Effect of roasting process on total lipids, fatty acids profile, nutritional quality and fuel properties of sesame seeds oil.

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Abstract

Sesame is one of the oldest well-known oilseeds to mankind. It is an amazingly healthful food of nutritive value as well as medicinal properties still used from ancient time. Accordingly, this research was aimed to study the effect of roasting process on total lipids, fatty acids profile, nutritional quality and fuel properties of sesame seeds oil were studied. Result showed that triglycerides exhibited the major percentage, while polar lipids recorded the lowest percentage of the total lipids in sesame seeds oil, while the amount of triglycerides, 1,2 and 1,3 diglycerides and polar lipids were decreased, while free fatty acids, free sterols and sterol ester and hydrocarbons were increased during roasted process using oven greater compared to vacuum in sesame seeds oil. Results also, showed that show that linoleic acid (C18:2) was predominant fatty acid unsaturated followed by oleic acid (C18:1), while show that palmitic (C16:0) was predominant fatty acid saturated followed by stearic (C18:0), from saturated fatty acids. Also total saturated fatty acids were decreased, while total unsaturated fatty acids were increased in sesame seeds oil. Whereas no significant difference between raw and roasted sesame oil in fatty acids profile. Also, results indicated that Cox value good and that sesame seeds oil is almost stable and can be used to protect vegetable oils from oxidative degradation. Results showed that nutritional quality indices were values considered excellent, thus sesame seeds oil has high nutritional quality due to higher polyunsaturated fatty acids compare with saturated fatty acids. Results showed that Higher Heating Value (HHV) and Cetane Number (CN) in sesame seeds oil thus, sesame oil has good fuel properties and it can be used in the production of biodiesel fuel. While no significant difference between raw and roasted sesame seeds oil from selected varieties in fuel properties.

Keywords: Sesame seeds oil, Total lipids, Fatty acids profile, Nutritional quality and fuel properties.

Introduction

Sesame seeds (*Sesamum indicum* L.) recognized as one of the most significant oilseed crop in worlds, sesame contains nearly about 40% to 60% oil. Sesame seeds belong to the family of *Pedaliaceae* and order of *Tubiflorae*. Tanzania was largest producer of sesame seeds crop in 2017 followed by Myanmar, India, Nigeria, Sudan, China and Ethiopia. In Egypt, the production of sesame seeds crop in 2017 reached to 36224 Ton [1].

Roasting is a significant thermal treatment used in oilseeds before oil extraction. It creates some desirable or undesirable changes in physicochemical and nutritional characteristics of the seeds. One of the required roasting process findings is to rise in antioxidant activity resulting from the creation of Maillard reaction products. The impact of roasting on total antioxidant ability of the seeds relies on the equilibrium between the heat degradation of natural antioxidant compounds and the creation of new antioxidant products [2].

The aim of roasting is to alter the microstructure, physical state or chemical structure of oil seeds by temperature and humidity, thus promoting oilseed cell destruction, oil accumulation and enzymatic inactivation. This will enhance the oil yield during pressing. Process Maillard reaction decreasing sugars with free amino acids not only enriches the flavor of sesame oil but also enhances antioxidant activity during roasting at high temperatures. Very high roasting temperatures will significantly harm the sesame protein and decrease nutritional value the sesame cakes. At the same time, this will lead to a deeper color of sesame oil and may even generate hazardous substances [3].

Hama found that roasting process affected the physiochemical properties of sesame seeds and oil, measurably in oil content, moisture, ash and unsaponifiable matter in 100 g of seeds. The oil content increased by roasting from 49.1 g and 51.1 g for unroasted and roasted seeds, respectively. El-Refai et al., found that moisture, protein and fiber contents were decreased whereas oil, ash and carbohydrates contents were increased during roasting using vacuum and oven. Also, they noted that colour, acid value, free fatty acids (%), peroxide and hydrolysis values were increased, while saponification value was decreased in sesame oil. Thus roasting process effect on

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chemical composition and physico-chemical properties of sesame seeds oil [4].

