Oilseeds from Arid Algeria: Fatty Acid Profiles, Physicochemical Properties, and Food Security Implications

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Summary: Food security in arid regions is challenged by climate change and reliance on imported goods, making the valorization of local, drought-tolerant crops a key strategy for sustainability; this study therefore aimed to characterize the physicochemical properties and fatty acid profiles of oils from five local oilseeds—peanut, safflower, rapeseed, soybean, and sunflower—cultivated in the arid El-Oued region of Algeria. Oils were obtained using the Soxhlet extraction method and analyzed for refractive index, acid value, and saponification value according to ISO and AOCS standards, while fatty acid profiles were determined by gas chromatography (GC-FID). The results revealed that peanut exhibited the highest oil yield (45.19 %), and while most oils met key quality standards, safflower and soybean oils showed elevated acid values, indicating a need for optimized post-harvest handling. Distinct fatty acid profiles were identified, with safflower being rich in oleic acid (65.95 %), soybean in linoleic acid (46.79 %), and rapeseed containing a notable amount of α-linolenic acid (9.88 %), resulting in an optimal Omega-6/Omega-3 ratio of 1.97. These findings underscore the high potential of locally adapted oilseeds, particularly peanut for its high yield and rapeseed for its balanced omega fatty acids, to contribute to food security, improved nutrition, and sustainable agricultural systems in arid regions like Algeria.

Keywords: Lipid chemistry; Nutritional analysis; Omega fatty acids; Sustainable agriculture.

Introduction

Global challenges, including climate change, supply chain disruptions, and geopolitical tensions, have underscored the critical importance of food security and self-sufficiency, particularly concerning edible oils [1, 2]. This is especially pertinent for Algeria, which currently imports over 85 % of its edible oil needs, representing a significant economic burden and vulnerability to international market volatilities [3, 4]. Valorizing local agricultural resources, such as drought-tolerant oilseed crops, presents a strategic pathway to reduce this dependency, enhance nutritional autonomy, and preserve biodiversity [5].

The El-Oued region in southeastern Algeria offers a compelling model for studying crop adaptation to extreme arid conditions. Characterized by a Mediterranean desert climate (Köppen-Geiger Csa), the region experiences exceptionally high summer temperatures (exceeding 45°C), minimal annual precipitation (<80 mm), and sandy soils with low organic matter. Despite these constraints, local cultivation of oilseeds has persisted, demonstrating a degree of inherent resilience. Nationally, oilseed cultivation remains limited, with an estimated total area of 28,000 hectares dominated by sunflower (≈12,000 ha) and peanut (≈9,000 ha), while rapeseed and soybean cultivation is below 4,000 hectares each [3, 4]. This modest production satisfies less than 20% of domestic demand, highlighting a substantial gap that this research seeks to address by identifying viable local alternatives.

Oilseed crops are primarily cultivated for their lipid-rich seeds, which yield oils for food and industrial applications [6, 7], while their by-products serve as valuable protein sources, classifying them as oleo-protein plants [8]. Vegetable oils are fundamental to human nutrition, providing energy, essential fatty acids, and enhancing the organoleptic properties of foods [9, 10]. The nutritional quality and health benefits of these oils are largely determined by their fatty acid profiles. Polyunsaturated fatty acids (PUFAs), namely Omega-3 (e.g., α-linolenic acid/ALA) and Omega-6 (e.g., linoleic acid/LA), are essential and must be obtained from the diet. They play crucial roles in cardiovascular health, brain function, and anti-inflammatory responses [11, 12]. Furthermore, their unique chemical properties make them valuable for pharmaceutical and cosmetic applications [13, 14].

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The quality and stability of vegetable oils are assessed through key physicochemical parameters such as acid value, saponification value, and refractive index. These indices provide critical insights into the free acidity, average molecular weight of fatty acids, and the degree of unsaturation, respectively, which collectively determine the oil's shelf-life, nutritional value, and suitability for various industrial uses, including biodiesel and cosmetics [15].

