Archives of Agriculture Sciences Journal
Print ISSN: 2535-1680
Online ISSN: 2535-1699

ARCHIVES OF AGRICULTURE SCIENCES JOURNAL
Volume 6, Issue 2, 2023, Pages 58–78

Available online at www.agricuta.edu.eg

DOI: https://dx.doi.org/10.21608/aasj.2023.205841.1149

Evaluation of quality attributes of chia (*Salvia hispanica*), moringa (*Moringa oleifera*) and flax (*Linum usitatissimum*) oils

Gadallah E. E., Abd El-hamied A. A., El-Naggar E. A., Mustafa M. A.*

Food Science and Technology Department, Faculty of Agriculture, Al-Azhar University, 71524 Assiut, Egypt

Abstract

Each year, the consumption of vegetable oils increases gradually. Around the world, there has been an increasing demand for oils from non-conventional sources to compliment the available ones. Some oils, such as chia, flax, and moringa, are consumed due to the nutritional properties and health promoters that have been recognized in their components. The current study aimed to characterization of chia (*Salvia hispanica* L.), moringa (*Moringa oleifera* Lam.) and flax (*Linum usitatissimum* L.) oils, in order to enable their applications in the development of new food products. Results showed that there were significant differences in various quality parameters such as saponification number, peroxide value, free fatty acids in oils extracted from non-conventional and conventional resources. All oils showed adequate values for acidity and oxidation status. Chia and flax oils showed a high content of polyunsaturated fatty acids (>70%), especially α-Linolenic acid, while moringa oil was rich in oleic acid. Moringa oil stood out for its higher oxidative stability (31.96 h) and higher amount of phenolic compounds (633.7 mg/kg) and carotenoids (17.50 mg/kg), but chia oil had higher content of total tocopherols (552.53 mg/kg). Thus, the oils can be used in technological processes and/ or in the formulation of new food products, in order to increase the nutritional value.

Keywords: chia, moringa, flax, oils, physicochemical properties, fatty acids, bioactive compounds.

*Corresponding author: Mustafa M. A.,
E-mail address: mustafahassan.2249@azhar.edu.eg

1. Introduction

Oils play a key role in human nutrition, act as a vehicle for fat-soluble vitamins, provide energy (Gibson, 2018), impart nutritional value, taste, texture, aroma, and palatability to food, act as a heat transfer medium during the frying process, and provide consistency and specific fusion characteristics to the products containing them (Rogers, 2018). There is increasing awareness of the importance of vegetable oils, as source of food and health enhancing compounds. Thus, the world demand for vegetable oil is set to rise even more rapidly from year to year, and this trend will impact on the price levels of oils. It is therefore important that poor countries and communities which have non-conventional seed oils carry out research that can lead to commercial production of their seed oils to at least satisfy local demand (Olagunju, 2006). In this context, the evaluation of chia, *moringa oleifera* and flax oils, obtained by cold pressing, becomes important, in order to make feasible their use in the development of new food products. Chia (*Salvia hispanica* L.) is an annual herbaceous plant that belongs to the *Lamiaceae* family, native from southern Mexico and northern Guatemala. More recently chia has been cultivated for commercial purposes in Argentina, Colombia, Ecuador, Peru, Bolivia, Paraguay and Australia (*Busilacchi et al.*, 2013). The increasing interest in the study of chia seed is due to their nutritional and health promoting properties that have been recognized in some of their components, namely it's high content of oil (25–32%) and essential fatty acids (21.4-32.6 g/100 g), which contains higher polyunsaturated fatty acids, mainly α-linolenic acid (59.9-63.2 g/100 g) and a low percentage of saturated fatty acids (Bodoira *et al.*, 2017; Porras-Loaiza *et al.*, 2014). Also, the high content in minerals, proteins, dietary fiber and other bioactive components such as tocopherols and phenolic compounds (Capitani *et al.*, 2012; Marineli *et al.*, 2014; Porras-Loaiza *et al.*, 2014). Furthermore, chia seed intake has been reported to be associated with significantly reduced levels of serum triglycerides and low-density lipoproteins and increased levels of high-density lipoprotein (Fernandez *et al.*, 2008). Moringa (*Moringa oleifera* Lam., *Moringaceae*) is a highly valued plant that is mostly cultivated in the tropical and subtropical regions. It is used for food, medication and industrial purposes. In recent years, because of the gap between demand and production of vegetable oils in many developing countries, research focusing on the use of unconventional oil seeds as a source of vegetable oils has become important (Bhatnagar and Gopalakrishna, 2013). The seeds have the edible oil known as Ben oil. *M. oleifera* seeds contain 19-47% oil commercially known as Ben oil and are rich in palmitic, stearic, behenic and oleic acids (Ojiako and Okeke, 2013). Ben oil is reported to have very high oleic acid (70%) and smells a pleasant peanut like fragrance. Ben oil is more stable than canola oil, soybean oil and palm oil when used in frying (Nguyen *et al.*, 2011). Ben oil is considered equivalent to olive oil in terms of fatty acid composition (Zhao and Zhang, 2013). Moringa seed oil obtained using cold press system can be used as edible oil due to the possibility that it may contain higher proportions of essential fatty acid and other functional compounds in comparison to some other edible oils. Due to the fact that it does not involve use of heat and organic solvents, cold press oil can be regarded as safe and more natural, (Goldberg, 2003). Flax (*Linum usitatissimum* L.) is an annual crop that is widely adapted to warm and cool climates. Flax belongs to the family *Linaceae*, a highly diverse family with more than 270 species spanning 14 genera. The genus *Linum* includes around 180 species distributed in six continents (Wang *et al.*, 2012). Flaxseed contains oil (37.1%), carbohydrates (28.9%), protein (20.3%), dietary fiber (4.8%), moisture (6.5%) and minerals (2.4%) and is recognized as an important oil seed and fiber crop (Singh *et al.*, 2011). Moreover, flaxseed is rich in phenolic compounds (lignans, ferulic and *p*-coumaric acid) and mucilage that are known for various bioactivities and beneficial intestinal function (Tuncel *et al.*, 2017). Flaxseed oil is a good source of α-linolenic acid (ALA), which is an n-3 polyunsaturated fatty acid whose consumption may prevent cardiovascular disease, non-alcoholic fatty liver disease, insulin resistance, Type 2 diabetes, and neurodegenerative diseases (Yu *et al.*, 2017). The aim of the present study therefore was to determine some physical and chemical properties, fatty acids, bioactive compounds as well as oxidative stability and antioxidant activity of the oil of chia seed and moringa seed as compared with flaxseed oil.

2. Materials and methods

2.1 Materials

2.1.1 The tested oils

Chia, moringa and flax seeds were obtained from the Agricultural Research Center, Giza, Egypt. The seeds were ground, and the oils was obtained by cold pressing. The extracted oil samples were transferred into brown glass bottles and stored in a refrigerator at 5^{o}C.