Hassan found that the sesame seeds oil high unsaturated fatty acids to 83.22%-85.20% in sesame seeds Giza 32 and Shandawil-3, respectively. While reached saturated fatty acids to 14.76%-16.74% in sesame seeds Giza 32 and Shandawil-3, respectively. Unsaturated fatty acids dominant oleic reached to 39.22%-41.63% and linoleic reached to 42.66%-42.77% in sesame seeds varieties. Whereas saturated fatty acids dominant palmitic reached to 7.81%-8.47% and stearic reached to 5.53%-8.13% in sesame seeds varieties [5].

Sesame seeds oil is rich source of unsaturated fatty acids reached to 84.61%, where the fatty acids composition of oil mainly includes oleic (18:1), 35.32% and linoleic (18:2), 42.62% acids, with palmitic (16:0), 11.49% and stearic (18:0), 2.64% in smaller amount and linolenic (18:3), 1.25%. Sesame seeds oil contains essential fatty acids in a considerable amount which includes ω3 (linolenic acid) and ω6 (linoleic acid) [6].

Yoshida illustrated that neutral lipids, phospholipids and glycolipids are the lipids in sesame seeds. The significant lipids fraction is neutral lipids, which make up approximately 91%~96% of total lipids. Phospholipids and glycolipids constitute about 3% of total lipids and 0.3~6% of total lipids. Sesame seeds percentage of phospholipids reduced with roasting temperature and time. Glycolipids content of sesame seeds, increased with roasting temperature and time. The glycolipid content increased from 6.9 mg/kg seeds (0.5% of total lipids) to 262.9 mg/kg seeds (17.2% of total lipids) when roasted in an electric oven from 120°C to 250°C for 30 minutes. Abou-Gharbia et al., showed that roasting at 200°C for 20 min of sesame seeds apparently caused some decomposition in triglycerides that were reflected in more than ten-fold increase in free fatty acids and appreciable increase in monoglycerides [7].

Reshma et al., studied fractionated the lipids of sesame seeds oil, methanol extract and residual oil using Thin-Layer Chromatography (TLC) technique. The fractions were identified as triglycerides, were (86.26%, 51.09% and 92.63%), free fatty acids were (5.09%, 26.41% and 2.80%), diglycerides were (6.00%, 16.42% and 3.98%), monoglycerides were (1.45, 4.30 and not detected), polar lipid were (2.62, 1.75 and 0.67) of the total lipid for sesame oil, methanol extract and residual oil, respectively. Accordingly, this study aimed to study the effect of roasting process on total lipids, fatty acids profile, nutritional quality and fuel properties of sesame seeds oil.

Materials and Methods

Two varieties of sesame seeds (*Sesamum indicum* L.) namely; Sohage-1 and Shandawil-3 were purchased during the summer 2016 from oil seeds department, field crops institute research, agricultural research center, Giza, Egypt. All chemicals and solvents, were obtained from El-Gomhouria medications company (ISO: 9001-2015), Cairo, Egypt [8].

Roasting of sesame seeds

Both sesame seeds (*Sesamum indicum* L.) varieties (Sohage-1 and Shandawil-3) were cleaned manually by removing all foreign matters such as stones, dirt and broken seeds, then divided into three different parts as follows:

- Seeds were used without any thermal treatment (control).
- Oven roasted sesame seeds: Seeds were roasted at 200°C for 15 minutes using a heating oven (ED-115, serial no 12-18171, Germany).
- Vacuum roasted sesame seeds: Seeds were roasted at 65°C for 15 minutes using an electrical oven under vacuum (Thermo scientific, model 6255, USA) [9].

Extraction sesame seeds oil

All sesame seeds varieties were extracted by using mechanical pressing in Al- Haedaya vegetables oil press in El Mahalla El Kobra, Egypt, then the extracted oil, filtrated and stored in refrigerator at 4°C until further analysis.

Separation and identification of lipids fractionation from sesame seeds oil by Thin Layer Chromatography (TLC)

The total lipids were separated on silica gel (GF254, type 60) plates (20 × 20) using a mixture solvent system of hexane: Diethyl ether and glacial acetic acid (80:20:1 v/v/v) as described by Mangold and Malins. The lipid fractions were visualized by exposure to iodine vapor. All lipid fractions were identified on thin layer plates by comparing their Rf values with those of known lipid standards. For quantitatively analysis the TLC were scanned using the charring densitometry technique. The area under each peak was measured by computer software (TLSee 2v.) from LabHut.com and the percentage of each fraction was computed with regard to the total area [10].