While previous studies have acknowledged the potential of local oilseeds in enhancing food security in arid North Africa [16] and their general adaptation to environmental stresses [17], comprehensive data on the chemical quality and detailed fatty acid composition of oils from species cultivated in the hyper-arid conditions of southeastern Algeria are scarce. Therefore, this study aims to provide a thorough characterization of the oils extracted from five local oilseed species—peanut, safflower, rapeseed, soybean, and sunflower—from the El-Oued region. By integrating physicochemical analyses with detailed fatty acid profiling via gas chromatography, this research seeks to evaluate their nutritional value, industrial potential, and adaptability. The findings are expected to contribute scientific evidence for selecting promising crops, optimizing local production, and ultimately supporting strategies for sustainable agriculture and enhanced food security in arid regions facing climate change.

Experimental

Material

The plant material consisted of five oilseed species cultivated locally in the El-Oued region (southeastern Algeria): peanut (*Arachis hypogaea* L.), safflower (*Carthamus tinctorius* L.), rapeseed (*Brassica napus* L.), soybean (*Glycine max* L.), and sunflower (*Helianthus annuus* L.). For each species, three independent seed samples (n = 3) were collected from different farms within the same agro-climatic zone during the 2021/2022 growing season to account for field-level variability.

El-Oued features a Mediterranean climate with hot, dry summers (classified as Csa according to the Köppen-Geiger system). The region experiences extremely high summer temperatures, often exceeding 45°C during July and August, and mild winters. A large daily temperature variation, characteristic of Saharan zones, is also observed.

Methods

The seeds from each sample were finely ground into a fine powder using an electric grinder to prepare them for analysis.

Oil extraction from seeds

Soxhlet extraction method

The oil extraction was performed using the Soxhlet method as described by Fornasari, Secco [18]. For each oilseed species, the extraction was performed in triplicate (n=3). Specifically, 50 g of ground seed powder was placed in a filter paper cartridge, which was inserted into the Soxhlet apparatus. 300 mL of analytical grade n-hexane was added to the flask. The extraction was carried out for several hours, depending on the oilseed species, at 69°C, according to the optimized parameters.

Solvent removal and oil recovery

After extraction, the solvent was removed using a rotary evaporator (Buchi R-210) at 40°C under reduced pressure, following the protocol described by López-Bascón and Luque de Castro [19]. The extracted oil was further dried in a vacuum oven at 40°C until constant weight was achieved to ensure complete solvent removal.

The oil content was calculated using the following formula: Oil Yield (%) = $(m/m_0) \times 100$
where: m = mass of extracted oil (g); m_0 = initial mass of ground seeds (g)

Physicochemical analysis

All physicochemical analyses (refractive index, saponification value, acid value) were conducted in triplicate (n=3) for each oil sample. The specific methods are detailed below.

Refractive index determination

The refractive index was measured using an Abbe refractometer following the updated ISO 6320:2021 method at 20°C [20]. Temperature corrections were applied using the standard equation: $n^{20d} = n^{td} + 0.00035(t - 20)$

where: n^{20d} = refractive index at 20°C
n^{td} = refractive index at measurement temperature t
t = actual measurement temperature (°C)

For comparability with Codex Alimentarius ranges specified at 40°C (n_D^{40}), the measured n_D^{20} values were converted using the temperature coefficient $\Delta n/\Delta T = -0.00035\ °C^{-1}$: $n_D^{40} = n_D^{20} - 0.00035 \times (40 - 20)$

Table-1: Physicochemical properties of oils from different seed species: Oil yield, refractive index, acid value, and saponification index.