2.1.2 Chemicals and reagent

All chemicals and reagents used in the analytical methods (analytical grade) were purchased from El-Gomhouria Trading Chemicals and Drugs Company, Assiut city, Egypt.

2.2 Methods

2.2.1 Extraction of the tested oils

Extraction of the oils under study prepared by Al-Baraka factory to extract natural oils, Hurghada-Egypt, by using cold pressure. The extracted oil was collected, filtrated and kept in sealed bottles (with N_2 introduced in dark under the refrigeration condition (0-4˚C) for further processing and analysis (Lalas, 1998; Ustun *et al.*, 1990).

2.2.2 Physical quality properties of the tested oils

2.2.2.1 Refractive index (R.I)

The refractive index of the tested oils was estimated according to the method described by AOAC (2005) with using a Zeiss refractometer at 25°C.

2.2.2.2 Viscosity

The flow time of the tested oils relatively for that of the distilled water was measured at 60°C using an Ostwald Viscosimeter, for measuring the efflux time in seconds required to discharge a fixed volume (5ml) of the tested oils, relatively for that of standard fluid (distilled water) according to the standard procedure of AOCS (1992).

2.2.2.3 Color

The color of the tested oil was determined by Lovibond tintometer (Model E) using the two-colored scales (yellow and red) cell (5-25 inch) of the instrument. The color of the tested oil sample was simulated and the numbers representing the degree of color were read off the scales according to the method described by AOAC (2005).

2.2.3 Chemical quality properties of the tested oils

The chemical properties of the oil acidity, iodine, peroxide, saponification, unsaponifiable matter values and were determined according to AOAC (2005).

2.2.4 Fatty acids composition of the tested oils

The methyl esters fatty acids were prepared as follows: the oil samples (2 g each) were transesterified by refluxing in dry methanol that contained ethanol chloride to yield fatty acid methyl esters (FAMEs) (Yeboah *et al.*, 2012). Fatty acids fraction for FAMEs samples were carried out by GC-MS equipped with flame ionization detector. The peak was measured by triangulation and the relative proportion of individual compound were therefore obtained by determining the partial areas in relation to total area (Yeboah *et al.*, 2012).

2.2.5 Bioactive compound of the tested oils

Qualitative analysis of bioactive compounds present in the oils was analyzed by GC-MS (Shimadzu Make QP - 2010 with non-polar 60 M RTX 5MS column) as described by Mahadkar *et al.* (2013).

2.2.5.1 Polyphenols content of the tested oil

Quantitative analysis was performed according to the peak area under the maximal absorbance wavelength, (Zhao *et al.*, 2019).

2.2.5.2 Carotenoids content of the tested oil

The level of total carotenoids in the oil was determined by spectrophotometry at 450 nm, (Pacheco *et al.*, 2014).

2.2.5.3 Tocopherols content of tested oils

Tocopherols (α, γ, and δ) analysis was carried out by high performance liquid chromatography (HPLC) following the method of Thompson and Hatina (1979), with slight modifications at Agricultural Research Center, Giza, Egypt.

2.2.6 The oxidative state and stability of the tested oils

2.2.6.1 Peroxide value

The peroxide value of the tested oils was determined according to the method described in AOAC (2005).

2.2.6.2 Anisidine value

The anisidine value was determined in triplicate for each of the samples based on AOCS (1992).

2.2.6.3 Thiobarbituric acid (TBA) value

The T, B, A, value of the tested oils was determined according to the method described in lemon (1975).

2.2.6.4 Specific extinction at 232 and 268 nm

The ultraviolet absorbance at 232 nm (conjugated dienes) and 268 nm (conjugated trienes) of oil samples were measure on a UV-spectrophotometer (UV-160 IPC UV-visible spectrophotometer (SHIMADZU)), according to the method as described by Danopoulos and Ninni (1972).

2.2.6.5 Induction period (IP)

Oxidative stability was evaluated by Rancimat method at Agric. Res. Center, Giza. An automated Metrohm Rancimat apparatus, Model 679. Testing was carried out at 120°C and oxidative stability was measured following the procedure described by Anwar *et al.* (2003). Briefly, oil (2.5 g) was carefully weighed into each of the six reaction vessels and analyzed simultaneously. The of the samples was automatically recorded and corresponded to the break point on the plotted curves.

2.2.6.6 Antioxidant activity of the tested oils

Antioxidant activity was determined to according to the method described by Dapkevicius *et al.* (1998).

2.3 Statistical analysis

Data were analyzed by analysis of variance (ANOVA) using a completely randomized factorial design. Basic statistics and ANOVA were performed to test the significance within replications and between treatments by using SPSS 25-software package (Pallant, 2005). (Duncan) tests were used to determine the differences among means at the level of 0.05%.

3. Results and Discussion

3.1 Physical properties of the extracted chia and moringa seed oils compared to the flax oil

The results of physical parameters of the extracted chia, moringa and flax seed oils including refractive index, viscosity and color index were determined and the obtained results are presented in Table (1). The obtained data showed that there were some observed differences in the physical properties of studied oils. Refractive index (RI) is one of foremost representative properties of crude oils, which used in the identification of fats and oils. The values: 1.48, 1.46 and 1.48 represent the refractive index for the chia, moringa and flax oils, respectively and there were significant differences ($p \geq 0.05$) among them. The data presented in same table, reported that, moringa oil showed the highest value of viscosity (52.78) compared with other oils, compatible with the composition of long-chain saturated fatty acids present in the oil, since viscosity is an intrinsic property of the composition of fatty acids. While the lowest value of viscosity was obtained by chia oil (43.22). The color of the edible oils is considered one of the most considerable commercial importance physical characteristics. From the obtained results showed in same Table, it could be observed that color of chia, moringa and flax seed oils, it was found to be (33.50 Y and 0.75 R), (28.20 Y, 0.85 R) and (23.20 Y, 1.80 R), respectively. Similar results are close to those reported by Zhang *et al.* (2011), Dalia *et al.* (2015), Fernandes *et al.* (2019), and Dominguez-Candela *et al.* (2022).

3.2 Chemical properties of the extracted chia and moringa seed oils compared to the flax oil

The chemical properties of oil are amongst the most important properties of the oil. The obtained data of the chemical properties (acidity, iodine value, saponification number and unsaponifiable matter (%)) of chia, moringa and flax seed oils are tabulated in Table (2). The acidity (% as oleic acid) is considered one of the most chemical constants for quality assurance of the edible fats and vegetable oils as a good indicator for the hydrolysis extent takes place in oils before and during extraction procedures. From data presented in Table (2) it could be concluded that acidity for all studied oils were ranged from 0.35 to 1.39 (as % oleic acid). The low acidity obtained for chia oil is an indication that the triacylglycerols present have not been hydrolysed. These findings are in similar to those observed in cold-pressed chia oil (Martínez *et al.*, 2012), the value of acidity (as oleic acid) was 0.49%, much lower than the maximum values established by Clara *et al.* (2020). Acidity measures the percentage content of free fatty acids in a given amount of oil. It also provides information on the extent of the decomposition of triglycerides in the oil by lipase action into free fatty acids and other physical factors such as light and heat (Muhammad *et al.*, 2011; Ochigbo and Paiko, 2011).