Fatty acid composition of sesame oil preparation of fatty acid methyl esters: Fatty acid methyl ester was prepared from total lipid by using rapid method according to the method of IUPAC. Whereas, fatty acid methyl esters were formed by trans-esterification with methanolic potassium hydroxide as an intermediate stage before saponification take place. Approximately 0.1 g of the oil was placed in 5 ml screw-top test tube and heptane (2 ml) was added to the tube then the tube was shaken. Methanolic potassium hydroxide solution (0.2 ml 2N) was put on the cap fitted with PTFE-joint, tighten the cap and shaken vigorously for 30 seconds. The tube was left to stratify until the upper solution become clear and the upper layer containing the methyl ester was decanted. The heptane solution is suitable for injection into the gas chromatograph [11].

Separation and identification of fatty acids methyl ester by Gas Liquid Chromatography (GLC)

Fatty acids methyl ester of seeds oil were separated and identified by gas-liquid chromatography (HP 6890 GC

capillary) equipped with a Flame Ionization Detector (FID) using a 60 m × 0.32 mm × 0.25 um DB-23 capillary column. The injector and detector temperature were set at 230°C and 250°C, respectively. Hydrogen gas (at flow rate 40 ml/min) was used as carrier gas and temperature programming was from 150°C to 170°C at 10°C/min and then from 170°C to 192°C at 5°C/min, holding five min then 192°C to 220°C during 10 min. individual methyl ester were identified by comparison to known standards [12].

Desaturation of sesame seeds oil

The efficiency of the desaturation pathway during the maturation process was calculated according to Mondal et al. The desaturation ratios from oleic to linoleic acid (ODR, Oleic Desaturation Ratio) and from linoleic to linolenic acid (LDR, Linoleic Desaturation Ratio) were calculated as follows:

$$\textbf{Oleic Desaturation Ratio (ODR)} = \frac{\%\ C_{18:2} + \%\ C_{18:3}}{\%\ C_{18:1} + \%\ C_{18:2} + \%\ C_{18:3}}$$

$$\textbf{Linoleic Desaturation Ratio (LDR)} = \frac{\%\ C18:3}{\%\ C18:2 + \%\ C18:3}$$

Where:

$C_{18:1}$: Oleic acid
$C_{18:2}$: Linoleic acid
$C_{18:3}$: Linolenic acid

Where,

$C_{18:1}$: Oleic acid; $C_{18:2}$: Linoleic acid; $C_{18:3}$: Linoleic acid.

Oxidizability value (Cox) of extracted sesame seeds oil

The oxidative stability of the extracted oils based on unsaturated fatty acids content was calculated according to Fatemi and Hammond (1980) as follow:

$$\textbf{Cox value} = \frac{1(C_{18:1}) + 10.3(C_{18:2}) + 21.6(C_{18:3})}{100}$$

Where: $C_{18:1}$: Oleic acid, $C_{18:2}$: Linoleic acid, $C_{18:3}$: Linolenic acid

Where: $C_{18:1}$: Oleic acid; $C_{18:2}$: Linoleic acid; $C_{18:3}$: Linoleic acid.

Nutritional quality index of sesame seeds oil

Nutritional quality, using five different indices, was evaluated based on the fatty acids composition of the oils. The Atherogenic Index (AI) and the Thrombogenic Index (TI) considered the monounsaturated acid levels were calculated according to Ulbricht and Southgate. The Polyunsaturated Fatty Acid (PUFA): Saturated Fatty Acid (SFA) and ω6:ω3 ratios were also calculated. The hypocholesterolemic: hypercholesterolemic ratio was calculated [13].

