Egypt. J. Chem. **Vol. 67**, No. 1 pp.297 - 308 (2024)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Physicochemical properties, bioactivity and stability of non-traditional oils as sustainable non-wood forest products from four species of Egyptian mahogany seeds

Eman F. Al-Amrousi[1*] and Magdy I. Bahnasy[2]

[1]Fats and Oils Dep., Food and Nutration Institute, National Research Centre, Cairo, Egypt.

[2]*Foresty and Timber trees Dep., Horticulture research institute, Agricultural Research Centre, Giza, Egypt.*

Abstract

Mahogany trees were cultivated in new forests in Egypt for both their excellent timber quality and their role in climate change mitigation, one of the sustinable development goals. This work aimed to study four different species of mahogany seed oils MSOs [Kaya Ivorensis (KIO), Kaya Senegalensis (KSO), Swietenia Mahogni Lam oil (SMLO), and Swietenia Macrophylla King oil (SMKO)] as non-wood forest products. Their proximate analysis, fatty acid composition, bioactive component, oxidation stability antioxidant , and antimicrobial activity were studied. They showed a high oil content ranging from 48.81 to 62.48 %. Oils from (KIO) and (KSO) were characterized by higher amounts monounsaturated fatty acid, while (SMLO) and (SMKO) were found to have higher amounts of polyunsaturated fatty acids. KIO and KSO showed lower oxidizability value (cox) and hence higher stability while SMLO and SMKO showed higher total phenolic content and antioxidant activity. Concerning phytosterol composition β-sitosterol and campesterol were the most abundant phytosterols in all MSO. It also showed the presence of hexasiloxane in KSO and the presence of lanosta-8, 24-dien-3-one and lonstan-3β-ol, 11β, 18-epoxy-19-iodo-acetate in SMIO and SMKO. SMLO and SMKO showed considerable antimicrobial and antifungal activity. These results showed the possibility of using MSO in variable applications such as pharmaceutical, pesticide, and oleochemical industries, production of biodiesel as well as a sustainable alternative to edible oils for non-food purposes.

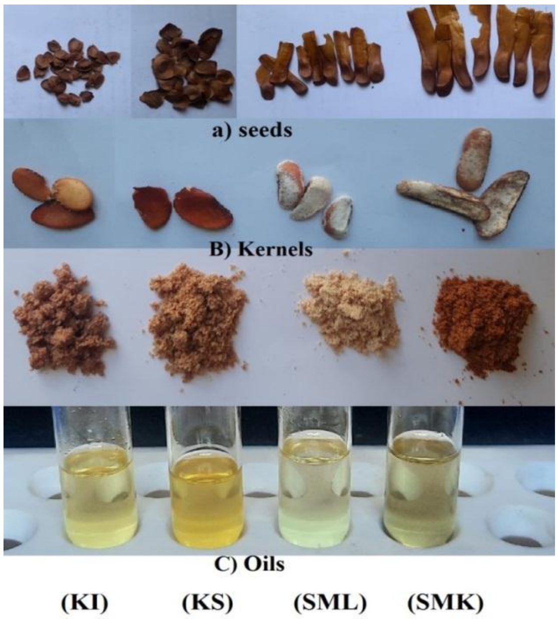
***Key words*: **Mahogany seed oil, non-traditional oil, total phenolic content, antioxidant activity, oxidative stability, antimicrobial activity, Egyptian soil and climate effect.

1. Introduction

Egypt is one of the world countries which have the least forest cover. There are few natural mangrove forests along the Red Sea. However, Egypt has a great opportunity for large-scale of afforestation as it has sufficient desert land and wastewater. The objectives of the afforestation include wood production and using the treated wastewater in an effective way. Moreover, it will achieve many ecologic, social, and economic objectives that can achieve many goals of sustainable development. Afforestation has a positive effect on agricultural lands as it improves their microclimate. The mahogany trees can be used as shelterbelt/ windbreaks to protect cultivated lands from damage by wind. They can also be used to improve irrigation and fertilization efficiency, conserve moisture in plants and soil, increase the yield of protected crops, help in sand dunes fixation, management of resources and mitigate climate changes. The Egyptian government asked for support from FAO to develop the plan of forest management for the Ismailia

*Corresponding author e-mail: menoamrousi@yahoo.com
Receive Date: 16 June 2023, Revise Date: 02 July 2023, Accept Date: 12 July 2023
DOI: 10.21608/EJCHEM.2023.218119.8146

serapium plantation with about 20% of its area cultivated with African kaya (a type of mahogany tree). Moreover, there is more interest from the government to widely cultivate the African kaya in the new administrative capital in Egypt [1]. Different types of mahogany trees are natively grown in America throughout the tropical regions such as Bolivia, Mexico, and Peru. They are also grown in Southern China, West India, and Malaysia [2]. Considering Africa, mahogany trees are cultivated in the fringing forest, savannah, and the drier parts of the forest regions [3]. Mahogany trees are exotic species of Meliaceae family. Due to its excellent timber quality, mechanical and physical properties, international markets and high prices in domestic, it has large-scale potential use for timber production plantations, especially in dry areas. It is used in the carpentry of high-class furniture, boats, and ships constructions, woodwork and the production of decorative veneers [4]. It's also used in avenues and gardens as an ornamental tree. The mahogany fruits are known as sky fruits because they point up towards the sky [2]. Recent studies showed that, besides the timber industry uses of Swietenia macrophylla King, it also has noteworthy values and benefits in the field of phytomedicine because of the variety of its biological activities [5]. Swietenia mahogany (L.) Jacq tree was used traditionally for the treatment of some diseases such as malaria, cardiovascular hypertension, diarrhea, and diabetes. Moreover, it was found that mahogany seeds extracts possess a lot of biological activities including antibiotic, antiviral, an inflammatory, anti-diarrheal, antimutagenic, antioxidant, antimalarial, antitumor, and anti-diabetic [2,6].The mahogany seeds (Fig 1) were found to have high amounts of oil content which have several important uses [7]. Mahogany oil is a good agent for skin healing. It is effective in the treatment of Rashes, sunburns, wounds, skin blemishes, facial neuralgia, hair loss, abrasions, and insect bites. It also can be used to provide relief for cases of rheumatism [8]. Many studies were done to study the production of biodiesel from mahogany seeds oil [7] and its oxidative stability[8,9]. The aims of this work were: Firstly, studying the physicochemical characterization of oils extracted from four species of mahogany namely Kaya Ivorensis (KI), Kaya Senegalensis (KS) Swietenia Mahogni Lam (SML), Swietenia Macrophylla King (SMK). Secondery, studying the effect of the Egyptian soil and climate on the oils composition. Finally, investigation of the possible applications of the MSO to find a new value-added of the mahogany trees



Figur 1: The four species of mahogany seeds, kerenls and oils

2. Materials and methods

2.1. Materials and chemicals

The seeds of KI and KS were collected from trees grown in Aswan Botanical Garden, Aswan, Egypt. Seeds of SML were collected from trees grown in the Agriculture Research Center farm at El-Kassasin, Ismailia, Egypt. Meanwhile, the seeds of SMK were collected from trees grown in Zoology garden at Giza, Egypt. Solvents were purchased from Elnasr Pharmaceutical Chemicals Co. (ADWIC), Egypt. DPPH$^{\bullet}$ was purchased from Sigma-Aldrich (St Louis, MO, USA). Folin-Ciocalteu reagent was purchased from Sisco Research Laboratories Chemicals, India.