Table (1): Physical properties of the extracted chia and moringa seed oils compared to the flax oil.

Description	Physical properties			
	Refractive index at 20℃	Viscosity	Color index	
			Yellow	Red
Chia oil	1.475 ±0.01^{B}	43.21 ±0.04^{C}	33.49 ±0.03^{A}	0.74 ±0.01^{C}
Moringa oil	1.455 ±0.01^{C}	52.78±0.05^{A}	28.21±0.07^{B}	0.85 ±0.01^{B}
Flax oil	1.479± 0.07^{A}	47.51±0.04^{B}	23.20 ±0.01^{C}	1.80 ±0.03^{A}

Values are the mean of triplicate determinations with standard division. The different letters at the column means significant differences at ($p \geq 0.05$) and the same letters means no significant differences.

Table (2): Chemical properties of the extracted chia and moringa seed oils compared to the flax oil.

Description	Chemical properties			
	Acidity (% as oleic acid)	Iodine value (I_2/100g of oil)	Saponification number (mg of KOH/g of oil)	Unsaponifiable matter (%)
Chia oil	0.35 ±0.07^{C}	186.28 ±0.20^{A}	193.91 ±1.16^{A}	0.85 ±0.01^{C}
Moringa oil	1.39 ±0.01^{A}	67.53 ±0.60^{C}	187.56 ±2.12^{B}	1.42 ±0.05^{A}
Flax oil	0.77 ±0.07^{B}	137.54 ±0.30^{B}	191.48 ±1.16^{A}	0.94 ±0.01^{B}

Values are the mean of triplicate determinations with standard division. The different letters at the column means significant differences at ($p \geq 0.05$) and the same letters means no significant differences.

From these results in Table (2), it could be concluded that the iodine values obtained were 186.28, 67.53 and 137.54 I_2/100g for chia, M. oleifera and flax oils, respectively. The values were significantly different ($p \geq 0.05$), and the values obtained were according to the expected. Moringa oil had the lowest iodine value among the oils. This low iodine value could be attributed to the small amount of linoleic acid found in moringa oil (0.55%). The iodine value is related to the degree of unsaturation of fatty acids in oil (Barradas *et al.*, 2015). The iodine value obtained for chia oil, which contains a high level of polyunsaturated acids, was much higher than for the other two oils. Low iodine value indicates lesser number of unsaturated bonds and lower susceptibility of such oil to oxidative rancidity. Oils with iodine values less than 100 mI_2/g are known as non-drying oils, above 100 mI_2/g but less than 130 mI_2/g as semi drying oils while above 130 mI_2/g as drying oils. These results are agreed with that obtained by Barakat and Ghazal (2016), and Fernandes *et al.* (2019). It is worthy mention that the saponification number (Table 2) for chia, moringa and flax oils were 193.91, 187.56 and 191.48, respectively. Chia oil presented higher saponification value (193.91 mg KOH/g). Thus, it can be inferred that this oil is composed of larger amounts of short chain fatty acids, corroborating with Marambe *et al.* (2005), Ixtaina *et al.* (2012), and Aly *et al.* (2016). There were no significant differences ($p \geq 0.05$) between the saponification value of chia oil and flax oil. A study by Michael *et al.* (2014) reported 155.68 mg KOH/g for moringa seed oil which is lower than those obtained in the present study. The saponification value of oil is a measure of its oxidation during storage and also indicates deterioration of the oils. High saponification value is an indication of the presence of fatty acids with higher number of carbon atoms. It provides information on the average molecular weight and hence, chain length of a lipid (Ardabili *et al.*, 2011). Regarding to the unsaponifiable matter (USM) (includes hydrocarbons, sterols, vitamins and pigments compounds) in chia, moringa and flax oils usually plays a crucial role in the oil stability. It is obvious from Table (2) that the moringa oil had the highest USM followed by flax and chia oils. Nevertheless, there were significant differences ($p \geq 0.05$) among them in unsaponifiable matter. Malecka (2002) reported that the unsaponifiable matter (USM) fractions of vegetable oils contain sterols, tocopherols, terpene alcohols, and hydrocarbons, which typically comprise 0.500-2.50% although some are much higher (5-6%). These data coincide with those obtained by Marambe *et al.* (2005), Segura-Campos *et al.* (2014), and Rahman *et al.* (2014).

3.3 Fatty acid composition of the extracted chia and moringa seed oils compared to the flax oil

The fatty acids composition of the extracted chia, moringa and flax oils were carried out by gas chromatography analysis; the obtained data are recorded in Table (3). These oils contain important fatty acid which are major sources of energy and also needed in the body for proper functioning (Derle *et al.*, 2016). The obtained results showed that the major saturated fatty acid in moringa oil was behenic acid which recorded 7.85%. While palmitic acid was presented the major saturated fatty acids in chia and flax oils which recorded 8.72 and 5.84%, respectively. These results are in agreement with those obtained by Singh *et al.* (2011), Shen *et al.* (2018), and Özcan (2018). With regards to the unsaturated fatty acids content as shown in Table (3), the chia and flax oils are characterized by a high content of α-Linolenic acid ($C_{18:3}$) was found to be the dominant unsaturated fatty acid and accounted 56.15 and 55.34%; respectively. While, it contained a considerable concentration of linoleic acid ($C_{18:2}$) 19.25 and 15.95% and oleic acid ($C_{18:1}$) 8.29 and 17.71%; respectively. α-Linolenic acid has potential health benefits such as in reduction of cardiovascular disease, atherosclerosis, diabetes, cancer, arthritis, osteoporosis, autoimmune and neurological disorders (Goyal *et al.*, 2014; Yu *et al.*, 2017). Oleic acid ($C_{18:1}$)

was found to be the major unsaturated fatty acid present in the moringa oil and its concentration was higher than in the chia and flax oils. Oleic acid, an omega-9-fatty acid found in significant amount in oils, is very good for food, medicinal and health purposes. Lipid soluble form of oleic acid is also widely used as a solvent for steroids (Aloko *et al.*, 2017). The above-mentioned results are in harmony with those obtained by Özcan (2018), Abad and Shahidi (2020), and Grajzer *et al.* (2020). The obtained results showed that total saturated fatty acids content chia, moringa and flax oils were 14.66, 26.35 and 11.00%; respectively, while the total unsaturated fatty acids contents were 85.34, 73.65 and 89.00%, thus the ratio between total unsaturated and total saturated (TUSFA/TSFA) were recorded as 5.82, 2.79 and 8.09 for chia, moringa and flax oils; respectively. Oils that have unsaturated to saturated fatty acid ratio above 0.4 are considered healthy and excellent in reducing the risk of heart diseases in consumers (Wood *et al.*, 2003).

Table (3): Fatty acid composition of the extracted chia and moringa seed oils compared to the flax oil.

