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Physicochemical Properties and Fatty Acids Composition of Sudanese *Moringa oleifera* Seed Oil

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Abstract: *Moringa oleifera* is a robust and fast-growing tree considered as one of the most beneficial trees worldwide since almost all parts of it are used as food, medicine, and for industrial purposes. This study aimed to investigate the physicochemical properties and fatty acid composition of *M. oleifera* seed oil. The oil was extracted by Soxhlet using n-hexane; the physicochemical properties of the seed oil were assessed by standard and established methods, as well, the fatty acid composition of the seed oil was determined by GC-MS. The golden yellow oil with characteristic odor obtained from the seeds had the following physicochemical properties: yield, 42.87%; freezing point, 0 °C; melting point, 21 °C; boiling point, 225 °C; refractive index (25 °C), 1.447; iodine value, 96.6 g/100g of oil; peroxide value, 7.6 meq.O_2/kg of oil; free fatty acids, 0.07%; acid value, 1.4 mg of KOH/g of oil; saponification value, 185.2 mg KOH/g of oil; unsaponifiable matter, 3.2; moisture and volatile value, 4.91 (wt.%); density, 0.900 g/cm^3; viscosity, 60.99 mm^2/s; specific gravity, 0.907. The fatty acids composition showed that oleic-acid (51.74%) was the major fatty acid and followed by behenic- (10.54%), palmitic- (9.20%), stearic- (8.46%), arachidic- (6.41%), gondic- (4.88%), lignoceric- (3.08%) and palmitoleic acid (2.85%). Therefore, more and advanced research should be undertaken for this abundant source of natural oil for edible oil and possible industrial applications.

Keywords: *Moringa oleifera*, seed oil, oil extraction, fatty acids.

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INTRODUCTION

Moringa oleifera Lamarck (fam. *Moringaceae*) tree is considered as one of the most beneficial trees in the world since all parts of this plant exploited as food, medicine, and for industrial purposes (1). *M. oleifera* is a fast-growing softwood tree native to sub-Himalayan tracts of Northern India and is one of 13 species within the same genus, and has become the most spread in tropical and subtropical regions at up to 2000 m (1). Furthermore, it is widely cultivated due to its high adaptability to environmental conditions (1,2). *M. oleifera* seed oil is a sustainable source of renewable energy for biodiesel production (3) due to its high content of monounsaturated fatty acids (4). There are enormous efforts to spread the use and cultivation of *M. oleifera* in many countries since it is a significant source of fats, proteins, β-carotene, vitamin C, iron, potassium and other nutrients with low toxicity of seeds and leaves (5). Some parts of this plant have drawn much attention and been studied for its various biological activities, including anti-atherosclerotic, immune-boosting, anti-

cardiovascular diseases, antiviral, antioxidant, antimicrobial, anti-inflammatory properties, and tumor-suppressive effects in skin papillomagensis, hepatocarcinoma, colon cancer, and myeloma (5). *M. oleifera* oil is high in oleic acid (>70%) and commercial common as "ben oil" or "behen oil" due to its content of behenic acid (6). Therefore, this study is aimed to investigate the physicochemical properties and fatty acid composition of Sudanese *M. oleifera* seed oil to increase the economic feasibility of future commercial cultivation and products of this tree.

MATERIALS AND METHODS

M. oleifera Seeds sample

M. oleifera seeds were obtained on 15 October 2017 from College of Forestry and Range Science, Sudan University of Science and Technology, Khartoum, Sudan. The seeds were dried and ground into coarse powder by using an electrical blender (Panasonic, Japan). Before grinding, the percentage moisture content of the plant materials was analyzed via a moisture content analyzer. The samples were sealed and kept in a desiccator to avoid any fungal activities.

Seeds Oil Extraction

The fixed oil (seed oil) was extracted via Soxhlet by using n-hexane and a mild extraction temperature was chosen to avoid thermal degradation (7). The crushed seeds were placed in the drying oven at 40 °C for 30 min prior to extraction. Constant heat was applied through the heating mantle and the extraction was conducted for a minimum extraction of 6 h. After complete extraction and cooling, the obtained oil was filtered through filter paper. The solvent was evaporated via a rotary evaporator, further dried under open air in a dark area. The yield of the oil was calculated and stored in hermetically closed dark bottles and kept in a refrigerator for further physicochemical study.

