ORIGINAL ARTICLE

AfAc Publisher
With Knowledge We Publish

Food Chemistry, Engineering, Processing and Packaging Functional and Novel Foods

Physicochemical characteristics and nutritional value of safflower oil: A potential sustainable crop for Egypt

Walid S. Abd El-Baset , Rania I.M. Almoselhy , Susan M.M. Abd-Elmageed

Oils and Fats Research Department, Food Technology Research Institute, Agricultural Research Center, Giza, Egypt
walid.salah@ymail.com / raniaalmoselhy@arc.sci.eg / susanabdelmgid76@gmail.com

ABSTRACT

Background: The Increasing demand for sustainable and economical non-traditional edible oils, as alternatives to common oils is pivotal to bridge the edible oils gap, coupled with negative impacts of climate change on the agroecological settings for common oilseed crop productivity. Safflower, being one of the fast-growing medicinal oilseeds crops rich in polyunsaturated fatty acids, known as the "king of linoleic acid", exhibits resilience to adverse environmental conditions such as high temperatures, drought, salinity, and marginal environments. **Aims:** This study aimed to comprehensively assess the physicochemical characteristics and lipid nutritional indices of safflower oil to validate its potential for expanded cultivation in Egypt. **Materials and Methods:** Safflower oil was extracted from seeds of two spineless varieties cultivated in Egypt. The oil was subjected to proximate analysis, physicochemical characterization, fatty acid profile determination, and α-tocopherol content analysis. Additionally, a frying stability test was carried out for safflower oil and its blends with soybean oil in different ratios, monitoring changes in free fatty acid, peroxide value, and total polar compounds. Lipid nutritional indices were calculated to assess the oil's health-promoting properties. **Results:** Safflower oil exhibited similar proximate composition and physicochemical characteristics to sunflower oil. The fatty acid profile of safflower oil was comparable to sunflower oil, with a lower oleic acid content and a higher linoleic acid content. Furthermore, safflower oil demonstrated satisfactory stability during the frying process. Lipid nutritional indices calculated based on the fatty acid profile revealed that safflower oil is a valuable source of ω-6 fatty acids. The oil exhibited favorable values for atherogenicity index (AI), thrombogenic index (TI), hypocholesterolemic / hypercholesterolemic (HH), health-promoting index (HPI), and possessed strong antioxidant properties due to its high α-tocopherol content. **Conclusion**: The findings of this study support the potential of safflower oil as a promising non-traditional edible oil, suitable for expanded cultivation in Egypt. Its favorable nutritional profile and stability make it a valuable addition to the dietary landscape.

Keywords: *Carthamus tinctorius* L., safflower oil, edible oil gap, lipid nutritional indices, frying stability, non-traditional edible oils.

ARTICLE INFORMATION

Corresponding author: Rania I.M. Almoselhy
E-mail: rania_almoselhy@outlook.com
Tel: +20 (10 92 49 79 77) - (12 86 92 55 53)

Received: July 10, 2024
Revised: October 03, 2024
Accepted: October 12, 2024
Published: October 16, 2024

Article edited by:
Pr. Khaled Méghit Boumédiène

Article reviewed by:
Dr. Farida Benmeziane
Dr. Afreen Usmani

Cite this article as:
Abd El-Baset, W. S., Almoselhy, R. I. M., Abd-Elmageed, S. M. M. (2024). Physicochemical characteristics and nutritional value of safflower oil: A potential sustainable crop for Egypt. *The North African Journal of Food and Nutrition Research, 8* (18): 140 – 153. https://doi.org/10.51745/najfnr.8.18.140-153