Fatty acids	Carbon chain	Samples		
		Chia oil	Moringa oil	Flax oil
Saturated				
Palmitic	$C_{16:0}$	8.72	6.46	5.84
Stearic	$C_{18:0}$	4.54	6.18	4.92
Arachidic	$C_{20:0}$	1.40	4.23	0.24
Behenic	$C_{22:0}$	ND*	7.85	ND*
Lignoceric	$C_{24:0}$	ND*	1.63	ND*
Unsaturated				
Palmitoleic	$C_{16:1}$	0.52	1.52	ND*
Oleic	$C_{18:1}$	8.29	68.80	17.71
Linoleic	$C_{18:2}$	19.25	0.55	15.95
α-Linolenic	$C_{18:3}$	56.15	0.12	55.34
Gadoleic	$C_{20:1}$	1.13	2.66	ND*
Total saturated fatty acids (TSFA)		14.66	26.35	11.00
Total unsaturated fatty acids (TUSFA)		85.34	73.65	89.00
TUSFA / TSFA		5.82	2.79	8.09
*ND= not detected				

3.4 Bioactive compounds of the extracted chia and moringa seed oils compared to the flax oil

Oil can be identified based on highly specific information about the compositions of minor components like tocols and phytosterols, especially when direct analysis is performed without derivatization. Data presented in Table (4) shows the bioactive compounds of the extracted chia, moringa and flax seed oils. Tabulated data showed that, moringa oil has the highest values for polyphenols (633.7mg/kg) and carotenoids (17.50 mg/kg), while the lowest polyphenols (95.9 mg/kg) and carotenoids (7.20 mg/kg) were in flax oil and there was significant difference ($p \geq 0.05$) between all oils. The obtained results in the present study showed that the oils were relatively high in polyphenols. The divergence of values between phenolic compounds can be attributed to several factors, such as the binding of polyphenols to other substances, changes in the chemical structure of polyphenols and in the oil extraction method (Everette *et al.,* 2010). These results are in concordance with those reported by Zhang *et al.* (2011), Alu'datt *et al.* (2013), and Bodoira *et al.* (2017). Regarding tocopherols (includes alpha, delta and gamma tocopherol) was tabulated in the same table, the importance of tocopherols present in vegetable oils is related to their antioxidant properties in animal and vegetable tissues and physiological functions (Tang, 2015). Chia oil presented the highest levels of gamma-tocopherol (530.36 mg/kg) and delta-tocopherol (22.17 mg/kg) compared with moringa and flax oils. Only in moringa oil was Alpha-tocopherol found and recorded (185.05 mg/kg). Similar results have been previously reported by Hosseinian *et al.* (2004), Ruttarattanamongkol *et al.* (2014), and Bodoira *et al.* (2017).

Table (4): Bioactive compounds of the extracted chia and moringa seed oils compared to the flax oil.

Description	Bioactive compounds				
	Polyphenols (mg/kg)	Carotenoids (mg/kg)	Tocopherols		
			Delta	Gamma	Alpha
Chia oil	117.1 ±0.12^B	8.40 ±0.01^B	22.17 ±0.02^A	530.36±0.46^A	ND*
Moringa oil	633.7 ±0.60^A	17.50 ±0.02^A	10.26 ±0.06^B	87.57 ±0.06^C	185.05±0.05
Flax oil	95.9 ±0.40^C	7.20 ±0.03^C	5.82 ±0.02^C	302.08±0.57^B	ND*

Values are the mean of triplicate determinations with standard division. The different letters at the column means significant differences at ($p \geq 0.05$) and the same letters means no significant differences. *ND= not detected.

3.5 Peroxide value (PV), anisidine value (ANV), thiobarbituric acid (TBA) and specific extension at 232nm and 268nm of the tested chia and moringa oils compared to the flax oil

The obtained data of the peroxide value (PV), anisidine value (AnV), thiobarbituric acid (TBA) and specific extinction at 232 and 268 nm of the tested chia and moringa oils compared to the flax oil are tabulated in Table (5). Peroxide value (PV), anisidine value (AnV), and totox value (TV) have been frequently utilized as the most important parameters to monitor the qualities of edible oils (Choo *et al.*, 2007). The obtained results (Table 5) showed that the peroxide value of all the seed oils were well within the limit of 15 milliequivalents of active oxygen/kg, based on the Codex Alimentarius Commission, (1999) standard for cold-pressed oils, this indicates that the oils will be stable to oxidative rancidity. The (PV) of moringa oil in the present study was 1.54 meq O_2/kg oil, which was lower than of 2.73 meq O_2/kg oil for chia oil and 2.94 meq O_2/kg oil for flax oil. This value was in agreement with that reported by Barakat and Ghazal, (2016), they reported that the (PV) of moringa oil extracted with cold press was 1.67 - 2.47 meq O_2/kg oil. Anisidine value helps in the determination of secondary oxidation products of fats and oils. The anisidine value of chia oil was 2.71 units and flax oil was 3.44 units higher than the moringa oil 1.84 units. This difference might be due to the presence of a high amount of antioxidants in moringa oil, which help in preventing oxidation. However, the anisidine value of chia and flax oils was slightly higher than the accepted anisidine value for good quality oil, *i.e.*, < 2 (Subramanian *et al.*, 2000). Also, those values of anisidine value of moringa which found to be well in line with that obtained by Anwar *et al.* (2005), and Manzoor *et al.* (2007). As shown in Table (5) the thiobarbituric acid (TBA) value for chia, moringa and flax oils were 2.46, 0.24 and 1.08 mg malonaldehyde/kg oil; respectively, the chia oil showed the highest level of TBA, while the moringa showed the lowest level of TBA. The TBA value is considered a good chemical quality criterion to identify the oxidative state of fresh edible oils and fats to measure the initial secondary oxidation extent has been done in these lipids. Therefore, the present result of the TBA value for all studied oils were much lower than the critical value, which must not be exceeding than 10 mg malonaldehyde/kg oil for the edible purposes as reported by Greene and Cumuze (1982). These values were approximately in agreement with Shokry (2012), and Sargi *et al.* (2013). From data in Table (5), it could be noticed that the specific extinction at 232 and 268 nm for chia, moringa and flax oils were (1.25, 0.48), (1.18, 0.41) and (1.65, 0.51), respectively, these values were in close approximately agreement with Anwar and Bhanger (2003), Martínez *et al.* (2012), and Herchi *et al.* (2015).

Table (5): Peroxide value (PV), anisidine value (AnV), thiobarbituric acid (TBA) and specific extension at 232nm and 268nm of the tested chia and moringa oils compared to the flax oil.

Description	Peroxide value (meq O_2 /kg oil)	Anisidine value	TBA value (mg malonaldehyde /kg oil)	Specific extension	
				At 232nm	At 268nm
Chia oil	2.73 ±0.15^{A}	2.71 ±0.02^{B}	2.46 ±0.01^{A}	1.25 ±0.004^{B}	0.48 ±0.002^{B}
Moringa oil	1.54 ±0.37^{B}	1.84 ±0.01^{C}	0.24 ±0.01^{C}	1.18 ±0.002^{C}	0.41 ±0.001^{C}
Flax oil	2.94 ±0.35^{A}	3.44 ±0.02^{A}	1.08 ±0.01^{B}	1.65 ±0.004^{A}	0.51 ±0.004^{A}

Values are the means of triplicate determinations with standard division. The different letters at the column means significant differences at ($p \geq 0.05$) and the same letters means no significant differences.