Determination of the Lipid Content

The lipid content of the oil was calculated as based on dry seed weight (50 g) that were used in the extraction and expressed in percentage. The mass (g) of the acquired oil was obtained by an experimental balance Mettler Toledo (Switzerland) with ± 0.001 g accuracy and the lipid content was determined according to the following (Equation 1).

$$\%Lipid = \frac{weight\ of\ oil(g)}{weight\ of\ sample(g)} \times 100 \quad (1)$$

Physical State, Color, Odor, Freezing, Melting and Boiling Points Determination

Physical state determined at 25 °C and color of the oil was determined visually whereas odor was determined using sensation through volatilized smell. For freezing point, a clear glass vial was filled with oil, a thermometer was immersed into the oil and the oil was solidified through the usage of ice blocks. The solidification temperature was recorded as the freezing point. While for melting point, the solidified oil was melted over a water bath (29 °C) and the melting point was recorded. Once more, a clear glass vial was filled with 10 mL of the oil and a thermometer was inserted, then the vial exposed to heat on a heating mantle and the oil was observed, where it starts circulating leading to boiling; the temperature at this point was recorded as the boiling point (8).

Density and Refractive Index Determination

The small empty vial was weighed and was filled with a known amount of oil up to the brim. The vial was weighed once more and the density was determined as follows (Equation 2):

$$Density,\ \rho = \frac{[weight\ of\ vial - oil(g)] - [weight\ of\ empty\ vial(g)]}{volume\ of\ oil} \quad (2)$$

The refractive index (RI) of the oil was determined according to standard method described by Jessinta et al., and Ustun-Argon et al. (9,10) with slight modifications. This index was determined at 25 °C by Pen Refractometer (Atago, Japan) with resolution and accuracy value of 0.1%, and ± 0.2% in 10-60 °C. The pen tip was dipped into the sample and the start key was pressed to obtain the reading. The measurement was repeated in triplicate and the average value was calculated.

Acid Value Analysis

The AV was calculated through direct titration methods of oil against standard potassium hydroxide in an alcoholic medium according to the method described by Jessinta et al. (9) with some modifications. A mass of 0.5 g of oil was weighed into a 250 mL conical flask and 50 mL of freshly neutralized hot ethyl alcohol and 1 mL of phenolphthalein indicator solution were added. The mixtures were boiled around 5 min and titrated against standardized potassium hydroxide (0.24 M). The AV was then calculated according to the following (Equation 3).

$$AV = \frac{[56.1][titration\ of\ standard(mL)][molarity\ of\ standard(M)]}{weight\ of\ sample(g)} \quad (3)$$

Fatty Acids Composition Analysis

The crude oil was analyzed as methyl ester to determine the fatty acid composition; where the oil was converted into fatty acid methyl ester via a transesterification reaction. A solution of (2 M) KOH (methanolic potassium hydroxide) was prepared. An amount of 2 mL of oil sample was dissolved in 10 mL of n-hexane in a test tube. About 1 mL of KOH was added into the same test tube and vortexed. The n-hexane layer was collected, washed twice with 4 mL of water after 15 min, and further dried over anhydrous sodium sulfate. The fatty acids composition analysis performed using a GC system coupled with an MS detector as method described by Jessinta et al, Yabalak and Tegın et al. with slight modification (9,11,12). The chromatography equipment and settings details are tabulated in Table 1.

Table 1: Chromatographic settings for the analysis of *M. oleifera* oil methyl ester.

Parameters	Settings
Chromatograph	Agilent Technologies 7890A GC Systems coupled with MS detector
Auto-sampler	GC autosampler
Column	Nonpolar capillary DB-1 of 100% dimethyl-polysiloxane (30 m, 0.25 mm i.d, film thickness 0.25 µm)
Carrier gas	Helium
Gas flow rate	1 mL/min
Injector mode	Splitless mode
Injector temp.	250 °C
Inject volume	1 µL
Temp. program	60 °C for 3 min, 240 °C at the rate of 3 °C/min and held for 10 min
Runtime	93 min
Lab data system	NIST Library Chem Station software

The composition of individual fatty acid was stated as a percentage. The percentages of saturated and unsaturated fatty acids were calculated by totaling the percentage of fatty acids detected via the analysis of fatty acid composition. The sum percentage of saturated fatty acids represented as total saturated fatty acids, whereas the sum of all unsaturated (mono- and polyunsaturated) represented as total unsaturated fatty acids (9).