1 Introduction

The edible oils sector's food insecurity has prompted extensive research into alternative oilseed crops to optimize their physical, chemical, and functional properties (Khan et al., 2024). Given the rise in edible oil consumption alongside dependency on imports and escalating costs, there is a growing interest in novel cultivars, with unique traits that differ from traditional sources. Safflower, as a valuable plant resource, holds significant potential to rival established oil-bearing crops in the future contributing to a more sustainable and diversified edible oil supply (Mursalykova et al., 2023). Safflower (*Carthamus tinctorius* L.), a member of the Asteraceae family, is gaining increasing attention as a potential source of flavonoids, phenols, alkaloids, polysaccharides, fatty acids, polyacetylene, and other bioactive components, is effective for treating cardiovascular, neurodegenerative, and respiratory diseases (Cheng et al., 2024). Historically, safflower has been used in traditional medicine in various cultures, including Persian, Chinese, Korean, Japanese, and other East Asian countries. In patients with Metabolic Syndrome (MetS), safflower oil consumption without lifestyle changes improved blood pressure, insulin resistance, and abdominal obesity. These improvements included decreased waist circumference, waist to hip ratio, and systolic and diastolic blood pressure (Ruyvaran et al., 2022). Cold-pressed safflower seed oil (SSO) exhibited strong antioxidants and antibacterial properties against a range of opportunistic skin infections. It appeared to possess a potent antifungal, growth inhibition mechanism in addition to bacteriostatic and bactericidal pathways (Khémiri et al., 2020). Furthermore, its ability to inhibit UVB-induced matrix metalloproteinase-1 (MMP-1) expression, which causes skin photoaging, SSO and its active ingredient acacetin may be used therapeutically as an anti-wrinkle treatment to improve skin health (Jeong et al., 2020).

Rich concentrations of vital unsaturated fatty acids, including oleic and linoleic acids, greatly add to their nutritional value and health-promoting effects, as well as boosting immunity with the management and prevention of a number of illnesses. Safflower seeds are rich in proteins, lipids, and carbohydrates with vitamins, minerals, and macro- and microelements (Iskakov et al., 2023). Safflower seed oil, besides being recognized as the "king of linoleic acid," is rich in omega 6, or the unsaturated fatty acid, linoleic acid. Safflower seed oil is considered an excellent raw material for the preparation of the conjugated linoleic acid with significant physiological functions, bearing the ability to reduce cholesterol and monounsaturated fatty acids in the body, with powerful antioxidant effects (Wang et al., 2024).

A high diet of animal fat with a high saturated fatty acid content can lead to a variety of life-threatening disorders. Therefore, various official health organizations and governmental agencies have performed operations to promote concepts aiming at reducing the saturated fat content in foodstuffs, stimulating the food industry companies to begin working on developing foods with minor fat or a different fatty acid composition. Essentially, the best strategy to substitute saturated fat is to use structured vegetable oils. Pre-emulsification, microencapsulation, the formation of gelled emulsions, and the development of oleogels are the four basic oil structuring procedures (Botella-Martínez et al., 2023). The future perspective for safflower seed oil is promising as it presents avenues for sustainable and economical innovation, enhanced functionality, and broader applications in the food industry by manufacturing oleogels and solid fats to replace animal fat in order to offer healthier vegetable fat compared with the risky animal fat (Almeida et al., 2022; Badem & Baştürk, 2023; Kang et al., 2023; Potdar et al., 2022).

Growing all over the world, safflower is a multipurpose crop that offers farmers a number of benefits. The plant can withstand long dry spells by drawing deep water till reaching the depth of four (4) m through its long, strong, and wide roots. Additionally, Safflower is a versatile crop that can tolerate some salinity, making it potentially advantageous for cultivation in saline soils. Safflower can be effectively cultivated with minimal maintenance on farmlands where pest animals and birds pose serious issues for other crops due to its spines, which discourage them. Furthermore, intercropping safflower with other crops can disrupt the life cycles of microorganisms responsible for various grain diseases (Shahid et al., 2020).

Given its low production and market capitalization, safflower may hold the key to bridging the vegetable oil gap for the expanding global population's needs. Not only does the final product exceed quality standards, but it also increases oil production. To ensure the quality and safety of safflower-based products, particularly when marketed with health claims, it is crucial to adhere to the European Pharmacopoeia standards (Deliorman Orhan et al., 2022).

The current study aimed to comprehensively investigate the physicochemical characteristics and lipid nutritional indices of safflower oil extracted from two Egyptian varieties. The objective was to evaluate the potential of safflower oil as a valuable addition to the Egyptian edible oil market, addressing the growing demand for sustainable and healthy oil sources.