Oilseed species "varieties"	Oil Yield (%)	Refractive index		Codex Alimentarius [27]	Acid value (mg KOH/g)	Codex Alimentarius [27]	Saponification index (mg KOH/g)	Codex Alimentarius [27]
		n_D^{20} (ISO 6320:2021)	n_D^{40} (converted)					
Peanut "Giant"	**45.19 ± 1.43^{A}**	**1.4717 ± 0.0285^{A}**	**(1.4647)**	**1.460-1.465**	**5.00 ± 0.346^{C}**		**28.05 ± 1.485^{D}**	**187-196**
Safflower	**15.694 ± 1.9^{C}**	**1.4769 ± 0.0533^{A}**	**(1.4662)**	**1.467-1.47**	**7.85 ± 0.071^{A}**		**25.245 ± 0.689^{E}**	**186-198**
Rapeseed "Local"	**30.092 ± 2.02^{B}**	**1.4735 ± 0.0189^{A}**	**(1.4658)**	**1.465-1.469**	**5.397 ± 0.503^{C}**	**4**	**30.855 ± 1.416^{C}**	**168-181**
Soybean "Yellow"	**15.99 ± 1.74^{C}**	**1.4745 ± 0.0185^{A}**	**(1.4665)**	**1.466-1.47**	**6.733 ± 1.159^{AB}**		**42.075 ± 0.69^{B}**	**189-195**
Sunflower "Black"	**26.70 ± 2.31^{B}**	**1.4749 ± 0.019^{A}**	**(1.4699)**	**1.461-1.468**	**5.617 ± 0.53^{BC}**		**95.37 ± 1.582^{A}**	**188-194**
P-value	**0.000*** **	**1,000^{NS}**	/	/	**0.002****	/	**0.000*** **	/

Values are means ± SD (n=3). Fisher's LSD test at α=0.05 was used. For each parameter, different letters denote significant differences. ^{NS} not significant, ** highly significant, *** extremely significant.

For Refractive index: Measured values are n_D^{20}. For comparability with Codex named-oil ranges at 40 °C (n_D^{40}), n_D^{20} values were converted using $\Delta n/\Delta T = -0.00035$ °C^{-1}. Example (peanut): 1.4717 → 1.4647 at 40 °C.

All reported values in Table 1 represent n_D^{20} measurements, with converted n_D^{40} values provided for direct comparison to Codex standards.

Saponification value determination

The saponification value was determined according to the modified AOCS Official Method Cd 3-25 [21]. One gram of oil was saponified with 25 mL of 0.5 N ethanolic KOH solution under reflux conditions. The excess alkali was titrated with 0.5 N HCl using phenolphthalein as indicator.

The saponification value (SV) was calculated using the equation: $SV = [(V_0 - V) \times N \times 56.1]/W$
where: V_0 = volume of HCl for blank (mL); V = volume of HCl for sample (mL); N = normality of HCl; W = sample weight (g); 56.1 = molecular weight of KOH

Acid value determination

The acid value was determined using the modified AOCS Official Method Cd 3a-63 [21]. One gram of oil was dissolved in 75 mL of hot neutral ethanol and titrated with standardized 0.1 N KOH solution using phenolphthalein as an indicator.

The acid value (AV) was calculated using the equation: $AV = (56.1 \times V \times N)/W$

where: V = volume of KOH solution used (mL); N = normality of KOH solution; W = sample weight (g)

Fatty acid composition analysis

Preparation of fatty acid methyl esters (FAMEs)

FAMEs were prepared following the optimized protocol described by Liu [22]. One gram of oil was trans-esterified using 10 mL of methanol and 0.2 mL of 2 M methanolic KOH under reflux for 30 minutes at 65 °C. The resulting FAMEs were extracted with n-hexane and dried over anhydrous sodium sulfate before analysis.

Gas chromatographic analysis

Fatty acid analysis was performed using a Shimadzu GC-2010 gas chromatograph equipped with a flame ionization detector (FID) and a DB-WAX capillary column (30 m × 0.32 mm i.d., 0.25 µm film thickness), following the method of Toishimanov, Nurgaliyeva [23].

Authentic FAME standards were obtained from Sigma-Aldrich (St. Louis, MO, USA) with ≥ 99 % purity, including reference compounds for C6:0 to C24:1 fatty acids. These standards were used for peak identification and retention time calibration. Compounds were quantified using the internal normalization method as described by Choe and Min [24].