Free Fatty Acid Analysis

The method described by Ouilly et al. (13), with slight modifications was adapted to determine the free fatty acids. An amount of 0.2 g of sample was weighed in 250 mL erlenmeyer flask with the addition of 50 mL of hot neutralized alcohol and 2 mL of phenolphthalein indicator. The solution was swirled to dissolve and titrated with standard sodium hydroxide (0.24 M) until the first permanent pink color that persists for 30 s. The volume of titration required for the changes was recorded and the free fatty acid (FFA) percentage was calculated as follows (Equation 4):

$$FFA\ as\ oleic(\%) = \frac{(Titration\ volume\ of\ standard\ (mL))\ (28.2)}{Weight\ of\ Sample\ (g)} \quad (4)$$

Iodine Value Analysis

The Iodine Value (IV) was determined through the method described by Jessinta et al. (9), with a slight modification via the Wijs reagent. An amount of sample was filtered through a dry filter paper and 0.35 g of sample was transferred into a clean, dry, 500 mL glass-stoppered flask containing 20 mL of carbon tetrachloride, and 25 mL of the Wijs solution was pipetted into the flask. The mixture was swirled and allowed to stand in the dark for 30 min. Potassium iodide solution (20 mL) and recently boiled and cooled water (100 mL) were added and the mixture was titrated with sodium thiosulfate (0.11 M) until the yellow color almost disappears. Starch was added and the titration was continued until the blue color disappears entirely. At the end of the titration, the stoppered container was shaken vigorously therefore any iodine remaining in solution may be absorbed by the potassium iodide to for the triiodide. Blank determination conducted in the same manner and condition and the IV calculated by (Equation 5).

$$Iodine\ Value = \frac{(Titration\ of\ blank-sample\ (mL))(Molarity\ of\ standard\ (M))(12.69)}{Weight\ of\ Sample\ (g)} \quad (5)$$

Peroxide Value Analysis

The method described by Jessinta et al. (9), with slight modification applied to determine the Peroxide Value (PV). An amount of 0.50 g of sample was weighed into 250 mL of stoppered conical flask together with 30 mL of acetic acid-chloroform mixture and swirled to dissolve. The mixture was then added to 0.5 mL saturated potassium iodide

and allowed to stand in the dark with occasional shaking for 1 min and 30 mL of water were added. The liberated iodine in the mixture was titrated with sodium thiosulfate (0.11 M) with vigorous shaking until the yellow color almost disappeared. Then, 0.5 mL of starch indicator was added and titration was continued until the blue color disappears. The PV was expressed as milliequivalent of peroxide oxygen per kg sample (meq/kg) via the following (Equation 6).

$$Peroxide\ value = \frac{(Titration\ of\ standard\ (mL))(Molarity\ of\ standard\ (M))(100)}{Weight\ of\ Sample\ (g)} \quad (6)$$

Moisture and Volatile Matter Analysis

Moisture and volatile matter were analyzed according to air oven method of AOCS and the method described by Jessinta et al. (9). About 5 g of oil was weighed on a previously dried and tarred dish. The dish was covered with a loose lid and was heated in the oven at 105±1 °C for 1 h. The dish was removed from the oven, cooled in a desiccator, and weighed. The plate was re-heated for the period of 1 h and the cooling and weighing process was repeated. The process was repeated until the weight change between two observations does not exceed 1 mg. The following equation 7, used to calculate the observations.

$$Moisture\ and\ volatile\ matter\ (\%) = \frac{(Loss\ of\ material\ on\ dry\ (g))(100)}{Weight\ of\ material\ taken\ for\ test\ (g)} \quad (7)$$