2 Material and Methods

2.1 Materials

2.1.1 Raw materials

Safflower seeds of two spineless varieties (Giza1, Kharga1) and sunflower seeds of one variety (Giza120) were procured from the Experimental Farm of Shandaweel Research Station, Sohag Governorate, Upper Egypt, via the Oil Crops Research Department, Field Crops Research Institute (FCRI), Agricultural Research Center (ARC), Egypt. Refined, bleached, and deodorized (RBD) soybean oil was obtained from Arma Company for Edible Oils, Egypt.

2.1.2 Chemicals and reagents

All solvents and chemicals used in the study were of analytical and HPLC grade and were obtained from Sigma-Aldrich, USA.

2.2 Methods

2.2.1 Extraction of safflower and sunflower crude oils

Spineless safflower and sunflower seeds were harvested from flowering plants cultivated in Upper Egypt. Safflower seed oil (SSO) and sunflower seed oil (SFO) were extracted using a

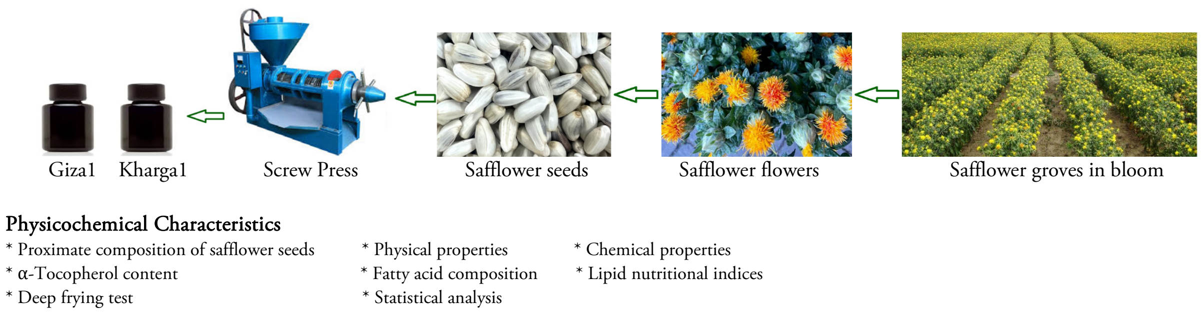

Figure 1. Experimental design of extraction and physicochemical characteristics of SSO

cold-press mechanical screw press configuration (Figure 1) after initial cleaning to remove impurities and dust. The extracted oils were stored in hermetically sealed containers in a dark environment until further analysis.

2.2.2 Analytical methods

2.2.2.1 Proximate composition analysis of safflower and sunflower seeds

Proximate composition analysis of safflower and sunflower seeds, including moisture, ash, lipid, and protein, was determined according to the AOAC Official Methods: 925.10, 942.05, 923.05, and 992.23, respectively, with total carbohydrates by difference and energy in calories per 100 g of seeds.

2.2.2.2 Physicochemical characteristics of safflowers, sunflower, and soybean oils

The physicochemical characteristics of the oils under study were determined by the official methods of analysis as: refractive index (AOCS Cc 7 – 25), specific gravity (AOCS Cc 10b – 25), color measurement (AOCS Cc 13e – 92), UV spectroscopic characteristics at 232 and 270 nm (ISO 3656:2011/Amd 1:2017), saponification value (AOCS Tl 1a-64), unsaponifiable matter (AOCS Ca 6a – 40), acidity (ISO 660:2020), peroxide value (AOAC 965.33), oxidative stability as induction period by Rancimat Method (AOCS Cd 12b – 92), α-tocopherol content (Wong et al., 1988), fatty acid composition (ISO 12966 – 2:2017).

