oil [37–39], resulting in a higher stability of moringa oil in frying. Linoleic acid in moringa oil (0.62 and 0.42% for MO and MP, respectively) was lower than in olive oil which ranged between 7.60–15.39%, while the amount of oleic acid varies according to the variety of olive oil ranged between 61.41–75.77% [40].

Generally, total saturated fatty acids decreased and total unsaturated fatty acids increased for MO and MP seeds oils as a function of the germination process. Similar results were observed after germination of black cumin seed by Mariod et al. (27), while Wanasundara et al. [41] reported different observation after flax seed germination for 8 days, but after 4 days of germination (near to 3 days period in the current study) no significant differences appeared.

As it obvious in Fig. 2, the germination process led to a decrease in palmitic and stearic acids in MO seed oil, while other saturated fatty acids did not change significantly. Elaidic, gondoic and erucic acids decreased after the germination process in MO. On the contrary, palmitoleic, oleic, linoleic and linolenic acids were not affected. In the case of MP, palmitic, palmitoleic and gondoic acids decreased as a function of the germination while an increase had occurred in lignoceric acid. The non-significant changes found for oleic acid were in agreement with Wanasundara et al. [41] who reported that, germination did not affect the oleic acid content after four days of germination. Same findings with ours were reported by Hahm et al. [29] about the decrease of palmitic acid after sesame seeds germination and no significant changes had appeared for stearic and oleic acids.

## Effect of germination on triacylglycerol profile in the seed oil

POO, SOO, OOO and SLO were the main dominant triacylglycerols in both MO and MP seeds oils (Fig. 3). MO had more SLO and PLS than MP while the other triacylglycerols were more in MP. As a result of containing higher amounts of oleic acid (70.76%) in MP the amount of OOO was remarkable higher in MP (38.3%) than in MO (34.3%).

The amount of OOO was higher than the results reported for soybean (2.5%), rapeseed (28.7%) and palm oil (4.0%) [42], while in olive oil it ranged between 30–50% [43].

The data show that, in the case of MO, germination led to a decrease of some triacylglycerols like POP, POS, SOS, SOO and LLL, while no significant differences were reported for PLP, POO, PLS, PLO and SLO. Only, OOO increased from 34.32 to 35.59% after germination.

This may be result from the increase of oleic acid after germination in MO. As for MP triacylglycerols, it could be noted that, POP, PLP, POS, PLS, PLO, SOO, OOO and SLO did not change significantly after germination process. Only POO and LLL decreased while SOS slightly increased after germination from 2.37 to 2.46%.

## Effect of germination on tocopherols content in the seed oil

The data presented in Fig. 4 show the tocopherols level of MO and MP raw and germinated samples. Generally, MO seed oil had higher level of tocopherols than MP seed oil which was in harmony with the results reported by Al Juhaimi et al. [44] while it was different with Özcan et al. [30]. α and γ-Tocopherols were the main tocopherols in both accounting for 20.92, 5.77, 10.22, and 1.08 mg/100 g in MO and MP seeds oils, respectively. δ-Tocopherol reached 1.10 mg/100 g in MO seed oil, while it was not detected in MP seed oil. The results reflected that germination process led to a decrease of all tocopherols in MO seed oil. In the case of MP seed oil, germination did not affect the content significantly.

The decrease of γ-tocopherol was in agreement with Carciochi et al. [45] and Li et al. [46] who studied the germination effect on quinoa seeds and flaxseeds. Different results were obtained by Tarasevičienė et al. [47] and Suryanti et al. [48] who reported that α-tocopherol increased after germination of some seeds.

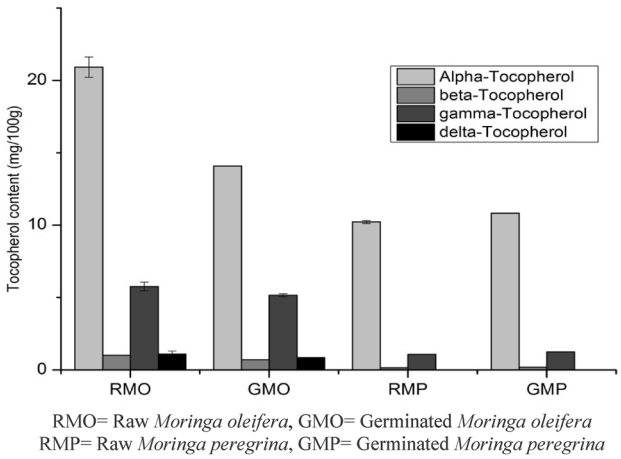


**Fig. 4** Tocopherol content (mg/100 g) of raw and germinated *Moringa oleifera* and *Moringa peregrina* seeds oils. *RMO* raw *Moringa oleifera*, *GMO* germinated *Moringa oleifera, RMP* raw *Moringa peregrina*, GMP germinated *Moringa peregrina*