Saponification Value Analysis

The saponification value of the oil sample was estimated using the Official Method of AOCS (9). Accurately, 2 g of the oil sample was weighed into a 250 mL conical flask. A volume of 25 mL of potassium hydroxide (1 N) was added, and then the flask and the content was refluxed for one hour. Simultaneously, another conical flask containing only 25 mL of potassium hydroxide (1 N) was prepared which served as a blank. The condenser connected and the content heated gently, but steadily for one hour. After the condenser and the flask have cooled, but not sufficiently to forming a gel, the content washed with a small amount of water and the condenser was removed. Then a few drops of phenolphthalein solution added to the flask and the sample was titrated with hydrochloric acid, (0.5 N) HCl until the pink color disappeared. The volume of the hydrochloric acid was recorded and the saponification value expressed as follows (Equation 8):

$$Saponification\ value\ (SV) = \frac{(56.1)(B-S)(C)(N\ of\ HCl)}{Weight\ of\ Sample\ (g)} \quad (8)$$

where, B and S are the volumes of hydrochloric acid required by blank and sample, respectively, and N is the concentration of hydrochloric acid.

Unsaponifiable Matter Analysis

The unsaponifiable matter analysis performed according to the method described by Jessinta et al. (9), with some modification. A volume of 50 mL of alcoholic potassium hydroxide was added into a conical flask containing 5 g of oil sample and was boiled under reflux conditions for one hour until a transparent medium is formed. The medium was then transferred into a separating funnel and was washed with petroleum ether allowing the layer to separate. The lower layer was collected and the top layer was continued washing for another 3 times with around 50 mL of solvent per wash. The etheric extracts were combined and further washed with alcohol and water, 25 mL each. The etheric solution was concentrated to 5 mL; then 2 mL of acetone was added with some heat under the water bath to remove the solvent and further dried at 100 °C for 30 min until a constant weight is obtained. Then the residue was dissolved in 50 mL of warm neutralized ethanol with phenolphthalein indicator and titrated with sodium hydroxide (0.02 M). The weight of FFA and unsaponifiable matter values were calculated according to the following Equations 9 and 10.

$$Weight\ of\ FFA\ in\ the\ extract = (0.282 \times Titration\ of\ standard\ (mL)(Molarity\ of\ standard\ (M)) \quad (9)$$

$$Unsaponifiable\ matter = \frac{100((Weight\ of\ residue) - (Weight\ of\ FFA\ in\ the\ extract))}{Weight\ of\ Sample\ (g)} \quad (10)$$

Statistical Analysis

The Statistical analysis of the results was done using MS Excel (2007) – version 12.0.4518.1014. The results performed in three repetitions and expressed as mean ± standard deviation.

RESULTS AND DISCUSSION

Lipid Content, Physical State, Color, and Odor

Table 2 shows various physicochemical properties of the *M. oleifera* seed oil. In general, the results showed that *M. oleifera* seed was found to be rich in oil with an average yield of 42.87% (w/w); and this

value is represented in terms of lipid content, and the oil was highly unsaturated with a high FFA. The obtained oil is liquid at room temperature of 25 °C, golden yellow in color with a nutty odor. The freezing, melting, boiling points, specific gravity and viscosity were 0 °C, 21 °C, 225 °C, 0.9070 and 60.99 mm^2/s, respectively.

The obtained yield is agreeable with the literature stating that this plant's seed contains 26.2-40.90% oil on dry matter basis. Previously (1,7,14), a yellow color was reported for *M. oleifera* seed oil and researchers showed that the variation in the color intensity of oil from the same plant species, but from diverse location might be attributed due to the existence of various pigments such as the chlorophyll content (15). The green color of the immature seeds vanishes subsequent maturation resulting in chlorophyll retention. Besides, there is also a report stated that the presence of moisture contents at greater levels affects the color of the oil, whereby the moisture raises the chlorophyll content and thus contribute in an increment of color intensity (15). The normal and thermal oxidation process of oil can also contribute towards the deterioration of lipids, and thus it might influence the color changes of the oil (15,16). From Table 2 it can be seen that the viscosity of *M. oleifera* seed oil is 60.99 mm^2/s which is considered high viscosity oil and it slightly lower than crude rubber seed oil (40.86 mm^2/s) and crude palm oil (38.1 mm^2/s). Therefore, it is not advisable to use *M. oleifera* seed oil directly as a fuel, because viscosity is an essential property that has to be monitored in vegetable oil to meet the gasoline standard.