2.2.2.3 Lipid nutritional indices from the fatty acid composition

Lipid nutritional indices were calculated from mathematical relations of the fatty acid composition. Polyunsaturated fatty acids/saturated fatty acids (PUFA/SFA), index of atherogenicity (IA), index of thrombogenicity (IT), hypocholsterolemic / hypercholesterolemic (HH), health-promoting index (HPI), and unsaturation index (UI) were calculated according to the method mentioned by Chen & Liu (2020). Iodine value (IV calculated) was determined by the formula assigned by Kyriakidis & Katsiloulis (2000). Whereas, the peroxidability index (PI) was calculated according to the method mentioned by Yun & Surh (2012), the allylic position equivalent (APE) and the bis-allylic position equivalent (BAPE) were calculated according to the method mentioned by Stoyanova & Romova (2024). The oxidative stability index was calculated according to the method mentioned by Pinto et al. (2021), and the oxidizability value (COX) was calculated according to the method mentioned by Fatemi & Hammond (1980). All the above-mentioned lipid indices with their mathematical formulas were tabulated in Table 1.

2.2.3 Deep frying test

The deep-frying procedure was performed according to the method described by Benmeziane et al. (2024) with some modifications, using a 4L capacity local electrical fryer, where the frying oil blends were classified into 2 categories as follows:

- Frying blends from the mixture of the 2 varieties of safflower oil (SSO) and soybean oil (SBO) in different ratios of SSO:SBO (100:0–20:80–40:60–60:40–80:20–50:50);
- Frying blends of sunflower oil (SFO) and soybean oil (SBO) in different ratios of SFO:SBO (100:0–20:80–40:60–60:40–80:20–50:50).

Then the frying cycles were performed uninterruptedly for a total of 6 hours in a day in a time interval of 1 hour for a complete frying cycle for 125 grams of fresh potato as French fries in 1 L of oil at 180 °C in a 1/8 ratio of potatoes/frying oil. The starting amount of frying oil is constant, and no additional fresh oil was added during the frying procedure in order to assess the quality and safety of the same used oil throughout the frying period. Alternatively, the amount of fresh potatoes was regularly reduced with development in the frying cycles to comply with the decreasing amount of the used frying oil to maintain a constant ratio of 1/8 between the amount of fresh potatoes to the amount of the remaining frying oil (w/w). The frying oil samples were collected at the end of each complete frying cycle for an hour (after 1, 2, 3, 4, 5, 6 hours) and stored in hermetically sealed containers till analysis of free fatty acid (FFA), peroxide value (PV), and total polar compounds (TPC) in the fried oil samples.

2.2.4 Statistical analysis

All measurements for proximate composition and physicochemical analyses were performed in triplicate. The fatty acid composition and analysis of FFA, PV, and TPC in the fried oils were carried out once for each oil sample. Data are presented as mean ± standard deviation (SD). Analysis of variance (ANOVA) was conducted with SPSS software at $p < 0.05$.

3 Results and discussion

3.1 Proximate composition of safflower and sunflower seeds

Proximate compositions per 100 g of safflower and sunflower seeds were explored to help better understand their nutritional values. The obtained results are tabulated in Table 2, and there were significant differences ($p < 0.05$) among the proximate composition parameters of the three kinds of oilseeds, from which there were two varieties of safflower (Giza1-Kharga1) with sunflower (Giza120) seeds.

Despite the significant differences ($p < 0.05$) among the proximate composition parameters of the abovementioned seeds (safflower and sunflower), they are still in close relationship because of their similar compositions, which revealed the high similarity between safflower and sunflower in their structure and proximate composition. Therefore, sunflowers have been selected as well-known common seeds to be compared with safflowers as the non-traditional seeds,

Table 1. Lipid nutritional indices with their formulas from the fatty acid composition