2.2. Methods

2.2.1. Preparation of Mahogany seeds and extraction of oils:

The hulls of the different mahogany seeds were removed and the seeds were grounded by lab mixer to fine powder. The different oils were extracted from the seeds two times using both mechanical stirring and sonication. The solvent of extraction was evaporated under vacuum and oil samples were kept at 4°C until analysis.

2.2.2. Proximate analysis and oil content:

The oil content was determined using n-hexane and soxhlet apparatus [10]. Acid value (AV) was determined according to the AOCS official method Ca 5a-40 [11], Peroxide value (PV) according to the AOCS official method Cd 8b-90 [12] and Iodine value (IV) according to the AOCS official method Tg 1-64 [13]. The oil viscosity was measured using a Brookfield digital viscometer (Middleboro, MA 02346, USA) at 25°C and cycling shear 100 S^{-1}. The results were expressed as centipoise (cP s) [14].

2.2.3. Determination of Fatty acid Composition:

Methylation of fatty acids was prepared using sodium methoxide[15]. Hewlett Packard HP 6890 gas chromatograph was operated under the following conditions: Detector, flame ionization (FID); column, capillary, 50.0 m X 200 μ m, 0.3 μ m thickness, polyethylene glycol TPA (HP-FFAP); N_2 with constant flow rate, initial flow 1.5 mL/min with average velocity 33 cm/s (41.9 psi); He flow rate, 30 ml/min; air flow rate, 300 ml/min; split ratio, 20:1, split flow, 30.3 ml/min; gas saver, 20 ml/min. Detector temperature, 250˚C; column temperature, 240˚C; injection temperature, 250˚C. Programmed temperature starting from 60˚C to reach a maximum of 240˚C was used for eluting the fatty acid methyl esters.

The oxidizability value of the oils (COX) was calculated using the following equation [16] Cox value ={[C18:1(%)]+ 10.3[C18:2(%)] +21.6[C18:3(%)]}/100.

2.2.4. Fourier-transform infrared spectroscopy (*FTIR*):

The infrared spectra were obtained from KBr-disks using a Nicolt IS-10 FT-IR Spectrophotometer and reported in cm^{-1} .

2.2.5. Determination of bioactive components:

Different bioactive components in the four species of MSOs such as phytosterol composition, total chlorophyll, carotenoids and phenolic content were determined to study their effect on the properties and applications of these oils.

2.2.5.1. ***Determination of phytosterol composition:***

Phytosterol composition was determined using Agilent 8860 GC with the Agilent 5977B GC/MSD system. One µL of the sample was injected on-Column type Agilent J&W HP-5ms Ultra Inert (p/n 19091S-433UI) Length 30 m, Diameter 0.25 mm, Film Thickness 0.25 µm, Control Mode Constant flow, Flow 1.2 mL/min of He. Inlet Connection Split Ratio at 50:1. The pressure of carrier gas (helium) inlet was 40 kPa. The temperature of the oven was programmed to start from 70 ºC (1 min) to 200 ºC at 15 ºC/min and hold at 3 min, then at 30 ºC/min to 280 ºC and hold for 5 min [17].

2.2.5.2 Total chlorophyll and carotenoids

Chlorophyll and carotenoid contents were calorimetrically determined according to Isabel Minguez-Mosquera et al [18]. The oil sample (1.5 g) was dissolved in cyclohexane (5 mL). The absorption of chlorophyll fraction and carotenoid fraction were measured at 670 and 470 nm respectively.

The following equations were used to calculate the pigment contents:

Chlorophyll (mg/kg) = $(A_{670} \times 106)/(613 \times 100 \times d)$

Carotenoid (mg/kg) = $(A_{470} \times 106)/ (2000 \times 100 \times d)$

Where, A is the measured absorbance and d is the thickness of the spectrophotometer cell (1 cm), 613 = E_0 the coefficients values of specific extinction applied of pheophytin and 2000 = E_0 the coefficients values of specific extinction applied of lutein.

2.2.5.2. ***Total phenolic content determination****:*

The polyphenols in the oils were extracted by dissolving 2.5 g of oil in 5ml hexane and the solution was extracted 3 times by 60% aqueous methanol employing a vortex for 2 min.The total phenolic content (TPC) in the extract was determined according to Folin-Ciocalteu colorimetric method [19] using Shimadzu, UV spectrophotometer UV-240.

2.2.6. Antioxidant activity and stability measurement

2.2.6.1. ***DPPH• radical scavenging assay***

DPPH• assay was used to measure the antioxidant activity of different oil samples by using toluene as a solvent according to Ramadan [20]. The amount of oil sample that can scavenge 50 % of DPPH• radicals (EC_{50}) was calculated by plotting the oil sample amounts against the value of the radical scavenging activity percentage (R.S.A. %) on the excel program. The relation line was drawn and the EC_{50} value was calculated from the resulting equation as described previously in our work [21].

2.2.6.2. Oxidative Stability (IP)

The induction period IP (oxidative stability) of MSOs was determined according to, AOCS Official Method Cd 12b–92 [22] using an automated Metrohm Professional Rancimat model 892 at a temperature of 110 ±0.1°C and an airflow of 20 L/h. [23].

2.2.7. Determination of Antibacterial and Antifungal:

Determination of MSOs impact on growth of pathogenic bacteria and fungi was carried out according to Kaya et al [24]. 100 µL of mahogany oil samples were injected into agar-well diffusion containing tested bacterial or fungal strains. The diameter of the inhibition zone was measured in millimeters for each oil sample against the control (bacterial and fungal growth plate). Wider zone diameter indicates higher inhibition and antimicrobial effect of oil samples.