## Effect of roasting on fatty acids composition in the seed oil

The fatty acid profile of MO seed oil submitted to different roasting conditions is presented in Table 1. The results show that, total saturated fatty acids increased as a result of increasing temperature and the time of roasting in comparison with the oil from the unroasted sample. The highest percentage of total saturated fatty acids was obtained at 150 ºC for 10 min reaching 23.20% and the lowest was found at 200 ºC for 20 min reaching 22.02%. Some saturated fatty acids decreased as a result of the roasting process like myristic, palmitic and lignoceric compared to the oil from unroasted sample.

Stearic, behenic and arachidic acid increased significantly during roasting process to the control. As for unsaturated fatty acids, elaidic acid was not detected at 100 ºC for both 10 and 20 min and at 150 ºC for 10 min, after that it started to appear at 150 ºC for 20 min (0.10%) and reached highest amount at 200 ºC for 20 min (4.88%).

No significant differences appeared for the content of oleic acid between oil from unroasted and roasted samples until using 150 ºC for 20 min which recorded the highest level of oleic acid (66.92%). Erucic acid was not detected in MP seed oil and only a small amount was found in MO seed oil (0.12%). Different results were mentioned by Kowalski et al. [49], Sagan et al. [50] and Xie et al. [51] for erucic acid in rapeseed oil reaching 0.36, 0.003, and 0.03%, respectively. Erucic acid decreased during roasting process compared to control sample.

In the case of MP seed oil, similar results were reported (Table 2). Generally, roasting of MO and MP seeds at 150 ºC for 20 min was the best treatment. This treatment led to an increase in total unsaturated fatty acids in MO and MP seeds oils accounting for about 77.22 and 80.55%, respectively. Also, using the previous treatment caused an increase in oleic acid accounted for 66.92 and 72.45% in MO and MP seed oils, respectively. In addition, the lowest amount of elaidic and erucic acids were found for this treatment.

Similar results with increasing stearic acid and decreasing oleic acid were mentioned by Omosuli et al. [52] who studied the effect of cabinet oven drying at 60 ºC for 2 h in *Moringa oleifera* seeds oil and found that palmitic acid increased during roasting at 60 ºC for 2 h which was in contrast with our results.