Generally, vegetable oil is highly viscous. Even though there are suggestions made by some authors reporting the viability of running raw vegetable oil as an alternative fuel in compression-ignition engines with slight modification and maintenance, but this will create problems related to long-term durability test due to high viscosity and low volatility of such oils. Particularly at low temperatures, viscosity increases influence the fuel's fluidity, which result in disruption of the injection of the fuel operation equipment. Furthermore, high viscosity also promotes soot formation and deposition on the engines due to poor fuel atomization. In contrast, high viscous oil has also its advantages. They afford additional lubrication of the injector and avoid leakage and exhaustion generated by fuel injection pumps that fits inaccurately resulted from low viscous oil (17).

Table 2: Physicochemical properties of *M. oleifera* seed oil.

Components	**Units**	**Experimental Values***
Yield	%	42.87
Color	-	Golden yellow
Odor	-	Nutty smell
Freezing point	^oC	0
Melting point	^oC	21
Boiling point	^oC	225
Density point at 25 °C	g/cm^3	0.90052
Viscosity	mm^2/s	60.99
Specific gravity		0.9070
Refractive index at 25 °C	-	1.44732
Acid value (% FFA as oleic)	mg KOH/g of oil	1.4
FFA		
Oleic	%	50.74
Behenic	%	10.54
Palmitic	%	9.20
Stearic	%	8.46
Arachidic	%	6.41
Gondic	%	4.88
Iodine value (IV)		96.6
Peroxide value	meq.O_2/kg of oil	7.6
Unsaponifiable matter	wt. %	3.2
Saponification value	mg KOH/g of oil	185.2
Moisture and volatile matter	wt. %	4.91
Total Saturated Fatty Acid	wt. %	38.76
Total Unsaturated Fatty Acid	wt. %	61.17

* Values recorded as mean average

Density, Viscosity, and Specific Gravity

The density recorded for the oil in this study is 0.90052 g/cm^3. The literature had reported value ranged from 0.195 to 1.024 g/cm^3 that is agreeable to the obtained result (18). The density differs as the concentration of the wall material varies at which more heavy material fits into spaces between the particles and causes an increase in mass and thus contribute towards high density (19).

Refractive Index
The RI value is acceptable according to the amount of unsaturated fatty acids and long-chain hydrocarbon. The RI of the *M. oleifera* oil is 1.447 and this attributed by the amount of unsaturated fatty acid, length of the hydrocarbon chain, molecular weight and degree of unsaturation as well as conjugation (20). Previously, Chatepa et al. (14) reported the RI for *M. oleifera* seed oil is in the range of 0.60-1.47, which closed to our obtained result.

Acid Value
Besides, the acid value (AV) is the relative measure of rancidity as FFAs that are formed during decomposition or hydrolysis of oil glycerides due to the action of moisture, temperature and/or lipolytic enzyme lipase. The AV obtained in this study is 1.4 mg KOH/g and this result is in the range when compared to the study recorded by Adegbe et al. (21) and Chatepa et al. (14) their reported values were 6.73 and 9.46 ± 0.02 mg KOH/g, respectively. Oxidation and hydrolysis processes are also factors that led towards increment in AV as the percentage of unsaturated fatty acids increase (7).

Iodine Value
Among various factors of oil classification, the drying quality of the oil can be considered as one of the factors of oil classification; it could be non-drying, semi-drying or drying oil through the analysis of the IV (22). The IV for the current study was 96.6 g/100 g, and it suggests that it is a non-drying oil and it is comparable to the standard IV of less than 100 g of I_2/100 g as per its physical state of remaining liquid at 25 °C, low aeration (23). The low IV represents the fewer amounts of unsaturated bonds and thus the oil has fewer tendencies to go through oxidative rancidity (7). Ogunsina et al. (24) reported that the iodine value for cold-pressed and n-hexane-extracted *Moringa* seed oils (CPMSO and HEMSO) were found to be 67.8 and 68.5 g of I_2/100 g oil, our obtained results for IV was found higher than their results. Furthermore, in general, researchers reported IV for *M. oleifera* ranged from 34.11-252.34 g I_2/100 g (5,14,25).