2.2.8. Statistical Analysis:

The results are presented as means ± standard deviations (SD) from three experiment replicates. Statistica 13.3 (TIBCO Software Inc., Palo Alto, CA, USA) program was used to prepare a one-way analysis of variance (ANOVA). Probability values of less than 5% ($p < 0.05$) were considered to be significant.

3. Results and discussion

3.1. Proximate analysis:

In this study, the stirring ultrasonic-assisted extraction method (SUEM) was used to avoid the effect of soxhlet heat on the major and minor bioactive components of the oils. Table 1 showed the physical and proximate analysis of different MSOs. The oil content was found to be higher in KIO followed by KSO, SMKO, and SMLO (62.48, 58.95, 52.61 and 48.88 % respectively) which were higher than that in the previous studies [3,25,26]. The lowest AV was given by SMLO (0.88 mg KOH/g) while the higher value was given by KSO (1.8 mg KOH/g). These values are similar to The AV recorded by Dignity et al [3]. Concerning PV, SMLO had the lower value (1.53 meq/Kg) while KIO and KSO had PV of 2.05 and 2.06 meq/Kg respectively which is significantly lower than the values recorded previously by Dignity et al and Okieimen and Eromosele [3,26]. The higher PV was given by SMKO (10.69 meq/Kg). IV results showed that SMIO and SMKO (109.85 and 113.22 g I_2/100g respectively) were higher in unsaturation rather than KIO and KSO (68.6 and 73.46 g I_2/100g respectively). Considering oils viscosity, KIO was found to have the higher viscosity (49 cP s) followed by KSO, SMLO, and SMKO as indicated in Table 1.

Table 1: Proximate analysis of the four mahogany seed oils:

	Mahogany seed oils			
	KIO	**KSO**	**SMLO**	**SMKO**
Oil content %	62.48 ^{a} ± 0.01	58.95 ^{a} ± 0.04	48.88 ^{c} ± 0.06	52.61 ^{b} ± 0.1
Viscosity (cP s)	49.00 ^{a} ± 3.9	37.00 ^{b} ± 4.0	33.00 ^{bc} ± 2.6	29.79 ^{c} ± 1.0l
AV (mg KOH/g)	1.74 ^{b} ± 0.017	1.88 ^{a} ± 0.01	0.88 ^{d} ± 0.05	1.50 ^{c} ± 0.04
PV (meq/Kg)	2.05 ^{b} ± 0.05	2.06 ^{b} ± 0.04	1.53 ^{b} ± 0.01	10.69 ^{a} ± 1.93
IV (g I_2/100g)	68.6 ^{d} ± 0.13	73.46 ^{c} ± 1.96	109.85 ^{b} ± 1.85	113.22 ^{a} ± 1.75

AV =acid value, PV =peroxide value, IV =iodine value, KIO = Kaya ivorensis oil, KSO = Kaya senegalensis oil, SMLO = Swieteniamahogni lam oil, SMKO = Swietenia macrophylla king oil. $^{a–d}$—Different symbols within the same rows indicate significant difference at $p < 0.05$.

3.2. Major components fatty acid composition:

Table 2 represents the constituents of the fatty acids in the four MSOs. They have different concentrations of saturated (SFA) and unsaturated fatty acids (UFA). KSO has the lowest SFA (18.43%), while the other kinds have almost the same SFA (23.92, 24.12, and 21.44 % for KIO, SMLO, and SMKO respectively). Palmitic acid was the most abundant SFA in SMLO and SMKO while stearic acid was the most abundant SFA in KIO and KSO (Table 2).

KIO and KSO have higher amounts of monounsaturated fatty acids (MUFA) which was represented only in oleic acid ω9 (67.76 and 68.86 respectively). Omega 9 possesses many pharmacological actions such as modulating lipid, cardiovascular, inflammatory, and cancer [27]. SMLO and SMKO were found to have less than half of these amounts of oleic acid (26.26 and 26.35 % respectively). This can be explained by the difference between temperatures in the growing areas. KIO and KSO were cultivated in Aswan in Upper Egypt where the hot and dry climate. Meanwhile, SML and SMK were cultivated in Ismailia and Cairo in Lower Egypt near the Mediterranean Sea, where the moderate temperature and humidity. These results agree with Ivanov's rule that says, high temperature may associate with the increase of oleic acid and a decrease in polyunsaturated fatty acids (linoleic acid) [28,29]. Ranalli et al. also reported that there is a negative correlation between oleic acid percentage and the atmosphere humidity [30].

Concerning the polyunsaturated fatty acids, linoleic acid ω6 was in higher concentration in KIO, KSO, SMLO, and SMKO (7.28, 9.63, 29.39, and 42.96% respectively). Unexpected high amounts of essential fatty acid, linolenic acid (ω3), were detected in both SMLO and SMKO (19.81 and 9.1% respectively). Lower concentrations of ω3 were also found in KIO and KSO (1.04 and 0.84% respectively). These unexpected amounts of ω3, which were not recorded before in MSOs, may be referred to the special nature of the Egyptian soil composition as well as the temperate climate of Egypt that may affect the chemical and physical composition of the plant different parts [31]. The polyunsaturation of MSO indicates their health benefits especially for diabetic, high cholesterol, and cardiovascular patients [2].

The ratio ω6/ ω3 in Table 2 showed that KSO has the highest ratio (11.46: 1) while SMLO has the lowest ratio (1.48: 1). The balance of ω6/ ω3 ratio is important in decreasing coronary heart disease risk. The lower ω6/ω3 ratio has a suppressive effect on many diseases as cancer, cardiovascular, autoimmune and inflammatory diseases. The ratio (4:1) is associated with a decrease of about 70% of total mortality. The ratio of 2.3:1 can suppress the inflammation in patients with rheumatoid arthritis, the ratio of 5:1 has a beneficial effect on asthma patients where, the 10:1 ratio has adverse consequences [32]. Hu also suggested that ω 6/ ω3 of 10:1 or less can reduce cardiovascular diseases [33].

It's noteworthy to mention that, these fatty acids have important effects on human health. Oleic acid has a positive effect in the prevention of some diseases including atherosclerosis, cancer and thrombosis. Linoleic (ω6) also has an important role in the neutralization of SFA and the prevention of the accumulation of cholesterol in the blood vessels. Moreover, it is governing the nervous system functions and improves the utilization of fat-soluble vitamins [10]. The ratio of PUFA/SFA proportions with postprandial level of HDL-C in plasmas, which increased with decreasing of PUFA/SFA [34].