$$\textbf{Atherogenic index (AI)} = \frac{C_{12:0} + (4xC_{14:0}) + C_{16:0}}{\sum \text{MUFA} + \sum \omega 6 + \sum \omega 3}$$

$$\textbf{Thrombogenic index (TI)} = \frac{C_{14:0} + C_{16:0} + C_{18:0}}{(0.5x\sum \text{MUFA}) + (0.5x\sum \omega 6) + (3x + \sum \omega 3)}$$

$$\textbf{Hypocholesterolemic: Hypercholesterolemic ratio (HH)} = \frac{(C_{18:1\ cis\ 9} + C_{18:2\ \omega 6} + C_{20:4\ \omega 6} + C_{18:3\ \omega 3} + C_{20:5\ \omega 3} + C_{22:5\ \omega 3} + C_{22:6\ \omega 3})}{C_{14:0} + C_{16:0}}$$

Where:

$C_{18:1}$: Oleic acid, $C_{18:2}$: Linoleic acid, $C_{18:3}$: Linolenic acid, $C_{20:4}$: Arachidonic acid, $C_{20:5}$: Eicosapentaenoic acid, $C_{22:5}$: Clupandoic acid, $C_{22:6}$: Docosahexaenoic acid, $C_{12:0}$: Lauric acid, $C_{14:0}$: Myristic acid , $C_{16:0}$:Palmitic acid ,. MUFA: Monounsaturated fatty acids, ω6: Omega 6, ω3: Omega 3.

Where,

$C_{18:1}$: Oleic acid; $C_{18:2}$: Linoleic acid; $C_{18:3}$: Linolenic acid; $C_{20:4}$: Arachidonic acid; $C_{20:5}$: Eicosapentaenoic acid; $C_{22:5}$: Clupandoic acid; $C_{22:6}$: Docosahexaenoic acid; $C_{12:0}$: Lauric acid; $C_{14:0}$: Myristic acid; $C_{16:0}$: Palmitic acid; MUFA: Monounsaturated fatty acids; ω6: Omega 6; ω3: Omega 3.

Fuel properties of sesame seeds oil

The Higher Heating Value (HHV) of sesame seeds oil was calculated from the Iodine Value (IV) and Saponification Value (SV) using the following formula as mentioned by Demirbas:

The Higher Heating Value HHV=49.43-(0.041 × SV)-(0.015 × IV)

The Cetane Number (CN) of the oil was determined according to the equation of Bose: The Cetane Number (CN)=46.3+(5458/SV)-(0.225 × IV)

Statistical analysis

Collected data were analyzed with Analysis of Variance (ANOVA) procedures using Co-state version (6.400) statistical software. Differences between means compared by LSD at 5% level of significant.

Results and Discussion

Total lipids fractions of raw and roasted sesame seeds oil

Total lipids of raw and roasted sesame seeds oil were qualitative and quantitative fractionated are presented in Table 1 and in Figure 1. Results show that the total lipids consisted of seven fractions namely polar lipids, monoglycerides, 1,2 and 1,3 diglyerides, free sterol, free fatty acids, triglycerides, sterol ester and hydrocarbons for all of sesame seeds oil samples. Triglycerides exhibited the major percentage of the total lipids being 63.79% and 63.17%, whereas polar lipids recorded the lowest percentage of the total lipids (1.46% and 1.72%) in raw sesame seeds oil variety (Shandaweel-3 and Sohage-1), respectively. Results also, reveal that there were a significant differences at ($p<0.05$) in triglycerides, free fatty acids, free sterols and 1,2 and 1,3 triglycerides of raw and roasted process of sesame oil (Shandaweel-3 and Sohage-1), while no significant differences at ($p<0.05$) in polar lipids of raw and vacuum roasted of sesame oil (Shandaweel-3 and Sohage-1). Also there were a significant differences at ($p<0.05$) in monoglycerides of raw

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sesame oil (Shandaweel-3 and Sohage-1) while no significant differences at ($p<0.05$) in roasted process. From results also, could be observed that the amount of triglycerides, 1,2 and 1,3 diglycerides and polar lipids were lower and free fatty acids, free sterols and sterol ester and hydrocarbons were higher in roasted process than other of raw sesame oil for (Shandaweel-3 and Sohage-1). Thermal process (roasted) caused some decomposition or hydrolysis in triglycerides content that reflected in increase amount of free fatty acids and free sterol. Polar lipids, monoglycerides and diglycerides also decreased thus, may be due to degradation during roasting (Table 1 and Figure 1).