3.6 Determination of the oxidative stability of the extracted chia and moringa seed oils compared to the flax oil

Oxidative stability is a major parameter for assessing the qualities of oils and fats since providing a good reckoning of their susceptibilities to oxidative degeneration, which is the main cause of their changes (Aparicio *et al.*, 1999). The induction period, which is a characteristic of the purity and the oxidative stability of the edible oils and fats (Tsaknis and Lalas, 2002 and Anwar *et al.*, 2003), was measured by the Rancimat method at 120°C from which the oxidative stability criteria. As indicated in the obtained data (Table 6), the induction periods (Rancimat at 120°C) of the tested oils were found to be 0.36, 31.96 and 0.47 hours for chia, moringa and flax oils, respectively. Thereupon, the shelf-life periods at ambient temperature were 0.37, 32.56 and 0.48 months for the former tested oils, respectively. Therefore, the tested moringa oil exhibited a higher good resistance to the oxidative rancidity than those for the chia and flax oils. These results are in agreement with those obtained by Tsaknis and Lalas (2002), Rahman *et al.* (2009), Ixtaina *et al.* (2012), and Suri *et al.* (2020).

Table (6): Determination of the oxidative stability of the extracted chia and moringa seed oils compared to the flax oil.

Description	Oxidative stability			
	Rancimat at 120˚C	Calculated at ambient temperature		
	Induction period (h)	Induction (months)	Expired (months)	Shelf-life (months)
Chia oil	0.36	0.20	0.53	0.37
Moringa oil	31.96	17.71	47.42	32.56
Flax oil	0.47	0.26	0.70	0.48

3.7 Antioxidant activity of the extracted chia and moringa seed oils compared to the flax oil under different concentrations of oils

The oils of chia, moringa and flax was subjected to the antioxidant activity using the 1,1-dipheny l-2-picrylhydrazyl (DPPH) radical scavenging assay at 10, 25, 50,100, 250, 500, 750 and 1000 µg. The concentration of antioxidant substances dependent correlation between DPPH radical scavenging activity and different levels of antioxidant. The results indicated that increasing DPPH radical scavenging activity with increasing antioxidant levels up to certain degree and then decreased for the higher antioxidant levels. From the results shown in Table (7) it could be seen that the concentration of chia and moringa oils (100 µg) recorded the significantly ($p \geq 0.05$) difference higher inhibition percentage of radical DPPH among all the concentrations of chia and moringa oils (75.33 and 70.16%, respectively). While in the flax oil the concentration of (50 µg) recorded the significantly ($p \geq 0.05$) difference higher inhibition percentage of radical DPPH among all the concentrations of flax oil (76.41%). The maximum DPPH radical scavenging activity could be regarded as the critical effective concentration presenting the maximum increasing effect. Such a dual tendency on the DPPH radical scavenging activity may be the basic property of antioxidant activity (Zhang *et al.*, 2008). Also, from the same Table it can be observed that flax oil had higher activities than other essential oils (76.41%) under level 50 µg, while moringa oil had significantly ($p \geq 0.05$) difference the lower (19.74%) under the level 10 µg. These results are in agreement with those obtained by Ogbunugafor *et al.* (2011), Barthet *et al.* (2014), and Bodoira *et al.* (2017).

Table (7): Antioxidant activity of the extracted chia and moringa seed oils compared to the flax oil under different concentrations of oils.

Concentration of oils (µg of oils)	DPPH inhibition (%)		
	Chia oil	Moringa oil	Flax oil
10	33.09 ±2.43^{B}	19.74 ±2.40^{C}	66.67 ±2.54^{A}
25	45.61 ±2.54^{B}	36.82 ±2.01^{C}	74.25 ±1.10^{A}
50	67.27 ±1.46^{B}	68.71 ±1.10^{B}	77.37 ±0.91^{A}
100	75.33 ±0.75^{A}	70.16 ±1.10^{B}	65.58 ±1.10^{C}
250	69.80 ±1.46^{A}	67.03 ±0.75^{B}	64.74 ±1.10^{C}
500	62.70 ±1.10^{A}	60.77 ±1.46^{A}	60.89 ±0.91^{A}
750	57.88 ±1.10^{A}	56.44 ±1.10^{A}	58.36 ±1.27^{A}
1000	52.59 ±0.91^{A}	54.27 ±1.46^{A}	54.39 ±1.10^{A}

Values are the means of triplicate determinations with standard division. The different letters at the row means significant differences at ($p \geq 0.05$) and the same letters means no significant differences.

4. Conclusion

Population growth, economic progress and urbanization lead to an increase in the consumption of oils and fats as well as greater dietary diversity in both developing and developed nations. The quantity and quality of dietary fat and the influence of specific fatty acids on lipid metabolism and health continues to be the subject of much research, discussion and debate. In the current study we have attempted to carry out comprehensive lipid profiling of some oils, such as chia, moringa and flax oil. All oils showed adequate values for acidity and oxidation status. Chia and flax oils showed a high content of polyunsaturated fatty acids (>70%), especially α-Linolenic acid, while moringa oil was rich in oleic acid. Based on these results can be recommended that opportunities for extracting oils from non-conventional sources should be encouraged.

References

Abad, A. and Shahidi, F. (2020), "Compositional characteristics and oxidative stability of chia seed oil (*Salvia hispanica* L)", *Food*

Production, Processing and Nutrition, Vol. 2 No. 1, pp. 1–8.

Aloko, S., Azubuike, C. P. and Coker, H. A. (2017), "Physicochemical properties and lubricant potentials of Blighia sapida Sapindaceaeae seed oil in solid dosage formulations", *Tropical Journal of Pharmaceutical Research*, Vol. 16 No. 2, pp.305–311.

Alu'datt, M. H., Rababah, T., Ereifej, K. and Alli, I. (2013), "Distribution, antioxidant and characterisation of phenolic compounds in soybeans, flaxseed and olives", *Food Chemistry*, Vol. 139 No. 1–4, pp. 93–99.

Aly, A. A., Maraei, R. W. and Ali, H. G. (2016), "Fatty acids profile and chemical composition of Egyptian Moringa oleifera seed oils", *Journal of the American Oil Chemists' Society*, Vol. 93 No. 3, pp. 397–404.

Anwar, F. and Bhanger, M. I. (2003), "Analytical characterization of Moringa oleifera seed oil grown in temperate regions of Pakistan", *Journal of Agricultural and food Chemistry*, Vol. 51 No. 22, pp. 6558–6563.