The cox value: The cox value is an indicator of the oxidation stability of the oil. Its calculation was based on the percentage and the index of oxidation of the 18 carbons unsaturated fatty acids [35,36]. The higher cox value means lower stability [37] so the significantly lower cox values of KIO and KSO (1.65 and 1.8 respectively) make them more stable than SMLO and SMKO which have higher cox values (7.56 and 6.64 respectively) as shown in Table 2. These results mean that KIO, KSO has significantly higher stability than the other mahogany types.

Table 2: Fatty acid composition of the four mahogany seed oils:

Fatty acid	Mahogany seed oils			
	KIO	KSO	SMLO	SMKO
Saturated fatty acids				
Palmitic acid (C16:0)	9.91± 0.06	6.97± 0.05	11.64 ± 0.03	14.23± 0.16
Stearic acid (C18:0)	12.60 ± 0.0	10.56± 0.04	10.84 ± 0.03	5.80 ±0.14
Arachidic acid (C20:0)	1.41± 0.01	0.90 ± 0.001	1.64 ± 0.01	0.67 ± 0.01
Docosanoic acid(C22:0)	---	---	---	0.17 ± 0.001
Tetracosanoic acid (C24:0)	---	---	---	0.57 ± 0.002
Total SFA	23.92	18.43	24.12	21.44
monounsaturated fatty acid				

Palmitoleic acid (C16:1)	---	---	0.42 ± 0.01	---
Oleic acid (C18:1) ω9	67.76 ± 0.03	68.86 ± 0.04	26.26 ± 0.20	26.35 ± 0.01
Eicosenoic acid (C20:1)	---	---	---	0.15 ± 0.003
Total MUFA	67.75	68.86	26.65	26.46
Polyunsaturated fatty acids				
Linoleic acid (C18:2) ω6	7.28 ± 0.01	9.63 ± 0.02	29.39 ± 0.06	42.96 ±0.08
Linolenic acid (C18:3) ω3	1.04 ± 0.02	0.84 ± 0.03	19.81± 0.01	9.1± 0.07
Unknown	---	2.24 ± 0.12	---	---
Total PUFA	8.32	10.47	49.18	51.96
Total UFA	76.07	79.32	75.83	78.42
Total FA	100	100	100	100
Relations				
SFA/ UFA	0.314	0.232	0.318	0.273
Essential fatty acids (ω6+ ω3)	8.32	10.47	49.18	51.96
Cox value	1.65	1.86	7.51	6.61
PUFA/ SFA	0.348	0.568	2.039	2.424
L/Ln (w6/w3)	7	11.46	1.48	4.71

KIO = Kaya ivorensis oil, KSO = Kaya senegalensis oil, SMLO = Swieteniamahogni lam oil, SMKO = Swietenia macrophylla king oil. FA = fatty acids, SFA = saturated fatty acids, MUFA= monounsaturated fatty acids , PUFA = polyunsaturated fatty acids , UFA = unsaturated fatty acids, L= lenoliec acid, Ln = lenolienic acid.

3.3. FTIR identification:

FTIR identification showed that there is no significant difference between the four oils. FTIR in Fig 2 showed absorption at 2925, 2856, and 1373 cm^{-1} for long-chain linear aliphatic methyl -CH, $-CH_2$, and - CH_3 respectively [25]. Absorption at 1745 cm^{-1} showed the carbonyl C=O stretch that belongs to triglycerides, while the acidity was confirmed by CO stretching vibration at 1164cm^{-1} [8]. The OH of the carboxylic group was shown by the absorption at 1030 cm^{-1} and 3467 cm^{-1} [38,39].

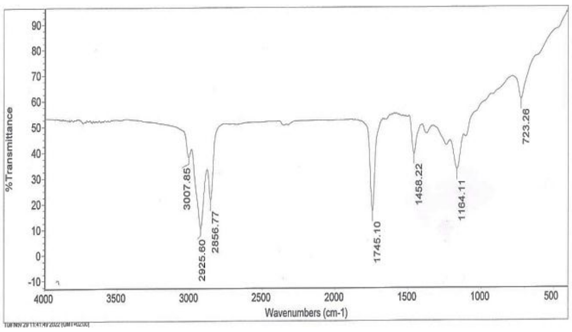


Figure 2: FTIR spectrum of Swietenia Macrophylla King oil (SMKO).

3.4. Bioactive compounds

3.4.1. Phytosterols composition

In spite of the importance of phytosterols in the oils, previous studies on the mahogany oil phytosterol composition were not found yet. The phytosterol composition of MSOs was studied using GC mass. It was found that the most abundant phytosterol in the four types of MSO was β-sitosterol followed by campesterol. KIO and KSO have a higher percentage of β-sitosterol, whereas SMLO and KIO have the higher percentage of campesterol (Table 3). It should be noticed that phytosterols are a natural antioxidant that can increase the oil stability. They also have multiple biological effects as reduction of serum cholesterol level and the risks of cardiovascular diseases. In addition, they have antimicrobial, anticancer, atherogenicity, and anti-inflammatory effects [40,41]. KIO and KSO have 82.29 and 84.96 % β -Sitosterol while SMLO and SMKO have 67.96 and 66.82% respectively. These percentages were found to be close to the β–Sitosterol percentages in avocado, walnut and olive oils [40]. Δ5 Avenasterol (isofucosterol), a characteristic sterol of algae, seaweed, and diatom, was found in the four different types of MSOs by percentages ranging from 2.82 to 4.04 %. It has antidiabetic, anticancer, and anti-inflammatory effects [42].

lanosta-8, 24-dien-3-one (triterpenoid) was also found in both SMLO and SMKO in a considerable percentage, especially in SMKO (5.44 and 14.5% respectively). The Lonstan-3β-ol, 11β, 18-epoxy-19-iodo-acetate was found in SMLO in a percentage of 5.84 %. This type of sterol was found to have antifungal activity. Smaili et al. [43] reported that the triterpenoid derivatives were effective in the protection of tomato plants against verticilliumdahlia but they were phytotoxic at higher concentrations. They were found to be responsible for dermal irritation [44]. It was also reported that these natural products inhibit cholesterol uptake and cholesterol ester formation, and hence it becomes inhibitor of cholesterol absorption which is the key risk factor for coronary heart disease [45].

GC mass analysis also showed the presence of hexasiloxane, which is known for its antimicrobial, antiseptic, and hair and skin conditioning agent, only in KSO (1.91%) [46].