**Table 1** Effect of roasting process on fatty acid composition (%) of *Moringa oleifera* seed oil

| Fatty acids | RMO | R 1 | R 2 | R 3 | R 4 | R 5 | R 6 |
|---|---|---|---|---|---|---|---|
| Myristic $C_{14:0}$ | 0.15 ± 0.023a | 0.10 ± 0.0bc | 0.09 ± 0.0c | 0.09 ± 0.0c | 0.10 ± 0.006bc | 0.10 ± 0.0bc | 0.11 ± 0.0b |
| Palmitic $C_{16:0}$ | 5.90 ± 0.139a | 5.60 ± 0.145b | 5.20 ± 0.090c | 5.55 ± 0.020b | 5.46 ± 0.140c | 5.55 ± 0.050b | 5.64 ± 0.025b |
| Margaric $C_{17:0}$ | 0.08 ± 0.010a | 0.08 ± 0.023a | 0.09 ± 0.006a | 0.08 ± 0.0a | 0.09 ± 0.010a | 0.09 ± 0.0a | 0.08 ± 0.0a |
| Stearic $C_{18:0}$ | 4.45 ± 0.112c | 5.31 ± 0.040a | 5.37 ± 0.030a | 5.48 ± 0.006a | 5.36 ± 0.275a | 5.42 ± 0.006a | 4.94 ± 0.00b |
| Arachidic $C_{20:0}$ | 3.21 ± 0.046c | 3.36 ± 0.085b | 3.56 ± 0.045a | 3.56 ± 0.010b | 3.37 ± 0.055b | 3.39 ± 0.025b | 3.34 ± 0.006b |
| Behenic $C_{22:0}$ | 6.49 ± 0.082c | 6.86 ± 0.200b | 7.44 ± 0.205a | 7.25 ± 0.035a | 6.77 ± 0.155b | 6.87 ± 0.065b | 6.69 ± 0.010bc |
| Lignoceric $C_{24:0}$ | 1.36 ± 0.023a | 1.12 ± 0.030c | 1.16 ± 0.045c | 1.19 ± 0.015c | 1.06 ± 0.025d | 1.08 ± .006d | 1.22 ± 0.00b |
| Total SFA | 21.64 | 22.43 | 22.91 | 23.20 | 22.21 | 22.50 | 22.02 |
| Palmitoleic $C_{16:1}$ $\Delta^{9c}$ | 1.42 ± 0.040d | 1.54 ± 0.006ab | 1.42 ± 0.020d | 1.58 ± 0.006a | 1.49 ± 0.065bc | 1.45 ± 0.025 cd | 1.33 ± 0.006e |
| Elaidic $C_{18:1}$ $\Delta^{9t}$ | 0.26 ± 0.029c | N.D | N.D | N.D | 0.10 ± 0.015d | 1.10 ± 0.010b | 4.88 ± 0.015a |
| Oleic $C_{18:1}$ $\Delta^{9c}$ | 65.78 ± 1.054b | 65.10 ± 0.240b | 65.75 ± 0.575b | 65.27 ± 0.035b | 66.92 ± 0.205a | 65.87 ± 0.195b | 61.87 ± 0.025c |
| Vaccenic $C_{18:1}$ $\Delta^{11t}$ | 6.15 ± 0.045c | 6.33 ± 0.015b | 6.02 ± 0.045d | 6.52 ± 0.006a | 6.03 ± 0.115d | 6.25 ± 0.025b | 5.84 ± 0.00e |
| Linoleic $C_{18:2}$ $\Delta^{9,12c}$ | 0.62 ± 0.010b | 0.60 ± 0.00c | 0.59 ± 0.015c | 0.64 ± 0.006a | 0.60 ± 0.006c | 0.56 ± 0.006d | 0.43 ± 0.006e |
| Linolenic $C_{18:3}$ $\Delta^{9,12,15c}$ | 0.17 ± 0.00b | 0.19 ± 0.006a | 0.17 ± 0.00b | 0.19 ± 0.00a | 0.18 ± 0.006b | 0.15 ± 0.00c | 0.09 ± 0.006d |
| Gondoic $C_{20:1}$ $\Delta^{11c}$ | 2.29 ± 0.012a | 1.79 ± 0.045c | 1.86 ± 0.020bc | 1.82 ± 0.006bc | 1.81 ± 0.090bc | 1.80 ± 0.015c | 1.88 ± 0.006b |
| Erucic $C_{22:1}$ $\Delta^{13c}$ | 0.12 ± 0.015a | 0.08 ± 0.012bc | 0.10 ± 0.006b | 0.09 ± 0.000bc | 0.09 ± 0.006bc | 0.08 ± 0.006c | 0.09 ± 0.006bc |
| Total USFA | 76.81 | 75.63 | 75.91 | 76.11 | 77.22 | 77.26 | 76.41 |
| Total FA | 98.45 | 98.06 | 98.82 | 99.31 | 99.43 | 99.76 | 98.43 |

Values are means ± SD. *N.D* not detected. Means having the different case letter(s) within a column are significantly different at $p \leq 0.05$

*RMO* raw *Moringa oleifera*, *R1* Roasted at 100 ºC for 10 min, *R2* Roasted at 100 ºC for 20 min, *R3* Roasted at 150 ºC for 10 min, *R4* Roasted at 150 ºC for 20 min, *R5* Roasted at 200 ºC for 10 min, *R6* Roasted at 200 ºC for 20 min