Note: Due to budget constraints and the high cost of comprehensive fatty acid profiling, coupled with limited laboratory resources and the absence of specific funding for this study, a single oil sample per seed species was analyzed. The reported fatty acid compositions represent single measurements from representative samples for each oilseed species.

Statistical analysis

Statistical analysis was performed using Minitab 16 software. For parameters where multiple measurements were obtained (oil yield, refractive index, acid value, and saponification value), one-way analysis of variance (ANOVA) was conducted followed by

Fisher's Least Significant Difference (LSD) test at α = 0.05 to compare means between different oilseed species.

Results and Discussion

Seed-oil yield

The oil yields among the five studied oilseed species varied significantly (Table 1), forming distinct groups based on their productivity. Peanut exhibited the highest oil yield (45.19 %), significantly outperforming rapeseed (30.09 %) and sunflower (26.70%), which formed an intermediate group. The oil yield of sunflower in our study was slightly lower than the 28.5 % reported by Leon, Andrade [20] for sunflower cultivated under optimal conditions, a difference likely attributed to the arid climate of El-Oued limiting seed-oil accumulation. Soybean and safflower, yielding approximately 16 %, represented the lowest group. This marked variation underscores the potential of peanut as a primary oil crop in arid regions, given its high oil content and adaptability. While safflower and soybean showed relatively low oil yields, they remain valuable for other applications, such as protein-rich feedstock [25]. These findings are consistent with previous studies highlighting the influence of genetic and environmental factors on oilseed productivity [21, 26].

Physicochemical Properties

The refractive indices, measured at 20°C (n_D^{20}) following ISO 6320:2021, ranged from 1.4717 to 1.4769 across all samples, showing no significant differences (p = 1.000). When converted to standard temperature of 40°C (n_D^{40}) using the temperature coefficient $\Delta n/\Delta T = -0.00035\ °C^{-1}$ for comparison with Codex Alimentarius [27] standards, the values ranged from 1.4647 to 1.4699. All converted values fell within the respective Codex ranges for each oil type, confirming their conformity with international standards for edible oils and their suitability for human consumption [28]. This consistency in refractive indices indicates proper oil purity and appropriate degrees of unsaturation across the studied oilseed species.

Acid values exhibited significant differences (p = 0.002). Safflower oil recorded the highest value (7.85 mg KOH/g), surpassing the Codex Alimentarius limit of 4 mg KOH/g for crude oils and exceeding the 4.2 mg KOH/g reported for sesame oil by Gharby, Harhar [28]. This elevation is likely due to the high temperatures and prolonged storage conditions in El-Oued, which accelerate oil degradation. Soybean oil also showed elevated values (6.73 mg KOH/g), higher than the 5.8 mg KOH/g reported by Bellaloui, Mengistu [26] for temperate climates, further implicating the harsh local environment in reducing oil stability. In contrast, peanut, rapeseed, and sunflower oils had lower acid values, enhancing their stability and consumer acceptance.

The saponification indices differed significantly (p < 0.001). Sunflower oil recorded the highest value (95.37 mg KOH/g), comparable to the 94.5 mg KOH/g reported for high oleic sunflower oil by Flagella, Rotunno [29], suggesting a consistent fatty acid composition with other high-quality sunflower oils. These findings align with studies indicating that fatty acid chain length is a crucial determinant of oil applications in food and industrial contexts [15]

Fatty acid composition

Gas chromatography analysis revealed significant differences in the fatty acid profiles (Table 2, Fig. 1). For comprehensive chromatographic details, including peak identification and quantification parameters for all fatty acids, refer to the Supplementary Data. However, quantification of all fatty acids, including trace components, was performed using Shimadzu GCsolution software with automatic baseline correction. Each sample was analyzed, and identification was confirmed using ≥ 99 % purity FAME standards (Sigma-Aldrich), with relative standard deviations <5% for minor components.