Table 3: Phytosterol composition (%) of the four mahogany seed oils:

Mahogany seed oils				
	KIO	**KSO**	**SMLO**	**SMKO**
Phytosterol composition (%)				
Campasterol	10.29 ± 0.06	7.68 ± 0.05	10.77 ± 0.05	7.81 ± 0.01
Stigmasterol	3.39 ±0.01	1.91 ±0.01	7.17 ±0.04	4.18 ±0.01
β-sitosterol	82.29 ±0.2	84.96 ±0.7	67.96 ±0.6	66.82 ±0.6
γ-sitosterol	---	---	---	3.25 ±0.03
Isofucosterol	4.04 ±0.02	3.54 ±0.03	2.82 ±0.01	3.45 ±0.03
Lanosta-8,24-dien-3-one	---	---	5.44 ±0.03	14.5 ±0.04
Lonstan-3β-ol,11β,18-epoxy-19-iodo-acetae	---	---	5.84 ± 0.03	---
Hexasiloxane	---	1.91± 0.01	---	---

KIO = Kaya ivorensis oil, KSO = Kaya senegalensis oil, SMLO = Swieteniamahogni lam oil, SMKO = Swietenia macrophylla king oil.

3.4.2. Carotenoids content

Concerning carotenoids, KSO has the higher amount of chlorophyll (1.37 mg/kg oil) followed by SMLO, SMKO and KIO (0.89, 0.77 and 0.75 mg/kg oil respectively). Considering carotenoids SMLO and SMKO have higher amounts (0.7 mg/kg oil) while KIO has a lower amount of 0.37 mg/kg oil (Table 4). Chlorophylls and carotenoids have an important role in the oil oxidative activity. They have an antioxidant nature as they can capture free radicals just like α-tocopherol. They also can act as photosensitizers in the oil [47].

3.4.3. Total phenolic content:

Polyphenols are powerful natural antioxidants that can increase the stability and the shelf life of the oil [48]. Data in Table 4 showed the values of TPC of the four different types of MSOs. The results in the table showed that both SML and SMKO have high phenolic content (165.5 and 148.8 mg gallic acid equivalent /1g oil). The results indicated also that KIO and KSO have low amounts of TPC (45.52 and 66 mg gallic acid equivalent /1g oil)

3.5. Antioxidant activity:

Table 4 showed the EC_{50} and antiradical power (ARP = 1/ EC_{50}) of MSO measured by $DPPH^{\bullet}$ radical scavenging assay. SMLO was found to have considerably higher activity with lower EC_{50} (31.42) followed by SMKO, KSO, and KIO with higher EC_{50} (134.03, 147.16, and 181.81 respectively). These results were directly proportion with The TPC results as shown by the relation in Figure 3. SMLO has higher TPC and consequently higher antioxidant activity while KIO has lower TPC and lower antioxidant activity. This relation refers to the ability of the hydroxyl groups in phenolic compounds to scavenge the free radicals and hence, increase the oil's antioxidant activity [49].

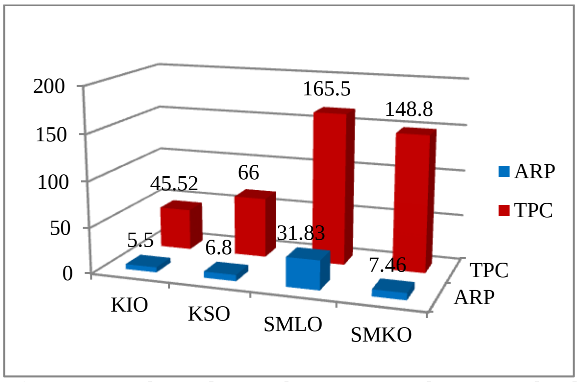
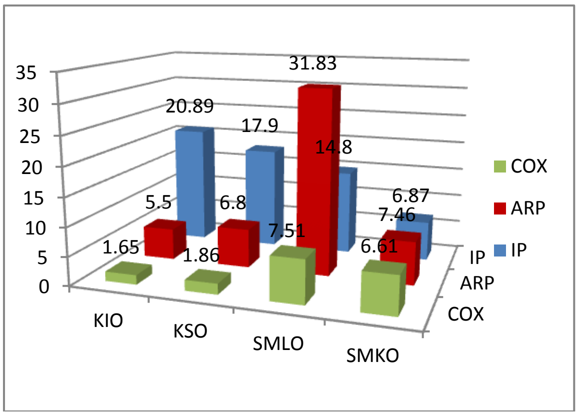


Figure 3: The relation bet ween the antiradical power (ARP×1000) and the total phenolic content of mahogany seed oils

3.6. Oxidation stability:

The induction period (IP) measured by the rancimate method (Table 4) was an indication of the oxidation and thermal stability of the oil. The higher IP was given by KIO (20.89 h) followed by KSO and SMLO (17.9 and 14.8 h respectively). Figure 4 shows the relations between the IP and both ARP and cox value. SMLO has the highest ARP, but it has high unsaturation (cox value of 7.56) which has a negative effect on its stability and makes it more acceptable to the oxidation process [16]. For these reasons, it has a lower IP than that of KIO and KSO which have lower unsaturation (cox values of 1.65 and 1.86 respectively). SMKO has higher TPC than that of KIO and KSO but it still has the lowest IP (6.87 h) this may be due to its low ARP and high Cox value (6.64) as shown in Figure 4. These results indicate the significant competition between the level of fatty acid unsaturation and antioxidant activity and their effect on oxidation and thermal stability of the oil.



Figur 4: The relation between the oil stability(IP) and both ARP and Cox value of the mahogany seed oils and

Table 4: Bioactive compounds, antioxidant activity and oxidative stability of the four mahogany seed oils.

	Mahogany seed oils			
	KIO	**KSO**	**SMLO**	**SMKO**
	Bioactive compounds			
Chlorophyl (mg/kg)	$0.75^b \pm 0.03$	$1.37^a \pm 0.02$	$0.89^b \pm 0.01$	$0.77^b \pm 0.02$
Carotenoids (mg/kg)	$0.37^c \pm 0.02$	$0.58^b \pm 0.01$	$0.7^a \pm 0.00$	$0.71^a \pm 0.01$
TPC (mg gallic acid/ 1g oil)	$45.52^d \pm 1.01$	$66^c \pm 7.77$	$165.5^b \pm 14.14$	$148.8^a \pm 6.99$
	Antioxidant activity and oxidative stability			
EC_{50} (mg oil)	181.81	147.16	31.42	134.03
ARP x 1000	5.50	6.80	31.83	7.46
IP	20.89	17.9	14.8	6.8

KIO = Kaya ivorensis oil, KSO = Kaya senegalensis oil, SMLO = Swieteniamahogni lam oil, SMKO = Swietenia macrophylla king oil. TPC = Total phenolic content, EC_{50} = the amount of oil sample that can scavenge 50% of free radical DPPH•, ARP = antiradical power [$(1/EC_{50})\times1000$], IP = induction period, $^{a–d}$—Different symbols within the same rows indicate significant difference at $p < 0.05$.