**Table 2** Effect of roasting process on fatty acid composition (%) of *Moringa peregrina* seed oil

| Fatty acids | RMP | R 1 | R 2 | R 3 | R 4 | R 5 | R 6 |
|---|---|---|---|---|---|---|---|
| Myristic C14:0 | 0.10 ± 0.010a | 0.08 ± 0.006 cd | 0.08 ± 0.00bcd | 0.09 ± 0.00ab | 0.08 ± 0.010bcd | 0.09 ± 0.006bc | 0.07 ± 0.00d |
| Palmitic C16:0 | 8.61 ± 0.075b | 8.57 ± 0.010b | 7.55 ± 0.031e | 7.91 ± 0.030d | 7.34 ± 0.068f | 8.08 ± 0.025c | 8.76 ± 0.025a |
| Margaric C17:0 | 0.16 ± 0.006a | 0.14 ± 0.012b | 0.11 ± 0.012c | 0.14 ± 0.006b | 0.11 ± 0.012c | 0.16 ± 0.012a | 0.13 ± 0.006b |
| Stearic C18:0 | 5.37 ± 0.045e | 5.87 ± 0.040b | 6.22 ± 0.032a | 5.41 ± 0.040d | 4.96 ± 0.031f | 5.60 ± 0.045c | 5.34 ± 0.025e |
| Arachidic C20:0 | 2.61 ± 0.060c | 2.78 ± 0.031b | 3.02 ± 0.030a | 2.74 ± 0.040b | 2.59 ± 0.032c | 2.71 ± 0.061b | 2.62 ± 0.021c |
| Behenic C22:0 | 2.89 ± 0.075d | 3.01 ± 0.061c | 3.47 ± 0.031a | 3.21 ± 0.012b | 3.19 ± 0.040b | 3.03 ± 0.055c | 3.00 ± 0.059c |
| Lignoceric C24:0 | 0.73 ± 0.015c | 0.79 ± 0.045ab | 0.81 ± 0.026a | 0.85 ± 0.015a | 0.79 ± 0.035ab | 0.69 ± 0.021c | 0.75 ± 0.051bc |
| Total SFA | 20.47 | 21.24 | 21.26 | 20.35 | 19.06 | 20.36 | 20.67 |
| Palmitoleic C16:1 | 2.43 ± 0.040b | 2.27 ± 0.031c | 2.09 ± 0.006d | 2.64 ± 0.040a | 1.78 ± 0.064f | 2.01 ± 0.044e | 2.45 ± 0.036b |
| Elaidic C18:1 Δ9t | N.D | N.D | N.D | N.D | 0.13 ± 0.021c | 1.92 ± 0.050b | 4.26 ± 0.031a |
| Oleic C18:1 Δ9c | 70.76 ± 0.070b | 69.70 ± 0.025d | 69.85 ± 0.401d | 70.34 ± 0.148c | 72.54 ± 0.150a | 69.87 ± 0.026de | 66.53 ± 0.093e |
| Vaccenic C18:1 Δ11 | 3.57 ± 0.010e | 3.74 ± 0.026c | 3.88 ± 0.035b | 3.86 ± 0.031b | 3.96 ± 0.031a | 3.63 ± 0.012d | 3.32 ± 0.015f |
| Linoleic C18:2 Δ 9,12 | 0.42 ± 0.010bc | 0.37 ± 0.015d | 0.44 ± 0.025b | 0.44 ± 0.006b | 0.48 ± 0.006a | 0.41 ± 0.010c | 0.33 ± 0.017e |
| Linolenic C18:3 Δ 9,12,15 | N.D | N.D | N.D | N.D | N.D | N.D | N.D |
| Gondoic C20:1 Δ11 | 1.58 ± 0.020c | 1.75 ± 0.032a | 1.72 ± 0.015a | 1.79 ± 0.015a | 1.66 ± 0.010b | 1.55 ± 0.015c | 1.55 ± 0.012c |
| Erucic C22:1 Δ13 | N.D | N.D | N.D | N.D | N.D | N.D | N.D |
| Total USFA | 78.76 | 77.83 | 77.98 | 79.07 | 80.55 | 79.39 | 78.44 |
| Total FA | 99.23 | 99.07 | 99.24 | 99.42 | 99.61 | 99.75 | 99.11 |

Values are means ± SD. *N.D* not detected. Means having the different case letter(s) within a row are significantly different at $p \leq 0.05$

*RMP* raw *Moringa peregrine*, *R1* Roasted at 100 ºC for 10 min, *R2* Roasted at 100 ºC for 20 min, *R3* Roasted at 150 ºC for 10 min, *R4* Roasted at 150 ºC for 20 min, *R5* Roasted at 200 ºC for 10 min, *R6* Roasted at 200 ºC for 20 min