Safflower oil was the richest in oleic acid (65.95 %), comparable to the 67.3 % reported for genetically modified varieties by Rauf, Fatima [21], indicating that local varieties naturally possess high oleic acid levels, ideal for oxidative stability. Soybean oil showed the highest linoleic acid content (46.79 %), slightly above the 42.5 % reported by Bukowski and Goslee [30] under similar arid conditions, potentially due to variations in soil or irrigation. Linoleic acid is critical for cardiovascular health [31].

Rapeseed oil exhibited the highest α-linolenic acid content (9.88 %), resulting in an optimal Omega-6/Omega-3 ratio of 1.97. This ratio falls within the recommended range of 1–4 for cardiovascular health [9] and is more favorable than some commercial oils (typically ~2.5), highlighting its superior nutritional quality. The total unsaturated fatty acid content was 93.50 %, higher than the 90.2 % reported by Chen and Liu [32] for conventional rapeseed oils. Notably, erucic acid was not detected, confirming the oil's compliance with international safety standards [27] and suggesting the use of improved, low-erucic acid cultivars in the region.

Table-2: Main fatty acids identified by Gas Chromatography in oils from different oilseed species.

Oilseed species		Peanut	Safflower	Rapeseed	Soybean	Sunflower
Fatty acid	Name	Concentration (%)				
C6:0	Caproïc acid	0.60	ND	ND	ND	ND
C8:0	Caprylic acid	0.82	ND	ND	ND	ND
C10:0	Capric acid	0.71	ND	ND	ND	ND
C11:0	Undécylic acid	1.47	ND	ND	ND	ND
C12:0	Lauric acid	0.61	ND	ND	ND	ND
C13:0	Tridécylic acid	1.29	ND	ND	ND	ND
C14:0	Myristic acid	0.33	ND	ND	2.31	ND
C14:1	Myristoléic acid	ND	ND	ND	1.74	ND
C16:0	Palmitic acid	ND	7.12	6.50	12.67	6.41
C16:1	Palmitoléic acid	ND	2.78	ND	ND	ND
C17:0	Margaric acid	ND	3.19	ND	ND	ND
C18:0	Stéaric acid	4.71	8.91	ND	4.60	4.81
C18:1 ω-9	Oléic acid	26.90	65.95	64.17	20	47.54
C18:2 ω-6	Linoléic acid	26.88	ND	19.45	46.79	30.26
C18:3 ω-3	α-linoléic acid	0.55	1.17	9.88	5.59	ND
C18:3 ω-6	γ-linoléic acid	0.26	ND	ND	0.27	ND
C20:0	Arachidic acid	ND	ND	ND	1.21	ND
C20:3 ω-6+ C21:0	Dihomo-γ-linolénic acid	ND	ND	ND	1.46	ND
C20:4 ω-6	Arachidonic acid	1.45	ND	ND	0.27	ND
C20:5 ω-3	Eicosapentaénoïc acid	ND	ND	ND	0.62	ND
C22:6	Docosahexaénoïc acid	0.58	ND	ND	0.30	2.30
C23:0	Tricosylic acid	1.07	ND	ND	1.28	ND
C24:1	Lignocéric acid	ND	ND	ND	0.45	ND
	∑ SFA	20.06	10.31	6.50	22.06	11.23
	∑ MUFA	26.91	11.70	64.17	22.19	47.55
	∑ PUFA	29.74	67.13	29.33	55.75	32.56
	∑ UFA	56.65	78.83	93.50	77.94	80.11

SFA: Saturated fatty acids; MUFA: Monounsaturated fatty acids; PUFA: Polyunsaturated fatty acids; UFA: Unsaturated fatty acids; ND: Not detected.

Peanut oil demonstrated a balanced composition of oleic (26.90 %) and linoleic acids (26.88 %), complemented by medium-chain fatty acids, enhancing its versatility. Sunflower oil showed a favorable profile of oleic (47.54 %) and linoleic acids (30.26 %), with the presence of docosahexaenoic acid (2.30 %) further boosting its nutritional appeal [33].