3.7. Antibacterial and antifungal activity:

The antibacterial activity of the four species of MSOs was evaluated using ofloxacin (standard antibiotic) as a control reference. In general, results in Table 5 show the considerable antibacterial effect of the applied SMLO and SMKO against gram-negative strains of bacteria (*Salmonella senftenberg* ATCC 8400, *Escherichia coli* ATCC 11228, *Staphylococcus aureus* ATCC 33591 and *Bacillus subtilis* DB 100 (Tab. 5) The activity of SMKO up to 59.5 and 62.7% of the control against *Staphylococcus aureus* ATCC 33591 and *Bacillus subtilis* DB 100 respectively. The results also showed that the KIO and KSO have low and moderate antimicrobial activity (Table 5).

Considering the antifungal activity, the results in Table 5 represent the diameter of the fungal growth inhibition zone. The results showed higher efficiency of SMLO and SMKO as antifungals more than KIO and KSO, which were far from the effect of the control reference nystatin (standard fungicidal). Some types of fatty acids were known as sporogenic agents for toxigenic fungi and increase spore formation (vegetative growth) that leads to less production of toxins during the fungi live-cycle. The high unsaturated fatty acids content which is recognized to have a degradable influence on mycotoxin secretion in some fungal biological systems may decrease the oil antifungal activity [37]. The obtained results manifested more impact of SMLO followed by SMKO on *Fusarium graminearum ATCC 56091* species. Although the oil antifungal activity can be manifested by limited impact on agar media growth, it comparatively still possesses the ability to protect the seeds and increase their shelf-life. Generally, SMLO and SMKO had higher antimicrobial and antifungal activity. This may be attributed to the existence of the triterpenoid namely lanosta-8, 24-dien-3-one and Lonstan-3β-ol, 11β, 18-epoxy-19-iodo-acetate which were reported to have antimicrobial activity [43,44]. The antibacterial activity is also affected by the amounts of minor bioactive components such as phenolic acids, flavonoids sterol and tocopherols [50].

3.8. Potential applications of mahogany seed oils

From these results usage of MSO can be suggested in different applications. KSO can be used in pharmaceutical industries such as hair and skin conditioner as it contains hexasiloxane while SMIO and SMKO can be used in pharmaceutical and pesticides industries due to the presence of lanosta-8, 24-dien-3-one and Lonstan-3β-ol,11β,18-epoxy-19-iodo-acetate which have antifungal activity. The antimicrobial activity of mahogany oil make it suitable to be applied in coating film used in food packaging to protect fruits and vegetables from spoilage due to microbial contamination and to increase their shelf life [51]. The high unsaturation of MSO makes it suitable for some oleochemicals preparation such as epoxides which have an important role in the plastic and polyvinyl chloride industries. Moreover, MSO are considered as interesting and sustainable alternatives to edible oils in the production of biofuel. The use of these oils can reduce the negative potential impact on the global food supply and resolve the food-non-food debate raised on the extensive edible oils consumption for non-food purposes, especially in the poor and developing countries [52,53].

Table 5: Antibacterial and antifungal activities of the four studied mahogany seed oils against microbial pathogen strains.

	Antibacterial activity (Inhibition Zone Diameter mm)				
	Mahogany seed oil				**Standard**
	KIO	**KSO**	**SMLO**	**SMKO**	**Ofloxacin**
***Salmonella senftenberg* ATCC 8400**	2.0 ± 0.94	4.0 ± 1.1	7.7 ± 0.5	6.9 ± 1.0	23.71 ± 0.13
***Escherichia coli* ATCC 11228**	4.0 ± 0.94	7.0 ± 1.5	8.8 ± 1.07	7.7 ± 0.38	20.42 ± 0.58
Staphylococcus aureus ATCC 33591	3.0 ± 0.71	6.0 ± 0.9	9.7 ± 0.3	13.5 ± 1.5	22.66 ± 0.33
Bacillus subtilis DB 100	2.0 ± 0.71	5.0 ± 0.58	8.8 ± 0.38	13.8 ± 1.0	22.1 ± 0.57
Antifungal activity (Inhibition Zone Diameter mm)					**Nystatin**
***Aspergillus flavus* ITEM 698**	1.5 ± 0.33	7.8 ± 1.1	14.6 ± 1.1	10.6 ± 0.5	26.21 ± 0.14
Aspergillusc arbonarius ITEM 5010	3.6 ± 1.1	8 ± 1.0	13.9 ± 1.0	10.6 ± 0.5	26.82 ± 0.58
Penicillium verrucosum NRRL 695	2.6 ± 1.1	7.7 ± 1.1	12.33 ± 0.5	9.6 ± 0.5	26.58 ± 0.27
Fusarium graminearum ATCC 56091	5.6 ± 1.1	10.3 ± 1.5	16.6 ± 0.58	13 ± 1.0	29.43 ± 0.18

4. Conclusion:

It was concluded that the oils extracted from mahogany seeds cultivated in Egypt showed special characteristics than that were recorded in previous works. KIO and KSO fatty acid composition was found to be lower in unsaturation than that of SMLO and SMKO, the low in unsaturation makes it more stable and has higher oxidation stability. On the other hand, SMLO and SMKO showed higher TPC and antioxidant activity. Phytosterol composition also showed the presence of some important sterols such as avenasterol, hexasiloxane (antimicrobial, antiseptic, and hair and skin conditioning agent), lanosta-8, 24-dien-3-one and Lonstan-3β-ol,11β,18-epoxy-19-iodo-acetate (antimicrobial activity and inhibit the absorption of cholesterols). These data and results gave the mahogany tree new added-value besides their wood production. It can be used as a valuable, renewable and sustainable source for non-conventional oils that can be applied in different fields such as food additives, food packaging, pharmaceutical, pesticides, and oleochemical industries. Moreover, these oils can be used as a sustainable alternative to edible oils in the production of biofuel and other non-food purposes.

Conflicts of Interest: The authors declare that they have no conflict of interest in this article.