Table 1. *Total lipids fractions of raw and roasted sesame seeds oils.*

Treatments	Shandaweel -3			Sohage-1		
Lipid fractions (%)	Raw sesame seeds oil	Roasted sesame seeds oil		Raw sesame seeds oil	Roasted sesame seeds oil	
		Vacuum	Oven		Vacuum	Oven
Polar lipids	1.46^{b}	1.41b^{c}	1.29^{c}	1.72^{a}	1.60^{a}	1.30^{c}
Monoglycerides	13.18^{c}	12.60^{d}	13.93^{b}	14.69^{a}	13.86^{b}	14.60^{b}
1,2 and 1,3 diglycerides	12.15^{a}	11.51^{b}	10.75^{c}	11.49^{b}	10.96^{c}	10.05^{d}
Free sterol	2.89^{d}	3.49^{c}	4.62^{a}	2.05^{e}	2.84^{d}	4.02^{b}
Free fatty acid	4.74^{e}	6.21^{d}	7.57^{b}	4.94e	7.01^{c}	8.50^{a}
Triglycerides	63.79^{a}	62.18^{c}	57.75^{f}	63.17^{b}	60.88^{d}	58.33^{e}
Sterol ester and hydrocarbons	1.79^{d}	2.60^{c}	4.09^{a}	1.94^{d}	2.85b^{c}	3.20^{b}

Note: Means of triplicate samples. $^{a, b, c, d, f}$ Means different superscripts within the row are significantly different at $p<0.05$

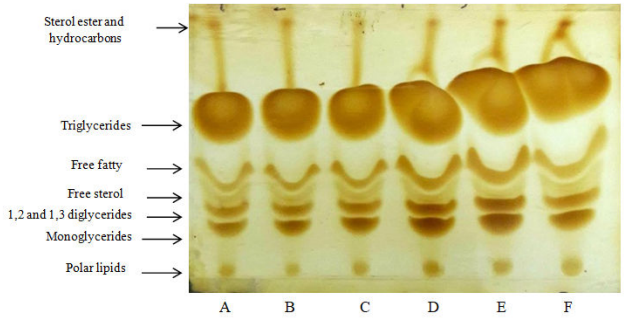

Figure 1. *Thin layer chromatogram of total lipids fractions of raw and roasted sesame seeds oil treatments: A) Raw of Shandaweel-3 oil ; B) Vacuum roasted of Shandaweel-3 oil; C) Oven roasted of Shandaweel-3 oil; D) Raw of Sohage-1 oil; E) Vacuum roasted of Sohage-1 oil; F) Oven roasted of Sohage-1 oil.*

Fatty acids profile of raw and roasted sesame seeds oil

Effect of roasting process on fatty acids profiles of sesame seeds oil are presented in Table 2. The fatty acids composition of sesame seeds oil showed that linoleic acid (C18:2) was predominant fatty acid followed by oleic acid (C18:1) which were in the ranges 42.58%-43.10% and 41.10%-41.49%, respectively. The major fatty acids observed in sesame seeds oil samples were oleic (C18:1), linoleic (C18:2), palmitic (C16:0) and stearic (C18:0). The major saturated fatty acids in sesame seeds oil samples were palmitic (8.90%-9.05%) and stearic (5.25%-5.82%) with small arachidic acid (0.57%-0.60%), whereas the main unsaturated fatty acids were oleic acid (41.10%-41.49%) and linoleic acid (42.58%-43.10%) with small linolenic acid (0.28%-0.30%). Results showed that slightly differences in values fatty acids between raw and roasted process of sesame seeds oil of Shandaweel-3 and Sohage-1 varieties. The ratio of SFA to USFA in oil samples was ranged from 0.18 to 0.19 which clearly indicated that the high amount of USFA. Results indicated that sesame seeds oil have the high amount of unsaturated fatty acids which were 84.89% and 84.50% in raw sesame oil Shandaweel-3 and Sohage-1, respectively, while saturated fatty acids begin 15.11% and 15.50% in raw sesame seeds oil of Shandaweel-3 and Sohage-1, respectively.