Comparative Analysis and Implications for Food Security

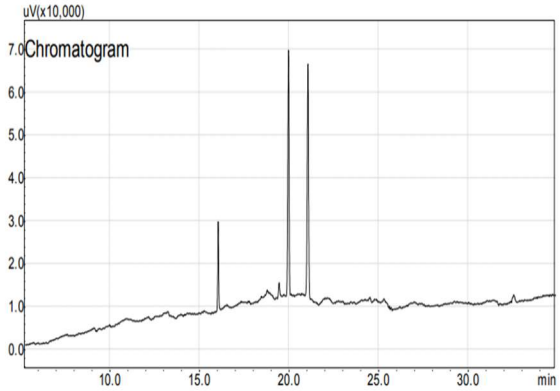
The fatty acid profiles from El-Oued align with global ranges while exhibiting local shifts consistent with arid production conditions. Safflower (*Carthamus tinctorius*) was found to be oleic-dominant, with approximately 66 % oleic acid representation, which positions it as a mid-oleic phenotype rather than the high-oleic lines that typically exhibit oleic acid contents of 70 % to 80 % [34, 35]. This mid-oleic characteristic may be influenced by the arid conditions prevalent in the region, as stress conditions can affect fatty acid accumulation [35].

Rapeseed (*Brassica napus*) displayed an average of around 10 % alpha-linolenic acid (ALA), which is consistent with typical values for canola varieties that range between 8% and 12 % ALA [36]. Such profiles indicate the capacity for rapeseed grown in arid conditions to maintain its essential fatty acid content, which is crucial for nutritional value [36].

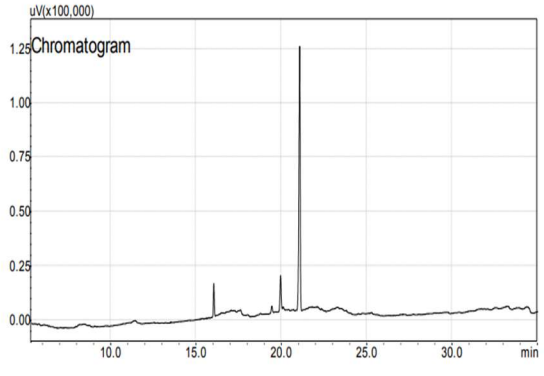
Soybean oil (*Glycine max*) was linoleic-rich, with an approximate content of 47%, aligning with established standard compositions for soybeans [37]. This consistency in fatty acid profiles indicates that, despite regional variations, the fundamental biochemical composition remains robust, potentially allowing for broader agricultural adaptability in the face of climatic variations [37].

These comparisons reveal two key strategic levers: i) genotype selection—introducing high-oleic varieties for safflower, sunflower, and peanut to enhance oxidative stability and shelf-life; and ii) post-harvest management—improving handling practices to mitigate free fatty acid increases under high-temperature conditions.

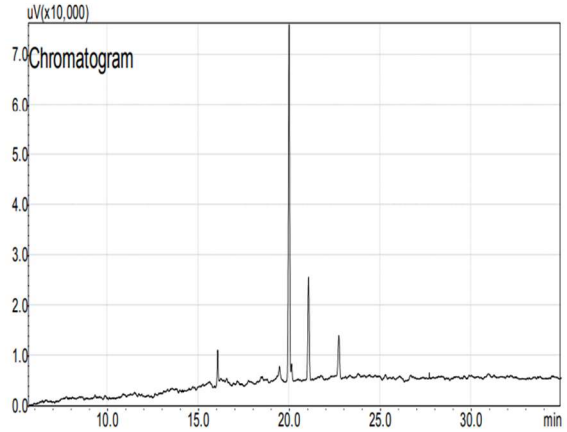
Algeria remains a net importer of edible oils, with significant annual imports (e.g., ~0.5 MMT of soybean oil; [3, 4]. Substituting even a fraction of these imports with locally adapted oilseeds can reduce import dependency and foreign exchange expenditure. Our data identify peanut as the leading candidate for high oil yield under hyper-arid conditions, while rapeseed offers a favorable ω-6/ω-3 ratio. Integrating these biochemical insights with climate-resilient genotypes and optimized post-harvest practices can foster the development of robust regional oil value chains. This approach advances import substitution, improves nutritional outcomes, and supports farmer livelihoods in the face of climate change and water scarcity.