Referances

1- FAO, Food and Agriculture Organization of the United Nations, 2012. Serapium forest plantation, Ismailia: Forest management plan 2013-2023, country report: Egypt, Rome Forestry Department, Project LTO, GCP/RAB/013/ITA https://www.fao.org/forestry/35797-04ea237588d31b69a127a93c49e1c0af2.pdf

2- Yadav, S., 2018. Antibacterial activity of mahogany (swietenia mahogany (l.) jacq.) seeds oil and analysis of their fatty acids" International Journal of Creative Research Thoughts (IJCRT). 6 (1), 570-582

3- Dignity, E.S., Esther, A., Awodi, Y.P., 2019. Effects of Heat Treatments of Afzelia Africana(African mahogany) Seed and Aril Cap on the Characeristics of the Oil. Acta Scientific Nutritional Health. 3(5), 19-25.

4- Nikiema, A., Pasternak, D.,.2018. Khaya senegalensis (Desr.) A.Juss. [Internet] Record from PROTA4U. Louppe, D., Oteng-Amoako, A.A. & Brink, M. (Editors). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l’Afrique tropicale), Wageningen, Netherlands. <http://www.prota4u.org/search.asp>. Accessed 14 March 2018.

5- Moghadamtousi, S.Z., Goh, B.H., Chan, C.K., Shabab, T., Kadir, H.A., 2013. Biological activities and phytochemicals of Swietenia macrophylla King. Molecules. 18(9),10465-10483.

6- Ervina, M., 2020. The recent use of Swietenia mahagoni (L.) Jacq. as antidiabetes type 2 phytomedicine: A systematic review. Heliyon. 6(3),e03536.

7- Arazo, R., Abonitalla, M.R., Gomez, J.M., Quimada, N.E., Yamuta, K.M.D., Mugot, D.A., Hanif, M.U. 2016. Biodiesel production from Swietenia macrophylla (Mahogany) seeds. Journal of Higher Education Research Disciplines. 1(2),8-19.

8- Ibrahim, H., Fasanya, O.O., Hayatudeen, A., Osa-Benedict, E.O., 2018. Fatty acid composition of Mahogany seed oil and its suitability for biodiesel production. Niger J Technol Res. 13,45-49.

9- Rana, S.M., Haque, M.A., Poddar, S., Sujan, S.M., Hossain, M., Jamal, M.S., 2015. Biodiesel production from non-edible Mahogany seed oil by dual step process and study of its oxidation stability. Bangladesh Journal of Scientific and Industrial Research. 50 (2), 77-86.

10- Khalid, I.I., Elhardallou, S.B. 2019. Physico-chemical properties and fatty acids composition of bitter and sweet lupine seed. Oriental Journal of Chemistry. 35 (3), 1148.

11- AOCS 2017. Official Methods of Analysis Cd 8b-90. Champaign, USA: AOCS Publishing.

12- AOCS 2017. Official Methods of Analysis Ca 5a-40. Champaign, USA: AOCS Publishing.

13- AOCS 2017. Official Methods of Analysis Tg 1-64. Champaign, USA: AOCS Publishing.

14- Salama, H.H., Hashim, A.F., 2022. A functional spreadable canola and milk proteins oleogels as a healthy system of candy gummies. Scientific report. 12 (1), 12619

15- Cert, A., Moreda, W., Pérez-Camino, M.D.C., 2000. Methods of preparation of fatty acid methyl esters (FAME). Statistical assessment of the precision characteristics from a collaborative trial. Grasas y aceites. 51(6),447-456.

16- Fatemi, S.H., Hammond, E.G., 1980. Analysis of oleate, linoleate and linolenate hydroperoxides in oxidized ester mixtures. Lipids. 15(5), 379-385.

17- Srigley, C.T., Hansen, S.L., Smith, S.A., Abraham, A., Bailey, E., Chen, X., ... & Cantrill, R., 2018. Sterols and stanols in foods and dietary supplements containing added phytosterols: a collaborative study. Journal of the American Oil Chemists' Society. 95(3), 247-257.

18- Isabel Minguez-Mosquera, M., Rejano-Navarro, L., Gandul-Rojas, B., SanchezGomez, A. H., Garrido-Fernandez, J. 1991. Color-pigment correlation in virgin olive oil. Journal of the American Oil Chemists' Society. 68(5), 332-336.

19- Fuentes, E., Báez, M.E., Bravo, M., Cid, C., Labra, F., 2012. Determination of total phenolic content in olive oil samples by UV–visible spectrometry and multivariate calibration. Food Analytical Methods. 5, 1311-1319.

20- Ramadan, M.F., 2013. Improving the stability and radical-scavenging activity of sunflower oil upon blending with black cumin (Nigella sativa) and coriander (Coriandrum sativum) seed oils. Journal of Food Biochemistry. 37 (3), 286-95.

21- El-Malah, M.H., Hassanein, M.M., Areif, M.H., Al-Amrousi, E.F., 2018. Utilization of natural antioxidants extracted from by-products using new methods to enhance the oxidative stability of cooking oils. Egypt. J. Food Sci. 46, 13-23.

22- AOCS 2017. Official methods and recommended practices of the American Oil Chemists’ Society Cd 12b–92, Oxidative stability index. The American Oil Chemists’ Society. Champaign, USA: AOCS Publishing.

23- Hassanein, M.M., Al-Amrousi, E.F., Abo-Elwafa, G.A., Abdel-Razek, A.G., 2022. Characterization of Egyptian Monovarietal Koroneiki Virgin Olive Oil and Its Co-Products. Egyptian Journal of Chemistry. 65(12),637-645.

24- Kaya, M., Ravikumar, P., Ilk, S., Mujtaba, M., Akyuz, L., Labidi, J., ... & Erkul, S. K. 2018. Production and characterization of chitosan based edible films from Berberis crataegina's fruit extract and seed oil” Innovative Food Science & Emerging Technologies. 45, 287-297.

25- Mursiti, S., Rahayu, E.F., Rosanti, Y.M., Nurjaya, I., 2019. Mahogany seeds oil: isolation and characterizations. InIOP Conference Series: Materials Science and Engineering. 509 (1), 012137. IOP Publishing.

26- Okieimen, F.E., Eromosele, C.O., 1999. Fatty acid composition of the seed oil of Khaya senegalensis. Bioresource Technology. 69 (3), 279-280.

27- Farag, M.A., Gad, M.Z., 2022. Omega-9 fatty acids: Potential roles in inflammation and cancer management. Journal of Genetic Engineering and Biotechnology. 20(1), 48.

28- Ivanov, S. 1927. Dependence of chemical composition of oil containing plant on the climate. Oil Fat Ind. 5, 29-31

29- Jukić Špika, M., Perica, S., Žanetić, M., Škevin, D., 2021. Virgin olive oil phenols, fatty acid composition and sensory profile: Can cultivar overpower environmental and ripening effect?. Antioxidants. 10 (5), 689.