During roasting process using vacuum and oven, the amount of total saturated fatty acids reached to 15.16%, 14.93%, 15.63% and 15.29% for Shandaweel-3 and Sohage-1 seeds oils, respectively. Regarding to the amount of total unsaturated fatty acids were 84.84%, 85.07%, 84.37% and 84.71% in vacuum and oven sesame seeds oils (Shandaweel-3 and Sohage-1), respectively. Oleic acid has a positive effect in lowering LDL and increase HDL amount in the blood. Also the presence of high polyunsaturated fatty acids content make it possible help to reduce high blood pressure and lower the amount of medication needed to control hypertension. Although sesame seeds oil contain more unsaturated fatty acids than saturated acids, the oil shows a remarkable stability to oxidation, which could be attributed to endogenous antioxidants such as tocopherols, sesamin, lignins and sesamolin. Gouveia et al., they found that sesame seeds oil is rich source of unsaturated fatty acids reached to 84.61% while saturated fatty acids reached to 15.25%, where the fatty acids composition of oil

mainly includes oleic (18:1) was 35.32% and linoleic (18:2) was 42.62%.

Also as shown in the same Table 2, the fatty acids ratios in this evaluation were very useful to estimate the relative efficiency of the desaturation pathways. The variability in the values of Oleic Desaturation Ratio (ODR) and Linoleic Desaturation Ratio (LDR) *i.e.,* the efficiency of the desaturation systems from C18:1 to C18:2 and from C18:2 to C18:3, respectively. Results showed that no observed differences of the values ODR and LDR in raw and roasted sesame seeds oil of Shandaweel-3 and Sohage-1. Mean values of ODR (0.51) were higher than LDR (0.01) these values explain that there were an increase of linoleic acid (C18:2) and decrease in linolenic acid (C18:3). Relatively higher average values of ODR and LDR explain the increase of linolenic acid (C18:3) content.

Oleic and linoleic acids were the major fatty acids in sesame seeds oil with mean values of 45.9% and 40.5%, respectively. Also low value of LDR indicating that low levels of linolenic acid formation in sesame seeds oil, while high value of LDR lead to high linolenic acid. While the high value of ODR values imply that the biosynthetic pathway of fatty acids is efficient in the formation of oleic to linoleic acids. Thus, oleic and linoleic acids are the major constituents of sesame seeds oil. Bhunia et al., reported that the high value of ODR in sesame seeds oil, this indicated that high level oleic and linoleic acids, while low LDR, indicating low levels of linolenic acid.

The Cox value index, which refers to oxidative stability of oil, is usually taken as a measure of tendency of oils to undergo oxidation such as rancidity test or Total Polar Material measurement (TPM) are recommended.

As shown in the same Table 2 the Cox value of raw and roasted sesame seeds oil samples were also determined. Results indicate that the maximum of the Cox values were 4.92 and 4.88 for vacuum and oven roasted sesame seeds oil of Shandaweel-3 and Sohage-1, respectively. The Cox value index is calculated based on unsaturated fatty acids percentage. Hassan who reported that the Cox values range from 4.85 to 4.91 in sesame seeds oil, thus sesame seeds oil is almost stable and it could be used for protection of vegetable oil against oxidative deterioration. The obtained results are in agreement with those reported (Table 2).