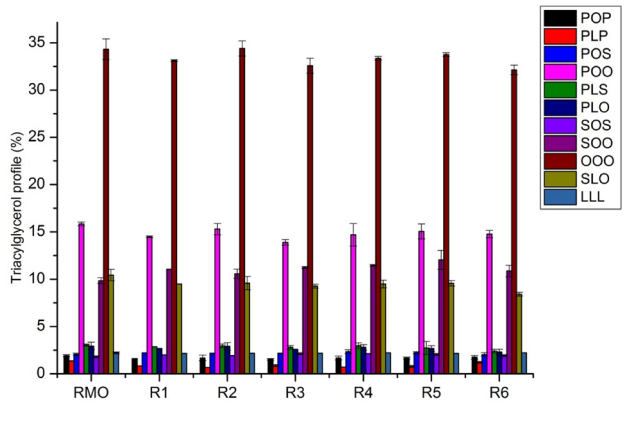


**Fig. 5** Effect of roasting process on triacylglycerol profile (%) of *Moringa oleifera* seed oil. *RMO* Raw *Moringa oleifers*, *R1* Roasted at 100 ºC for 10 min, *R2* Roasted at 100 ºC for 20 min, *R3* Roasted at 150 ºC for 10 min, *R4* Roasted at 150 ºC for 20 min, *R5* Roasted at 200 ºC for 10 min, *R6* Roasted at 200 ºC for 20 min

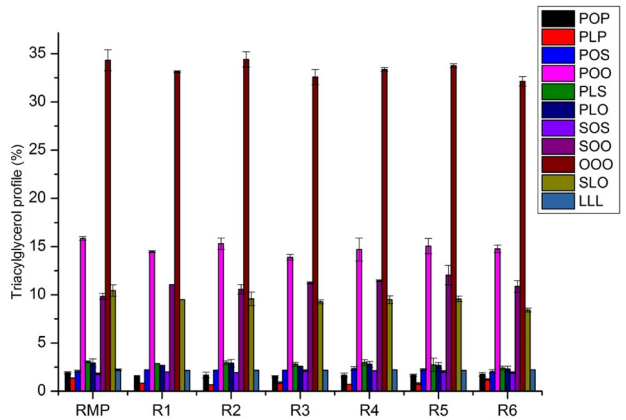


**Fig. 6** Effect of roasting process on triacylglycerol profile (%) of *Moringa peregrina* seed oil. *RMP* raw *Moringa peregrine*, *R1* Roasted at 100 ºC for 10 min, *R2* Roasted at 100 ºC for 20 min, *R3* Roasted at 150 ºC for 10 min, *R4* Roasted at 150 ºC for 20 min, *R5* Roasted at 200 ºC for 10 min, *R6* Roasted at 200 ºC for 20 min

## Effect of roasting on triacylglycerol profile in the seed oil

Roasting effect on MO seed oil triacylglycerol profile is shown in Fig. 5. The results revealed that, POP, PLP, POO, PLO, OOO and SLO decreased during roasting process compared to control, while, POS, SOS and SOO increased. In the case of MP seed oil, Fig. 6 shows the triacylglycerol profile of oil from unroasted and roasted samples. The percentage of OOO in oil from roasted MP samples decreased compared to untreated control, except using 150 ºC for 20 min showing the highest amount (40.07%) of OOO. This may be due to the effect of roasting on oleic acid in MP (Table 2) that increased during this treatment.

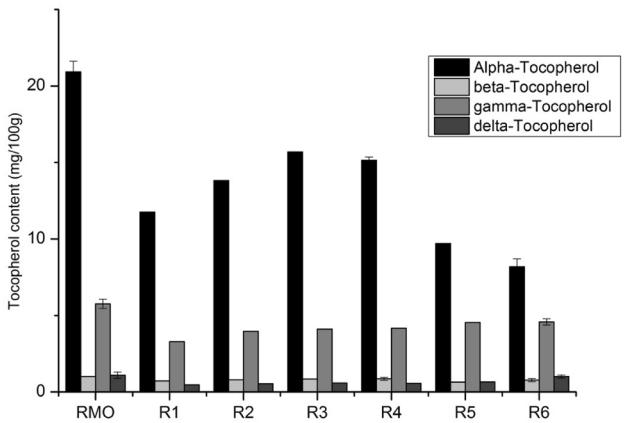


**Fig. 7** Effect of roasting process on tocopherol content (mg/100 g) of *Moringa oleifera* seed oil. *RMO* Raw *Moringa oleifers*, *R1* Roasted at 100 ºC for 10 min, *R2* Roasted at 100 ºC for 20 min, *R3* Roasted at 150 ºC for 10 min, *R4* Roasted at 150 ºC for 20 min, *R5* Roasted at 200 ºC for 10 min, *R6* Roasted at 200 ºC for 20 min