30- Ranalli, A., De Mattia, G., Ferrante, M.L., 1997. Comparative evaluation of the olive oil given by a new processing system. International journal of food science & technology. 32(4), 289-297.

31- El Qarnifa, S., El Antari, A., Hafidi, A., 2019. Effect of maturity and environmental conditions on chemical composition of olive oils of introduced cultivars in Morocco. Journal of Food Quality. 2019, 1-14.

32- Simopoulos, A. 2008. The Importance of the Omega-6/Omega-3 Fatty Acid Ratio in Cardiovascular Disease and Other Chronic Diseases. Exp. Biol. Med. 233(6), 674–688.

33- Hu, F.B., 2001. The balance between omega-6 and omega-3 fatty acids and the risk of coronary heart disease. Nutrition (Burbank, Los Angeles County, Calif.). 17(9), 741-742.

34- Karupaiah, T., Sundram, K., 2013. Modulation of human postprandial lipemia by changing ratios of polyunsaturated to saturated (P/S) fatty acid content of blended dietary fats: a cross-over design with repeated measures. Nutrition journal. 12(1), 1-11.

35- Herchi, W., Ammar, K.B., Bouali, I., Abdallah, I.B., Guetet, A., Boukhchina, S., 2016. Heating effects on physicochemical characteristics and antioxidant activity of flaxseed hull oil (Linum usitatissimum L). Food Science and Technology. 36, 97-102.

36- Fard, S.M., Ghasemi Afshar, P., Adeli Milani, M., 2020. A Comparison of the Quality Characteristics of the Virgin and Refined Olive Oils Supplied in Tarom Region, Iran

2019. Journal of Human Environment and Health Promotion. 6(2), 83-90.

37- Al-Amrousi, E.F., Badr, A.N., Abdel-Razek, A.G., Gromadzka, K., Drzewiecka, K., Hassanein, M.M., 2022. A Comprehensive Study of Lupin Seed Oils and the Roasting Effect on Their Chemical and Biological Activity. Plants. 11(17), 2301.

38- Musta, R., Nurliana, L., Halulanga, M.M., 2021. Synthesis of Methyl Ester Nitrate from Mahogany Seed Oil (Swietenia mahagoni Linn). Indonesian Journal of Chemical Research. 9 (1), 63- 68.

39- Al-Amrousi, E.F., 2016. Improvement of antioxidative potency of some edible oils. Thesis Submitted for Ph.D. Degree in Science (Organic Chemistry). Faculty of science, Benha University, Benha, Egypt.

40- Chanioti, S., Katsouli, M,, Tzia, C., 2021. β-Sitosterol as a functional bioactive. InA centum of valuable plant bioactives Jan 1 (pp. 193-212). Academic Press.

41- Adnan, M., Nazim Uddin Chy, M., Mostafa Kamal, A.T.M., Azad, M.O.K., Paul, A., Uddin, S.B., ... & Cho, D.H. 2019. Investigation of the biological activities and characterization of bioactive constituents of Ophiorrhiza rugosa var. prostrata (D. Don) & Mondal leaves through in vivo, in vitro, and in silico approaches. Molecules. 24(7), 1367.

42- Abdul, Q.A., Choi, R., J., Jung, H.A., Choi, J.S., 2016. Health benefit of fucosterol from marine algae: a review. Journal of the Science of Food and Agriculture. 96 (6), 1856-1866.

43- Smaili, A., Mazoir, N., Rifai, L.A., Koussa, T., Makroum, K., Benharref, A., Faize, M., 2017. Triterpene derivatives from Euphorbia enhance resistance against Verticillium wilt of tomato. Phytochemistry. 135, 169-180.

44- Chandra, R., Kumar, V., 2017. Detection of androgenic-mutagenic compounds and potential autochthonous bacterial communities during in situ bioremediation of post-methanated distillery sludge. Frontiers in microbiology. 8, 887.

45- Chiba, T., Sakurada, T., Watanabe, R., Yamaguchi, K., Kimura, Y., Kioka, N., ... & Ueda, K. 2014. Fomiroid A, a novel compound from the mushroom Fomitopsis nigra, inhibits NPC1L1-mediated cholesterol uptake via a mode of action distinct from that of ezetimibe. Plos one. 9(12), e116162.

46- Kumar, D., Karthik, M., Rajakumar, R. 2018. GC-MS analysis of bioactive compounds from ethanolic leaves extract of Eichhornia crassipes (Mart) Solms. and their pharmacological activities. Pharma Innov J. 7 (8), 459-462.

47- Abdel-Razek, A.G., Al-Amrousi, E,F,, Hassanein, M.M.M., 2020. Mitigate the extreme bitterness in virgin olive oil using natural aqueous solutions. Egypt. J. Chem. 63(10), 3975 - 3984.

48- El-Malah, M.H., Hassanein, M.M.M., Areif, M.H., Al-Amrousi, E.F., 2015. Utilization of Egyptian tomato waste as a potential source of natural antioxidants using solvents, microwave and ultrasound extraction methods. Am J Food Technol. 10, 14-25.

49- Al-Amrousi, E.F., Al Amrousi, F.A., Al-Amrousi, E.F., 2021. Liposome nanocapsules of aqueous extract from defatted wheat germ as by-products to enhance stability of biodiesel. Egypt. J. Chem. 64(12), 7669-7678.

50- Abdel-Razek, A.G., Abo-Elwafa, G.A., Al-Amrousi, E.F., Badr, A.N., Hassanein, M.M.M., Qian, Y., ... & Rudzińska, M. 2023. Effect of Refining and Fractionation Processes on Minor Components, Fatty Acids, Antioxidant and Antimicrobial Activities of Shea Butter. Foods. 12, 1626.

51- Abd-Elsalam, K.A., Murugan, K., 2022. Bio-Based Nanoemulsions for Agri-Food Applications. In: Hashim, A.F., Al-Amrousi, E.F., Abd-Elsalam, K.A., Nanolipid-based edible films to improve food shelf life, Elsevier, pp399-412, ISBN 9780323898461, https://doi.org/10.1016/B978-0-323-89846-1.00009-7.

52- Turco, R., Di Serio, M., 2020. Sustainable synthesis of epoxidized Cynara C. seed oil. Catalysts. 10(7), 721.

53- Turco, R., Tesser, R., Russo, V., Vitiello, R., Fagnano, M., Di Serio, M., 2020. Comparison of different possible technologies for epoxidation of Cynara cardunculus seed oil. European Journal of Lipid Science and Technology. 122(1),1900100.