Peroxide Value
The oil had also undergone some chemical decomposition process whereby the obtained PV is 7.6 meq O_2/kg; and was determined immediately after the extraction of the oil. PV indicates the rancidity process whereby the higher the PV, the higher is the oxidation level and the deterioration of lipids (26). Theoretically, oil that shows a high amount of PV is more prone to undergo rancidity that affects the total quality of the oil (20). A low peroxide value increases the appropriateness of the oil for long storage because of low level of oxidative and lipolytic activities. Adegbe et al. (21) reported that the PV 2.60 meq/kg for this oil which is lower than our result. Generally, many previous studies reported that the PV was found to between range from 1.67-10.47 meq/kg (5,14).

Moisture and Volatile Matter
Besides, the moisture and volatile matter analysis prove that the oil contains a low amount of moisture and volatile matter, whereby the value recorded is 4.91 wt.% thus, the low moisture content of the oil serves as an indication that the activities of the micro-organisms would be reduced and thereby increases the shelf life of the oil. The presence of water or moisture contributes towards hydrolysis in breaking up of triglycerides into glycerol and FFAs. Therefore, both oxidation and hydrolysis reduce the amount of unsaturated FFA and thus contributing towards the reducing of IV and average molecular weight and increasing in the AV (7). The moisture content reported previously, Abiodun et al. (27), Adejumo et al. (28), Leone et al. (1) and Orhevba et al. (6) reported that the moisture has range 0.60-20%.

Saponification Value and Unsaponifiable Matter
The saponification value (SV) used to know the amount of free fatty acid present in the oil, and amount of free fatty acid estimated by determining the quantity of alkali that should be added to the fat to make it neutral. The SV for studied oil 185.2 mg KOH/g and it is agreeable to that reported in literature, which is 55.91-230.81 (1,5,7,14,25,27–30). The unsaponifiable matter is that portion of oils and fats which is soluble in conventional fat solvents but is unsaponified via caustic alkali. Unsaponifiable matter does not react with bases during the formation of soap such as hydrocarbon, pigments, waxes, higher molecular weight alcohols, and sterols (AOCS Ca 6a-40, 1998). The unsaponifiable matter value for *M. oleifera* seed oil was 3.2 wt.%. Previously reported unsaponifiable matter *M. oleifera* seed oil which is determined by titration with sodium hydroxide solution in alcoholic, found to in a range between 0.60-0.83 (5, 27). The current studied oil showed higher unsaponifiable matter than the reported value. Therefore, due to the small value of unsaponifiable matter (< 2 wt.%), *M. oleifera* could be suitable in the application of biodiesel production (31). From the current study, it could be said that the oil had undergone some oxidation and hydrolysis process as indicated by the value of unsaturated fatty acids. This oxidation process might be influenced by storage of the oil whereby the presence of air in the bottle is in contact with the oil surface. Thus, the oxidation process converts the triglycerides into peroxides and hydroperoxides.

Free Fatty Acids, Fatty Acid Composition, Percentage of Saturated and Unsaturated Fatty Acid
Acids with long hydrocarbon chains; which is the main constituent of seed oil and known to be a

major parameter that differentiates the physicochemical properties of the seed oils. In this study, twenty-one different fatty acids were detected and include both saturated and unsaturated. The sequence arrangement according to the increasing percentage (>1%) of fatty acid is oleic-, behenic-, palmitic-, stearic-, arachidic-, gondic-, lignoceric- and palmitoleic acid; their percentage were 51.74, 10.54, 9.20, 8.46, 6.41, 4.88, 3.08 and 2.85%, respectively, in addition to kovats index for each as shown in Table 3.

The total percentage of fatty acids chains were 99.93 wt.%. All the values are represented as the relative percentage area from the sum of all identified peaks. The overall results of this analysis showed that the unsaturated fatty acid (UFA) makes 61.17 wt.% of the compositions, whereby the monounsaturated fatty acids (MUFA) are 60.31wt. %, polyunsaturated fatty acids (PUFA) are 0.86 wt. %; and the saturated fatty acids (SFA) were 38.76 wt.%, as shown in Figure 1. In general, our obtained results agreed to the results obtained by Lalas and Tsaknis (32) who claimed that oleic acid (71.60%) was a major component of *M. oleifera* seed oil, in addition to present of palmitic and behenic acid both up to 6.4%. Also, the results obtained by Adegbe et al. (21) mainly oleic acid (22.51%) and erucic acid (1.98%), palmitic (10.64%), stearic acid (6.07%), arachidic acid (2.21%) and docosanoic (behenic acid) (1.03%); confirmed the presences of the same acid, but the percentage of acids were slightly different from our obtained results.