№	Lipid nutritional index	Formula
1	PUFA/SFA	$\text{PUFA/SFA}=\frac{(\sum \text{PUFA})}{(\sum \text{SFA})}$
2	ω-6/ω-3 (n-6/n-3)	n-6/n-3 = ($C_{18:2}$/ $C_{18:3}$)
3	Atherogenicity Index (AI)	$\text{AI}=\frac{(C_{12:0} + 4 \times C_{14:0} + C_{16:0})}{(\sum \text{UFA})}$
4	Thrombogenicity Index (TI)	$\text{TI}=\frac{(C_{14:0} + C_{16:0} + C_{18:0}}{(0.5 \times \sum \text{MUFA})+ (0.5 \times \sum \text{n-6 PUFA})+ (3 \times \sum \text{n-3 PUFA})+\left(\frac{\sum \text{n-3 PUFA}}{\sum \text{n-6 PUFA}}\right)}$
5	Hypocholesterolemic /Hypercholesterolemic (HH)	$\text{HH ratio}=\frac{C_{18:1}\ (_{n-9})+ \sum \text{PUFA}}{(C_{12:0} + C_{14:0} + C_{16:0})}$
6	Health-promoting index (HPI)	$\text{HPI}=\frac{\sum \text{UFA}}{[C_{12:0} + (4 \times C_{14:0(} + C_{16:0}]}$
7	Unsaturation index (UI)	UI=1 ×(% monoenoic FA) +2 ×((% dienoic FA) +3 × (% trienoic FA) +4× (% tetraenoic FA) +5× (% pentaenoic FA) + 6× (% hexaenoic FA)
8	Iodine value (IV calculated)	Calculated IV: IV = xC1 + yC2 +zC3 (where: C1, C2, and C3 relate to the sum of the relative percentage concentrations of the unsaturated fatty acids (UFA) with one, two, and three double bonds (=), respectively, and the variables; x, y, and z, are numerical coefficients corresponding each type of oil.
9	Peroxidability index (PI)	PI= (% monoenoic FA×0.025) + (% dienoic FA×1) + (% trienoic FA×2) +(% tetraenoic FA×4)+(% pentaenoic FA×6)+(% hexaenoic FA×8)
10	Allylic Position equivalent (APE)	APE=2× (% $C_{18:1}$+% $C_{18:2}$+% $C_{18:3}$)
11	Bis-Allylic position equivalent (BAPE)	BAPE=% $C_{18:2}$+(2×% $C_{18:3}$)
12	Oxidative Stability Index (OSI)	OSI=3.91–(0.045×BAPE)
13	Oxidizability value (COX)	$\text{COX value}=\frac{1 \times C_{18:1} + 10.3 \times C_{18:2} + 21.6 \times C_{18:3}}{100}$

in order to simplify the concept of novel food (safflower seeds) with similar characteristics of sunflower seeds to be accepted by consumers as it bears already a highly similar structure with the difference involved in lower cost of characteristics) and chemical analysis (saponification value, unsaponifiable matter, acidity, peroxide value, oxidative stability test as induction period, total polar compounds, α-tocopherol content with the fatty acid composition).

Table 2. Proximate composition of safflower, sunflower, and soybean seeds per 100 g

Proximate composition Parameters	Safflower seeds Giza1	Safflower seeds Kharga1	Sunflower seeds Giza120
Oil content (Lipid)	28.47 ± 0.33[a]	26.60 ± 0.43[c]	27.58 ± 0.48[b]
Moisture	2.27 ± 0.02[c]	2.34 ± 0.02[b]	2.61 ± 0.03[a]
Ash	2.64 ± 0.01[c]	2.93 ± 0.01[a]	2.88 ± 0.01[b]
Protein	14.88 ± 0.05[c]	15.36 ± 0.06[b]	15.4 ± 0.06[a]
Carbohydrates	51.74 ± 0.13[b]	52.77 ± 0.15[a]	51.53 ± 0.18[c]
Energy (Calories)	522.71 ± 1.3[a]	511.92 ± 1.2[c]	515.94 ± 1.2[b]

Values are means of three replicates ±SD.
Values in the same row followed by different superscripts are significantly different at $p < 0.05$.