Anwar, F., Ashraf, M. and Bhanger, M. I. (2005), "Interprovenance variation in the composition of Moringa oleifera oilseeds from Pakistan", *Journal of the American Oil Chemists' Society*, Vol. 82 No. 1, pp. 45–51.

Anwar, F., Bhanger, M. I. and Kazi, T. G. (2003), "Relationship between rancimat and active oxygen method values at varying temperatures for several oils and fats", *Journal of the American Oil Chemists' Society*, Vol. 80 No. 2, pp. 151–155.

AOAC (2005), *Official methods of analysis association of official Agricultural chemists*, 14th Edition, The Association of Official Analytical Chemists, Washington, D.C., USA.

AOCS (1992), *Official methods and Recommended practices of the American Oil Chemists Society*, 4th Edition, AOCS Press, Champaign, Additions and Revisions, Method Cd 18–90.

Aparicio, R., Roda, L., Albi, M. A. and Gutiérrez, F. (1999**),** "Effect of various compounds on virgin olive oil stability measured by Rancimat", *Journal of Agricultural and Food Chemistry*, Vol. 47 No.10, pp. 4150–4155.

Ardabili, A. G., Farhoosh, R. and Khodaparast, M. H. M. (2011), "Chemical composition and physicochemical properties of pumpkin seeds (*Cucurbita pepo Subsp*. pepo Var. Styriaka) grown in Iran", *Journal of Agricultural Science and Technology*, Vol. 13, pp. 1053–1063.

Barakat, H. and Ghazal, G. A. (2016), "Physicochemical properties of Moringa oleifera seeds and their edible oil cultivated at different regions in Egypt", *Food and Nutrition Sciences*, Vol. 7 No. 6, pp. 472–484.

Barradas Filho, A. O., Barros, A. K. D., Labidi, S., Viegas, I. M. A., Marques, D. B., Romariz, A. R., de Sousa, R. M., Marques, A. L. B. and Marques, E. P. (2015), "Application of artificial neural networks to predict viscosity, iodine value and induction period of biodiesel focused on the study of oxidative stability", *Fuel*, Vol. 145, pp. 127–135.

Barthet, V. J., Klensporf-Pawlik, D. and Przybylski, R. (2014), "Antioxidant activity of flaxseed meal components", *Canadian Journal of Plant Science*, Vol. 94 No. 3, pp. 593–602.

Bhatnagar, A. S. and Gopala Krishna, A. G. (2013), "Natural antioxidants of the Jaffna variety of Moringa Oleifera seed oil of Indian origin as compared to other vegetable oils", *Grasas y Aceites*, Vol. 64 No. 5, pp. 537–545.

Bodoira, R. M., Penci, M. C., Ribotta, P. D. and Martínez, M. L. (2017), "Chia (*Salvia hispanica* L.) oil stability: Study of the effect of natural antioxidants", *LWT-Food Science and Technology*, Vol. 75, pp. 107–113.

Busilacchi, H., Bueno, M., Severin, C., Di Sapio, O., Quiroga, M. and Flores, V. (2013), "Evaluation of *Salvia hispanica* L. cultivated in the South of Santa Fe (Argentine Republic)", *Tropical Crops*, Vol. 34 No. 4, pp. 55–59.

Capitani, M. E. A., Spotorno, V., Nolasco, S. M. and Tomás, M. C. (2012), "Physicochemical and functional characterization of by-products from chia (*Salvia hispanica* L.) seeds of Argentina", *LWT-Food Science and Technology*, Vol. 45 No.1, pp. 94–102.

Choo, W. S., Birch, J. and Dufour, J. P. (2007), "Physicochemical and quality characteristics of cold-pressed flaxseed oils", *Journal of Food composition and Analysis*, Vol. 20 No. 3–4, pp. 202–211.

Clara, M. P. F., Veronezi, C. M. and Jorge, N. (2020), "Evaluation of quality of chia (*Salvia hispanica*), sesame (*Sesamum indicum*), and quinoa (*Chenopodium quinoa*) oils", *Brazilian Archives of Biology and Technology*, Vol. 63, pp. 1–7.

Codex Alimentarius Commission (1999), *Codex standard for named vegetable oils (CODEX-STAN 210)*, FAO, Rome, Italy, pp. 1–13.

Dalia, S. M., Lopez-Cervantes, J., Nunez-Gastelum, J., Mora-Lopez, M. S., Lopez-Hernandez, J. and Paseiro-Losada, P. (2015), "Effect of the refining process on *Moringa oleifera* seed oil quality", *Food Chemistry*, Vol. 187, pp. 53–57.

Danopoulos, A. A. and Ninni, V. L. (1972), "Detection of frozen fish deterioration by an ultraviolet spectrophotometric method", *Journal of Food Science*, Vol. 37 No. 5, pp. 649–651.

Dapkevicius, A., Venskutonis, R., Van Beek, T. and Linseen, J. (1998), "Antioxidant activity of extracts obtained by different isolation procedures from some aromatic herbs grown in Lithuania", *Journal of the Science of Food and Agriculture*, Vol. 77, pp. 140–146.

Derle, N. D., Derle, D. V., Bele, M. H. and Khatale, S. B. (2016), "Functionality testing of excipients: A Review", *International Journal of Pharmaceutical Sciences and Research*, Vol. 7 No. 8, pp. 3208–3217.

Dominguez-Candela, I., Lerma-Canto, A., Cardona, S. C., Lora, J. and Fombuena, V. (2022), "Physicochemical Characterization of Novel Epoxidized Vegetable Oil from Chia Seed Oil", *Materials*, Vol. 15 No. 9, pp. 3250–3269.

Everette, J. D., Bryant, Q. M., Green, A. M., Abbey, Y. A., Wangila, G. W. and Walker, R. B. (2010), "Thorough study of reactivity of various compound classes toward the Folin-Ciocalteu reagent", *Journal of agricultural and food chemistry*, Vol. *58* No.14, pp.8139–8144.

Fernandes, S. S., Tonato, D., Mazutti, M. A., de Abreu, B. R., da Costa Cabrera, D., D'Oca, C. D. R. M., Hernández, C. P. and de las Mercedes Salas-Mellado, M. (2019), "Yield and quality of chia oil extracted via different methods", *Journal of Food Engineering*, Vol. 262, pp. 200–208.

Fernandez, I., Vidueiros, S. M., Ayerza, R., Coates, W. and Pallaro, A. (2008), "Impact of chia (*Salvia hispanica* L). on the immune system: preliminary study", *Proceedings of the Nutrition Society*, Vol. 67(OCE1), p.12.

Gibson, M. (2018), "Food science and the culinary arts", Academic Press, USA.

Goldberg, G. (2003), *Recommendations of the task force. Plants: diet and health*, The report of a British Nutrition Foundation Task Force, Blackwell Science, Oxford, UK, pp. 282–285.

Goyal, A., Sharma, V., Upadhyay, N., Gill, S. and Sihag, M. (2014), "Flax and flaxseed oil: an ancient medicine & modern functional food", *Journal of food science and technology*, Vol. 51, pp. 1633–1653.