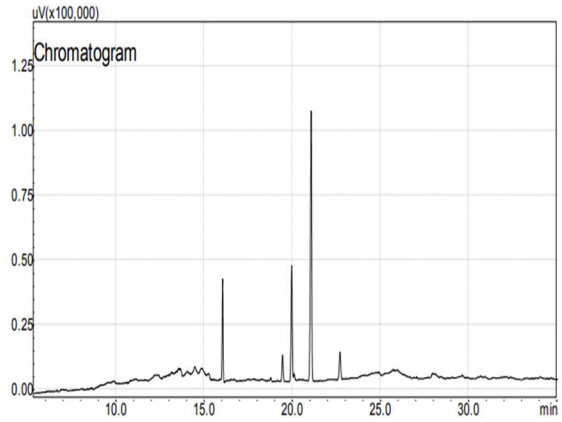
Peanut chromatogram



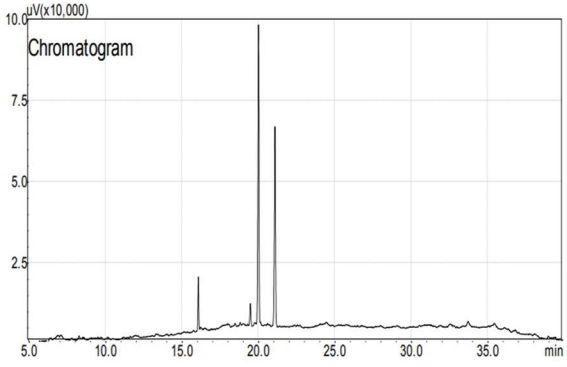
Safflower chromatogram



Rapeseed chromatogram



Soybean chromatogram



Sunflower chromatogram

Fig. 1: Gas chromatograms of fatty acid methyl esters (FAMEs) from (a) peanut, (b) safflower, (c) rapeseed, (d) soybean, and (e) sunflower oils analyzed by GC-FID. Peaks are labeled 1–10 corresponding to major identified fatty acids as follows: 1 = C16:0 (Palmitic acid); 2 = C18:0 (Stearic acid); 3 = C18:1 (Oleic acid); 4 = C18:2 (Linoleic acid); 5 = C18:3 (α-Linolenic acid); 6 = C20:0 (Arachidic acid); 7 = C20:4 (Arachidonic acid); 8 = C20:5 (EPA); 9 = C22:6 (DHA); 10 = Other minor FAMEs (< 1 %). Retention times were identified using ≥ 99 % purity FAME standards (Sigma-Aldrich). Baseline correction and automatic peak integration were performed using Shimadzu GCsolution software to ensure reproducible quantification of both major and minor fatty acids.

Conclusion

This study characterized oils from five oilseed species cultivated in the hyper-arid El-Oued region, Algeria. Significant diversity was found in oil yields, physicochemical properties, and fatty acid profiles. Peanut emerged as the most promising species due to its high oil yield (45.19 %) and stability. Physicochemical analyses confirmed most oils meet international edible standards, though elevated acid values in safflower and soybean oils indicate the need for improved post-harvest practices.

Fatty acid profiling revealed distinctive nutritional qualities: safflower oil was rich in oleic acid, soybean oil in linoleic acid, and rapeseed oil showed an optimal Omega-6/Omega-3 ratio (1.97) with no detected erucic acid. The presence of valuable fatty acids like docosahexaenoic acid in sunflower oil further enhances their health benefits.

These findings provide a scientific basis for reducing Algeria's dependence on imported edible oils by identifying locally adapted species with high nutritional value. Future work should focus on introducing improved varieties, optimizing cultivation and post-harvest techniques, and assessing economic viability to enhance climate-resilient agriculture and food security in arid regions.

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