Pereira et al. (25) results were also agreed our obtained results, as oleic acid was the major component in the extracted oil; but there was a slight difference in the percentage of these acids with our obtained results. Janaki (35) obtained results showed oleic acid, palmitic acid, stearic acid, linoleic acid, margaric acid, and α-linolenic acid. The percentages were 77.40 ± 0.40, 12.97 ± 0.15, 2.95 ± 0.04, 1.40 ± 0.01, 1.40 ± 0.15 and 1.39 ± 0.01, respectively. Where these results agreed our obtained results for oleic acid as major components, palmitic closed to and stearic acid was lower than our results, but for margaric acid and linoleic acid, results were very low, while linolenic acid not detected in our obtained results. The differences in the results obtaining by the researchers can be attributed to many factors, like environmental conditions, geographical origin, soil, cultivation climate, harvesting time, maturity, and the drying process (9,36).

Fatty acid composition of *M. oleifera* seed oil reported in the literature is shown in Table 4; our results agreed with many previously reported results.

Table 3: Fatty acid composition of *M. oleifera* seed oil.

Fatty acid	Formula	Structure	%	KI
Myristic	$C_{14}H_{28}O_2$	C14:0	0.23	1750[a]
5-Octadecenoic	$C_{18}H_{34}O_2$	C18:1	0.02	2383[a]
Pentadecylic	$C_{15}H_{30}O_2$	C15:0	0.02	1843[a]
Palmitoleic	$C_{16}H_{30}O_2$	C16:1	2.85	1936[a]
Palmitic	$C_{16}H_{32}O_2$	C16:0	9.20	1965[a]
Margaric	$C_{17}H_{34}O_2$	C17:0	0.19	2039[a]
Linoleic	$C_{18}H_{32}O_2$	C18:2	0.86	2109[a]
Oleic	$C_{18}H_{34}O_2$	C18:1	51.74	2115[a]
Stearic	$C_{18}H_{36}O_2$	C18:0	8.46	2170[a]
Arachidic	$C_{20}H_{40}O_2$	C20:0	6.41	2380[a]
Heneicosylic	$C_{21}H_{42}O_2$	C21:0	0.15	2463.2[a]
Behenic	$C_{22}H_{44}O_2$	C22:0	10.54	2569[a]
Tricosylic	$C_{23}H_{46}O_2$	C23:0	0.23	2668.1[a]
Cerotic	$C_{26}H_{52}O_2$	C26:0	0.23	2962[b]
Lignoceric	$C_{24}H_{48}O_2$	C24:0	3.08	2685[a]
Lauric	$C_{12}H_{24}O_2$	C12:0	0.02	1567[a]
Cis-10-Heptadecenoic	$C_{17}H_{32}O_2$	C17:1	0.12	2073.2[a]
Cis-10-Nonadecenoic	$C_{19}H_{36}O_2$	C19:1	0.09	2256 [a]
Erucic acid	$C_{22}H_{42}O_2$	C22:1	0.32	2572[b]
Paullinic	$C_{20}H_{38}O_2$	C20:1	0.29	2374[b]
Gondic	$C_{20}H_{38}O_2$	C20:1	4.88	2374[b]

* The obtained results in terms of fatty acid methyl esters from GC-MS library data system reviewed and the results listed out in the form of fatty acid chains. KI: kovats index, a: NIST (33) , b: Chemspider (34).