Grajzer, M., Szmalcel, K., Kuzminski, L., Witkowski, M., Kulma, A. and Prescha, A. (2020), "Characteristics and Antioxidant potential of cold-pressed oils possible strategies to improve oil stability", *Foods*, Vol. 9, pp. 1630–1648.

Greene, B. E. and Cumuze, T. H. (1982), "Relationship between TBA numbers and inexperienced panelists' assessments of oxidized flavor in cooked beef", *Journal of Food Science*, Vol. 47 No. 1, pp. 52–54.

Herchi, W., Bahashwan, S., Sebei, K., Saleh, H. B., Kallel, H. and Boukhchina, S. (2015), "Effects of germination on chemical composition and antioxidant activity of flaxseed (*Linum usitatissimum* L) oil", *Grasas y Aceites*, Vol. 66 No.1, pp. 057–057.

Hosseinian, F. S., Rowland, G. G., Bhirud, P. R., Dyck, J. H. and Tyler, R. T. (2004), "Chemical composition and physicochemical and hydrogenation characteristics of high-palmitic acid solin (low-linolenic acid flaxseed) oil", *Journal of the American Oil Chemists' Society*, Vol. 81, pp. 185–188.

Ixtaina, V. Y., Nolasco, S. M. and Tomás, M. C. (2012), "Oxidative stability of chia (*Salvia hispanica* L.) seed oil: effect of antioxidants and storage conditions", *Journal of the American Oil Chemists' Society*, Vol. 89 No. 6, pp. 1077–1090.

Lalas, S., (1998), *Quality and stability characterization of Moringa oleifera seed oil*, PhD Thesis, Lincolnshire and Humberside University, England, pp. 123.

Lemon, D. W. (1975), *An improved TBA test for rancidity*, New Series Circular, Fisheries and Marine Service, No. 5, Halifax-Laboratory, Halifax, Nova Scotia, Canada, pp.145.

Mahadkar, S., Valvi, S. and Jadhav, V. (2013), "Gas chromatography mass spectroscopic analysis of some bioactive compounds from five medicinally relevant wild edible plants", *Asian Journal of Pharmaceutical and Clinical Research*, Vol. 1 No. 6, pp.1–5.

Małecka, M. (2002), "Antioxidant properties of the unsaponifiable matter isolated from tomato seeds, oat grains and wheat germ oil", *Food Chemistry*, Vol. 79 No. 3, pp. 327–330.

Manzoor, M., Anwar, F., Iqbal, T. and Bhanger, M. I. (2007), "Physico-chemical characterization of Moringa concanensis seeds and seed oil", *Journal of the American Oil Chemists' Society*, Vol. 84, pp. 413–419.

Marambe, H., Purdy, S., Tse, T. and Reaney, M. J. (2005), "Flax oil and high linolenic oils", *Bailey's Industrial Oil and Fat Products*, pp. 1–23.

Marineli, R. S, Moraes, É. A., Lenquiste, S. A., Godoy, A. T., Eberlin, M. N. and Maróstica Jr, M. R. (2014), "Chemical characterization and antioxidant potential of Chilean chia seeds and oil (*Salvia hispanica* L.)", *LWT-Food Science and Technology*, Vol. 59 No. 2, pp. 1304–1310.

Martínez, M. L., Marín, M. A., Faller, C.

M. S., Revol, J., Penci, M. C. and Ribotta, P. D. (2012), "Chia (*Salvia hispanica* L.) oil extraction: Study of processing parameters", *LWT-Food Science and Technology*, Vol. 47 No. 1, pp. 78–82.

Michael, A., Fausat, A. and Doyinsola, I. (2014), "Extraction and physicochemical analysis of some selected seed oils", *International Journal of Advanced Chemistry*, Vol. 2 No. 2, pp. 70–73.

Muhammad, N., Bamishaiye, E., Bamishaiye, O., Usman, L. A., Salawu, M. O., Nafiu, M. O. and Oloyede, O. (2011), "Physicochemical properties and fatty acid composition of *cyperus esculentus* (Tiger Nut) tuber oil", *Bioresearch Bulletin*, Vol. *5*, pp. 51–54.

Nguyen, H. N., Gaspillo, P. D., Maridable, J. B., Malaluan, R. M., Hinode, H., Salim, C. and Huynh, H. K. P., (2011), "Extraction of oil from *Moringa oleifera* kernels using supercritical carbon dioxide with ethanol for pretreatment: optimization of the extraction process", *Chemical Engineering and Processing: Process Intensification*, Vol. 50, pp. 1207–1213.

Ochigbo, S. S. and Paiko, Y. B. (2011), "Effects of solvent blending on the characteristics of oils extracted from the seeds of *Chrysophyll umalbidium*", *International Journal of Science and Nature*, Vol. 2 No. 2, pp. 352–358.

Ogbunugafor, H. A., Eneh, F. U., Ozumba, A. N., Igwo-Ezikpe, M. N., Okpuzor, J., Igwilo, I. O. and Onyekwelu, O. A. (2011), "Physico-chemical and antioxidant properties of Moringa oleifera seed oil", *Pakistan Journal of Nutrition*, Vol. 10 No. 5, pp. 409–414

Ojiako, E. N. and Okeke, C. C., (2013), "Determination of antioxidant of *Moringa oleifera* seed oil and its use in the production of a body cream", *Asian Journal of Plant Science & Research*, Vol. 3, pp. 1–4.

Olagunju, A. O. (2006), *Extraction and characterization of oil from tiger nut seed (Cyperus esculentus) using 23 full factorial design*, M.Sc. Thesis, Department of Chemical Engineering, Federal University of Technology, Minna, Niger State, Nigeria.

Özcan, M.M. (2018), "Moringa spp.: Composition and bioactive properties", *South African Journal of Botany*, Vol. 129, pp. 25–31.

Pacheco, P., Peixoto, F. M., Borguini, R. G., Nascimento, L. S. M., Bobeda, C. R. R., Santiago, M. C. P. A. and Godoy, R. L. O. (2014), "Microscale extraction method for HPLC carotenoid analysis in vegetable matrices", *Scientia Agricola* Vol. 71, pp. 345–355.

Pallant, J. (2005), *SPSS Survival Manual*, 2nd ed., Open University Press, McGraw-Hill Education, USA, pp. 336.

Porras-Loaiza, P., Jiménez-Munguía, M. T., Sosa-Morales, M. E., Palou, E. and López-Malo, A. (2014), "Physical properties, chemical characterization and fatty acid composition of Mexican chia (*Salvia hispanica* L.) seeds", *International Journal of Food Science & Technology*, Vol. 49 No. 2, pp. 571–577.

Rahman, F., Nadeem, M., Azeem, M. W. and Zahoor, Y., (2014), "Comparison of chemical characteristics of high oleic acid fraction of *moringa oleifera* oil with some vegetable oils", *Pakistan Journal of Analytical & Environmental Chemistry*, Vol. 15 No. 1, pp. 80–83.