Table 2. *Fatty acids profile of raw and roasted sesame seeds oil.*

Treatments	**Shandaweel -3**			**Shohage-1**		
Fatty acids %	**Raw sesame seeds oil**	**Roasted sesame seeds oil**		**Raw sesame seeds oil**	**Roasted sesame seeds oil**	
		Vacuum	**Oven**		**Vacuum**	**Oven**
Myristic (14:0)	0.02	0.02	0.02	0.02	0.02	0.02
Palmitic 16:0	9.05	9.13	8.9	9.01	9	8.9
Heptadecanoic (17:0)	0.07	0.07	0.07	0.06	0.07	0.07
Stearic (18:0)	5.28	5.25	5.25	5.72	5.82	5.58
Arachidic (20:0)	0.57	0.57	0.57	0.58	0.6	0.59
Behenic (22:0)	0.12	0.12	0.12	0.11	0.12	0.13
Total saturated	15.11	15.16	14.93	15.5	15.63	15.29
Palmitoleic (16:1)	0.13	0.13	0.13	0.13	0.13	0.13
Heptadecenoic (17:1)	0.04	0.04	0.04	0.03	0.04	0.04
Oleic (18:1ω9)	41.47	41.49	41.3	41.28	41.1	41.3
Linoleic (18:2ω6)	42.77	42.71	43.1	42.58	42.62	42.74
Linolenic (18:3ω3)	0.29	0.28	0.3	0.3	0.3	0.3
Gadoleic (20:1)	0.19	0.19	0.2	0.18	0.18	0.2
Total unsaturated	84.89	84.84	85.07	84.5	84.37	84.71
MUFA	41.83	41.85	41.67	41.62	41.45	41.67
PUFA	43.06	42.99	43.4	42.88	42.92	43.04
T. saturated (SFAs)/T. unsaturated (USFAs)	0.18	0.18	0.18	0.18	0.19	0.18
Linoleic Desaturation Ratio (LDR)	0.01	0.01	0.01	0.01	0.01	0.01

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Oleic Desaturation Ratio (ODR)	0.51	0.51	0.51	0.51	0.51	0.51
Cox value	4.88	4.88	4.92	4.86	4.86	4.88

Nutritional quality of raw and roasted sesame seeds oil

Effect of roasting process on nutritional quality of raw and roasted sesame seeds oils are shown in Table 3. Nutritional quality of sesame seeds oil using five different indices was determined based on fatty acids profile. These indices are namely: PUFA: SFA ratio, ω6:ω3 ratio, Atherogenic Index (AI), Thorombogenic Index (TI) and Hypocholesterolemic: Hypercholesterolemic (H: H).

The ratio between PUFA and SFA below 0.45 is considered inadequate because of their potential to increase blood cholesterol levels. Results show that PUFA: SFA ratio in raw and roasted sesame seeds oil were 2.77 to 2.91 therefore, this values are considered excellent, thus sesame seeds oil has high nutritional quality due to a higher polyunsaturated fatty acids compare with saturated fatty acids.

The ω6:ω3 ratio is important for human health since excessive consumption of ω6, accompanied by decreased ingestion of ω3, is a risk factor for cardiovascular disorders. Results indicate that the ω6:ω3 ratios were 141.93 to 152.54 which the obtained value was below the recommended level (range of 5:1 to 10:1) by the WHO.

Atherogenic Index (AI) which considers the ratio of saturated fatty acid (lauric, myristic and palmitic) to unsaturated fatty acids and Thorombogenic Index (TI) which considers the saturated fatty acids, (myristic and palmitic and stearic) as thrombogenic and poly-unsaturated fatty acids (omega 3) and monounsaturated fatty acids with anti-thrombogenic effects. These indices are considered cardiovascular disease risk factors. Thus, these indexes must be kept low. Obtained results showed that Atherogenic Index (AI) and Thorombogenic Index (TI) were 0.11 and 0.33, respectively, in sesame seeds oil since this values the same of raw and roasted sesame seeds oil (Shandaweel-3 and Sohage-1). Atherogenic Index (AI) and Thorombogenic Index (TI) were lower than one for sesame seeds oil due to the cardioprotective effect of their PUFAs. So lower values of AI and TI indicate that there is a greater amount of anti-atherogenic and anti-thrombogenic fatty acids in the oil or fat and therefore, may be considered an important food in the prevention of cardiovascular diseases. These elevated indices are considered risk factors for cardiovascular diseases and when the values are lower than one, they may be considered cardio protective.

Hypocholesterolemic: Hypercholesterolemic (H: H) ratio considers specific effects of fatty acids on cholesterol metabolism and high ratio values (H:H) are desired from a nutritional standpoint. Results indicated that (H:H) ratio were (9.30 to 9.50) in sesame seeds oil. Guimaraes et al., found that the ω6:ω3 ratio of 97.8, PUFA: SFA ratio of 0.97, H: H ratio of 4.82 AI and TI lower than one in sesame seeds oil. While Gouveia et al., reported that PUFA: SFA ratio of 3.22, AI and TI lower than one in sesame seeds oil. Results obtained are in agreement with those reported by Guimaraes et al., and Gouveia et al., (Table 3).