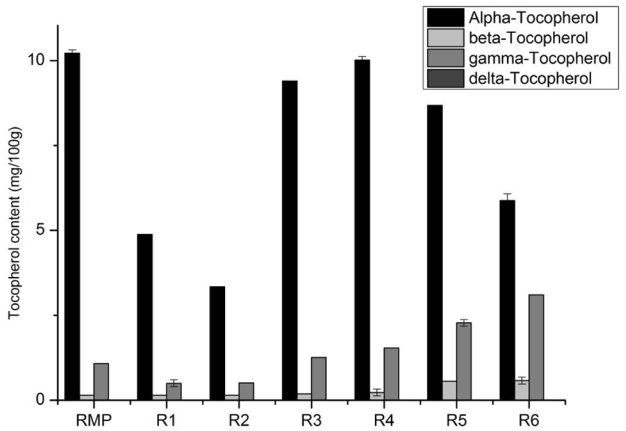


**Fig. 8** Effect of roasting process on tocopherol content (mg/100 g) of *Moringa peregrina* seed oil. *RMO* Raw *Moringa oleifers*, *R1* Roasted at 100 ºC for 10 min, *R2* Roasted at 100 ºC for 20 min, *R3* Roasted at 150 ºC for 10 min, *R4* Roasted at 150 ºC for 20 min, *R5* Roasted at 200 ºC for 10 min, *R6* Roasted at 200 ºC for 20 min

## Effect of roasting on tocopherol content in the seed oil

The effects of roasting on tocopherols level of MO and MP seeds oils are shown in Figs. 7 and 8. Results for MO seed oil indicated that all tocopherols decreased significantly as a result of roasting temperature and time compared to control. Using 150 ºC for 10 and 20 min resulted in the highest tocopherol amounts among the other treatments.

α-Tocopherol contents in MO and MP seeds oils significantly decreased as a function of roasting process compared to control but reached highest level at 150 ºC for 10 and 20 min. γ-Tocopherol in MO seed oil decreased during

roasting at 100 ºC; but gradually increased when roasting temperature increased to 150 ºC and 200 ºC.

β and γ-Tocopherols in MP seed oil showed the same attitude. Their amounts increased gradually with increasing roasting temperature.

Generally, using roasting temperature 150 ºC for 10 and 20 min was the best one among the other treatments for both MO and MP seeds oils.

Increasing the amount of tocopherols by increasing roasting temperature was reported by Lee et al. [53] who mentioned that the content of α, β and γ-tocopherol in safflower oil gradually increased from 441 to 520 mg/kg as roasting temperature increased from 140 to 180 ºC.

Also, the level of γ-tocopherol in oils was raised by roasting temperatures up to 200 °C but fell with higher roasting temperature [54]. In contrast, α and γ-tocopherol concentrations gradually decreased in roasted sesame seeds oil by using different temperatures for different periods [55].

Similar results were reported by Moreau et al. [56] who mentioned that γ-tocopherol amount of corn fiber oil increased as roasting temperature increased using a convection oven.

## Conclusion

Moringa is among the most highly valued and cultivated trees all over the world because of its medicinal and nutritional properties. It is also a good source of oil. Oleic acid was higher in MP than MO seeds oils, while vaccenic acid was higher in MO than in MP seeds oils. MO seed oil had higher total saturated fatty acids than MP seed oil but stearic and palmitic were higher in MP seed oil. Germination caused an increase oil content in both species. Palmitic and stearic acids decreased after germination in MO, while in MP only palmitic decreased. Oleic acid was not affected by germination in both oils. OOO was the main dominant triacylglycerols in both MO and MP seeds oils. It increased as a function of germination process in MO, while in MP it did not change. MO seed oil had higher level of tocopherols than MP seed oil. Germination process caused a decrease in all tocopherol contents in MO seed oil, while germination of MP seed oil did not affect. Using 150 ºC for 10 min was the best treatment among all treatments in the amount of total unsaturated fatty acids, oleic acid, tocopherols and OOO.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

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