Rahman, I. M., Barua, S., Nazimuddin, M., Begum, Z. A., Rahman, M. A. and Hasegawa, H. (2009), "Physicochemical properties of Moringa oleifera lam. Seed oil of the indigenous-cultivar of Bangladesh", *Journal of Food Lipids*, Vol. 16 No. 4, pp. 540–553.

Rogers, M. A. (2018), *Encyclopedia of Food Chemistry*, Elsevier, Amsterdam, Netherlands.

Ruttarattanamongkol, K., Siebenhandl-Ehn, S., Schreiner, M. and Petrasch, A. M. (2014), "Pilot-scale supercritical carbon dioxide extraction, physico-chemical properties and profile characterization of *Moringa oleifera* seed oil in comparison with conventional extraction methods", *Industrial Crops and Products*, Vol. 58, pp. 68–77.

Sargi, S. C., Silva, B. C., Santos, H. M. C., Montanher, P. F., Boeing, J. S., Santos Júnior, O. O., Souza, N. E. and Visentainer, J. V. (2013), "Antioxidant capacity and chemical composition in seeds rich in omega-3: chia, flax, and perilla", *Food Science and Technology*, Vol. 33, pp. 541–548.

Segura-Campos, M. R., Ciau-Solís, N., Rosado-Rubio, G., Chel-Guerrero, L. and Betancur-Ancona, D. (2014), "Physicochemical characterization of chia (*Salvia hispanica*) seed oil from Yucatán, México", *Agricultural Sciences*, Vol. 5, No. 3, pp.220–226

Shen, Y., Zheng, L., Jin, J., Li, X., Fu, J., Wang, M., Guan, Y. and Song, X. (2018), "Phytochemical and biological characteristics of Mexican chia seed oil", *Molecules*, Vol. 23 No. 12, pp. 3219–3235.

Shokry. A. M., (2012), *Utilization of Moringa seeds in food processing*, Ph.D. Thesis, Faculty of Agriculture, Ain Sham University, Egypt.

Singh, K. K., Mridula, D., Rehal, J. and Barnwal, P. (2011), "Flaxseed: a potential source of food, feed and fiber", *Critical Reviews in Food Science and Nutrition*, Vol. 51 No. 3, pp. 210–222.

Subramanian, R., Nandini, K. E., Sheila, P. M., Gopalakrishna, A. G., Raghavarao, K. S. M. S., Nakajima, M., Kimura, T. and Maekawa, T.

(2000), "Membrane processing of used frying oils", *Journal of the American Oil Chemists' Society*, Vol. 77 No. 3, pp. 323.

Suri, K., Singh, B., Kaur, A., Yadav, M. P. and Singh, N. (2020), "Influence of microwave roasting on chemical composition, oxidative stability and fatty acid composition of flaxseed (*Linum usitatissimum* L.) oil", *Food Chemistry*, Vol. 326, pp. 126974–126984.

Tang, Y., Li, X., Chen, P. X., Zhang, B., Hernandez, M., Zhang, H., Marcone, M. F., Liu, R. and Tsao, R. (2015), "Characterization of fatty acid, carotenoid, tocopherol/tocotrienol compositions and antioxidant activities in seeds of three Chenopodium quinoa Willd. genotypes", *Food chemistry*, Vol. 174, pp. 502–508.

Thompson, J. N. and Hatina, G. (1979), "Determination of tocopherols in foods and tissues by HPLC", *Journal of Liquid Chromatography*, Vol. 2, pp. 327.

Tsaknis, J. and Lalas, S. (2002), "Stability during frying of Moringa oleifera seed oil variety “Periyakulam 1”", *Journal of Food Composition and Analysis*, Vol. 15 No. 1, pp. 79–101.

Tuncel, N. B., Uygur, A. and Karagül Yüceer, Y. (2017), "The effects of infrared roasting on HCN content, chemical composition and storage stability of flaxseed and flaxseed oil", *Journal of the American Oil Chemists' Society*, Vol. 94 No. 6, pp. 877–884.

Ustun, G., Kent, L., Cekin, N. and Civelkoglu, H., (1990), "Investigation of the technological properties of Nigella Sativa (black cumin) seed oil", *Journal of the American Oil Chemists' Society*, Vol. 67 No.12, pp. 958–960.

Wang, Z., Hobson, N., Galindo, L., Zhu, S., Shi, D., McDill, J., Yang, L., Hawkins, S., Neutelings, G., Datla, R., Lambert, G., Galbraith, D. W., Grassa, C. J., Geraldes, A., Cronk, Q. C., Cullis, C., Dash, P. K., Kumar, P. A., Cloutier, s., Sharpe, A. G., Wong, G. K., Wang, J. and Deyholos, M. K. (2012), "The genome of flax (*Linum usitatissimum*) assembled de novo from short shotgun sequence reads", *The Plant Journal*, Vol. 72 No. 3, pp. 461–473.

Wood, J. D., Richardson, R. I., Nute, G. R., Fisher, A. V., Campo, M. M., Kasapidou, E., Sheard, P. R. and Enser, M. (2003), "Effects of fatty acids on meat quality: a review", *Meat science*, Vol. 66 No. 1, pp. 21–32.

Yeboah, S. O., Mitei, Y. C., Ngila, J. C., Wessjohann, L. and Schmidt, J. (2012), "Compositional and structural studies of the oils from two edible seeds: Tiger nut, Cyperus esculentum, and asiato, Pachira insignis, from Ghana", *Food Research International*, Vol. 47 No.

2, pp. 259–266.

Yu, X., Tang, Y., Liu, P., Xiao, L., Liu, L., Shen, R., Deng, R., and Yao, P. (2017), "Flaxseed oil alleviates chronic HFD-induced insulin resistance through remodeling lipid homeostasis in obese adipose tissue". *Journal of Agricultural and Food Chemistry*, Vol. 65 No. 44, pp. 9635–9646.

Zhang, Y., Ying, T. and Zhang, Y. (2008), "Reduction of acrylamide and its kinetics by addition of antioxidant of bamboo leaves (AOB) and extract of green tea (EGT) in asparagine–glucose microwave heating system", *Journal of food science*, Vol. 73 No. 2, pp. 60–66.

Zhang, Z. S., Wang, L. J., Li, D., Li, S. J. and Özkan, N. (2011), "Characteristics of flaxseed oil from two different flax plants", *International Journal of Food Properties*, Vol. *14* No. 6, pp. 1286–1296.

Zhao, C. N., Tang, G. Y., Cao, S. Y., Xu, X. Y., Gan, R. Y., Liu, Q., Mao, Q. Q., Shang, A. and Li, H. B. (2019), "Phenolic profiles and antioxidant activities of 30 tea infusions from green, black, oolong, white, yellow and dark teas", *Antioxidants*, Vol. 8 No. 7, pp. 215–229.

Zhao, S. and Zhang, D., (2013), "A parametric study of supercritical carbon dioxide extraction of oil from *Moringa oleifera* seeds using a response surface methodology", *Separation and Purification Technology*, Vol. 113, pp. 9–17.