Table 3. *Nutritional quality indeces of raw and roasted sesame seeds oil.*

Treatments	**Shandaweel-3**			**Sohage-1**		
Indeces	**Raw sesame seeds oil**	**Roasted sesame seeds oil**		**Raw sesame seeds oil**	**Roasted sesame seeds oil**	
		Vacuum	**Oven**		**Vacuum**	**Oven**
PUFA:SFA	2.85	2.84	2.91	2.77	2.75	2.81
ω6:ω3	147.48	152.54	143.67	141.93	142.07	142.47
Atherogenicc Index (AI)	0.11	0.11	0.11	0.11	0.11	.0.11
Thorombogenic Index (TI)	0.33	0.33	0.33	0.34	0.35	0.34
Hypocholesterolemic: Hypercholesterolemic (H: H)	9.31	9.3	9.5	9.32	9.31	9.46

Fuel properties of raw and roasted sesame seeds oil

Fuel properties for the combustion analysis of vegetable oils can be grouped conveniently into physical, chemical and thermal properties. From fuel properties of the Higher Heating Value (HHV) and the Cetane Number (CN) can be calculated by using the saponification and iodine values that important in diesel fuel quality. Fuel properties of sesame seeds oil are tabulated in Table 4. The Higher Heating Value (HHV), which is one of the most important properties of a fuel, is the amount of heat released during the combustion of 1 g of fuel to

raw sesame seeds oil of Shandaweel-3 and Sohage-1. Results indicated that there were no significant difference ($p<0.05$) in HHV of raw and roasted sesame seeds oil (Shandaweel-3 and Sohage-1) samples. The increase in heat content results from a high increase in the number of carbons and hydrogen, as well as an increase in the ratio of these elements relative to oxygen. A decrease in heat content is the result of fewer hydrogen atoms (*i.e.,* greater unsaturation) in the molecule.

The Cetane Number (CN) is one of the most commonly cited indicators of diesel fuel quality, especially the ignition quality. Results indicated that the cetane number were 52.03 and 51.39 in raw sesame seeds oil of Shandaweel-3 and Sohage-1, while decreased to 51.07 and 51.58 in vacuum and oven roasted sesame seeds oil of Shandaweel-3. Results showed that there were a significant difference ($p<0.05$) in the cetane number between raw and vacuum roasted of sesame seeds oil (Shandaweel-3) samples, whereas no significant difference ($p<0.05$) between raw, vacuum and oven roasted sesame seeds oil (Sohage-1) samples. The Cetane Number (CN) decreases with increasing unsaturation and increases with increasing chain length.

Finally, from obtained results, sesame seeds oil has good fuel properties; it can be used in the production of biodiesel fuel. Obtained results are similar with those reported by Demirbas, who reported that the Higher Heating Value (HHV) in sesame seeds oil was 39.43 MJ/kg (Table 4).

Table 4. *Fuel properties of raw and roasted sesame seeds oil triplicate samples.*

Treatments	**Shandaweel-3**			**Sohage-1**		
Fuel properties	**Raw sesame seeds oil**	**Roasted sesame seeds oil**		**Raw sesame seeds oil**	**Roasted sesame seeds oil**	
		Vacuum	**Oven**	**Vacuum**	**Oven**	
Higher Heating Value (HHV) MJ/kg	40.35^{ab}	40.31^{abc}	40.37^{a}	40.16^{bc}	40.40^{a}	40.11^{c}
Cetane Number (CN)	52.03^{a}	51.07^{b}	51.58^{ab}	51.39^{ab}	51.97^{a}	51.61^{ab}
Note: Triplicate samples. $^{a, b, c, d, f}$: Means different superscripts within the row are significantly different at $p<0.05$						

Conclusion

In conclusion, the obtained results indicated that the roasting process affected on total lipids in sesame seeds oil, while no significant difference between raw and roasted sesame oil in fatty acids profile and sesame seeds oil is almost stable and can be used to protect vegetable oils from oxidative degradation. Also results showed sesame seeds oil has high nutritional qualities due to higher polyunsaturated fatty acids compared with saturated fatty acids. Also, sesame seeds oil has good fuel properties and it can be used in the production of biodiesel fuel.

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