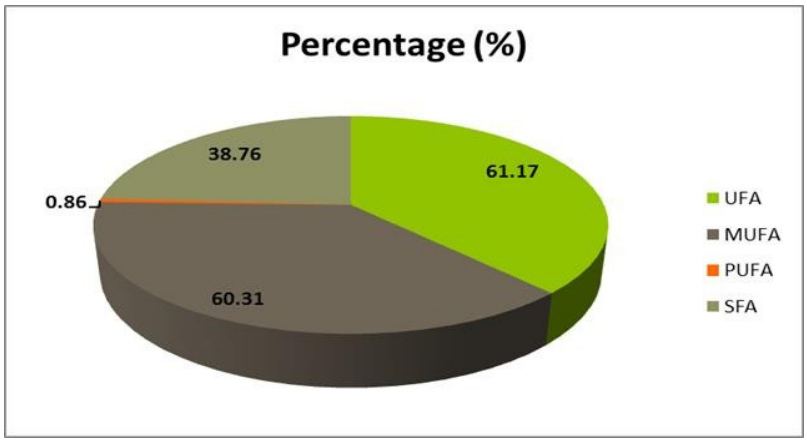

Figure 1: Types of fatty acids present in *M. oleifera* seed oil.

CONCLUSION

In this study, the physicochemical properties and fatty acid composition of the Sudanese *M. oleifera* seed oil assessed by standard and established methods. Based on the results of the study, the oil properties are interesting and promising for several applications. The overall results of this analysis show that the oil content was 42.87%; major fatty acid compositions were oleic acid (51.74%) and followed by behenic acid (10.54%), palmitic acid (9.20%), stearic acid (8.46%) and gondic acid (4.88%). The unsaturated fatty acid makes 61.17% of the compositions, whereby the MUFA, PUFA and SFA were 60.31, 0.86 and 38.76 wt.%. Most of the obtained results in this study were acceptable and similar to previous studies. Thus, the Sudanese *M. oleifera* seed oil which does not contain linolenic acid could not be suitable for several applications such as paint, varnish, and ink industries, but it might be suitable for other industrial aspects such as pharmaceutical, cosmetic, and food industries, due to its fatty acid content. Therefore, further studies on Sudanese *M. oleifera* are needed to investigate their potential as raw materials for new industrial products and applications to increase the economic feasibility of future commercial cultivation of the tree.

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AUTHORS CONTRIBUTION STATEMENT

Abeer A. Idris and Azhari H. Nour conceptualized and gathered the data with regard to this work. Mahmoud M. Ali, Ibrahim Y. Erwa, Omer A. Omer Ishag and Abdurahman H. Nour analyzed these data and necessary inputs were given towards the designing of the manuscript. All authors discussed the methodology and results and approved the final manuscript.

CONFLICT OF INTEREST

Authors declare no conflict of interest exists.

Table 4: Fatty acid composition of *M. oleifera* seed oil reported in literature.

Fatty acids		**Composition (%)***					
Lauric	C12:0	N/A	0-0.3	N/A	N/A	N/A	N/A
Myristic	C14:0	0.78	0.3-1.5	0.2	0.72	N/A	0.13
Palmitic	C16:0	10.64	25-46	7.8	6.1	5.66-6.46	6.46
Palmitoleic	C16:1	N/A	0.82–3.44	2.9	1.2	1.43-1.92	0.09
Stearic	C18:0	6.07	2.68–6.00	7.6	4.6	4.79-7.94	5.88
Oleic	C18:1	22.51	67.79–79.50	70	78.7	73.30-79.58	71.21
Linoleic	C18:2	N/A	0.83	0.9	N/A	0.58-0.59	0.06
Linolenic	C18:3	N/A	0.36	0.5	1.8	0.15-0.17	0.18
Arachidic	C20:0	2.21	2.14-4.08	4.2	2.3	1.57-5.1	3.62
Behenic	C22:0	1.03	4.57–7.10	6.2	4.5	2.62-3.62	6.41
Lignoceric	C24:0	N/A	0.54	N/A	N/A	N/A	N/A
Gondic	C20:1	N/A	N/A	N/A	N/A	N/A	N/A
	SFA	N/A	17.24–23.79	49.1	18.3	15.00-22.83	N/A
	MUFA	N/A	71.71–80.70	N/A	79.9	N/A	N/A
	PUFA	N/A	0.41–2.20	N/A	1.8	N/A	N/A
	UFA	N/A	N/A	50.9	79.9	77.14-84.98	N/A
References		(a)	(b)	(c)	(d)	(e)	(f)

N/A: Data not available, * some data modified as a mean average from origin sources a: Adegbe et al. (21), b: Leone et al. (1), c: Ghazali and Mohammed (37), d: Ogunsina et al. (24), e: Barakat and Ghazal (5), f: Lalas and Tsaknis (32).

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