Table 3. Physicochemical characteristics of safflower, sunflower, and soybean oils

Physicochemical parameters	Safflower oil Giza1	Safflower oil Kharga1	Sunflower oil Giza120	Soybean oil (RBD)
Refractive index at 25°C	1.4732 ± 0.0001[a]	1.4726 ± 0.0001[b]	1.4720 ± 0.0001[c]	1.4700 ± 0.0001[d]
Specific gravity at 25°C	0.919 ± 0.002[b]	0.922 ± 0.003[a]	0.917 ± 0.002[c]	0.919 ± 0.002[b]
Color measurement - Yellow	35 ± 0[a]	35 ± 0[a]	35 ± 0[a]	35 ± 0[a]
Color measurement - Red	3.8 ± 0.1[b]	4 ± 0.1[a]	2.9 ± 0.5[c]	2.0 ± 0.1[d]
UV characteristics - K_{232}	0.49 ± 0.01[c]	0.46 ± 0.01[d]	1.483 ± 0.01[b]	1.785 ± 0.01[a]
UV characteristics - K_{270}	0.038 ± 0.01[c]	0.033 ± 0.01[d]	0.231 ± 0.01[b]	0.413 ± 0.01[a]
Saponification value	189 ± 1[d]	190 ± 1[c]	192 ± 2[b]	196 ± 2[a]
Unsaponifiable matter (%)	0.92 ± 0.02[c]	0.95 ± 0.04[b]	1.02 ± 0.06[a]	0.90 ± 0.04[d]
Acidity (%as oleic acid)	0.43 ± 0.002[b]	0.23 ± 0.001[d]	0.44 ± 0.004[a]	0.35 ± 0.003[c]
Peroxide value (meq/kg)	3.22 ± 0.09[a]	2.26 ± 0.07[d]	2.65 ± 0.06[c]	2.73 ± 0.006[b]
Induction period (hrs.)	6.77 ± 0.33[d]	7.67 ± 0.44[c]	9.87 ± 0.54[b]	10.24 ± 0.67[a]
Total polar compounds (TPC)	11.4 ± 0.8[b]	11.4 ± 0.7[b]	12 ± 0.9[a]	10.9 ± 0.7[c]
α-Tocopherol content (mg/kg)	170 ± 1.5[b]	190 ± 1.7[a]	150 ± 1.1[c]	114 ± 1.0[d]

Values are means of three replicates ±SD.
Values in the same row followed by different superscripts are significantly different at $p < 0.05$.

safflower seeds, which is considered a good sustainable economic oilseed crop.

3.2 Physicochemical characteristics of safflowers, sunflowers, and soybean oils

Physicochemical characteristics of safflower, sunflower, and soybean oil were explored to help better understand their nutritional values. The obtained results are tabulated in Table 3, and there were significant differences ($p < 0.05$) among the physicochemical parameters of the four kinds of oils, from which there were two varieties of safflower (Giza1-Kharga1) and sunflower (Giza120) seeds with their oils extracted by cold pressing, and the soybean oil was refined, bleached, and deodorized (RBD) oil. All oils were subjected to physical analysis (refractive index, specific gravity, color, UV

Table 3 summarizes the physicochemical characteristics of SSO, SFO, and SBO where they have been checked with the Codex standard for named vegetable oils (CODEX STAN 210 – 1999, 2019). A great number of research papers and routine works are devoted to discrimination of different oil types and detecting adulteration in valuable oils such as safflower seed oil (Han et al., 2022; Zou et al., 2024), as its promotion as a medicinal plant oil with great health benefits encouraged bad people for its adulteration with cheaper oils to gain more profit from selling adulterated oil, threatening human health and accompanied by huge economic losses. Therefore, the physicochemical characteristics should be examined thoroughly and matched with the standards assigned by the official organizations as Codex Alimentarius International Food Standards supported by the Food and Agriculture Organization of the United Nations and the

Table 4. Fatty acid composition and lipid nutritional indices of SSO, SFO, and SBO

Fatty acid%	SSO Giza1	SSO Kharga1	SFO Giza120	SBO (RBD)
$C_{12:0}$	ND	ND	ND	ND
$C_{14:0}$	0.096	0.10	0.061	0.07
$C_{16:0}$	6.58	6.90	6.35	10.17
$C_{16:1}$	0.08	0.09	0.09	0.10
$C_{17:0}$	0.026	0.031	0.04	0.088
$C_{17:1}$	0.013	0.016	0.03	0.06
$C_{18:0}$	2.31	2.49	4.02	4.80
$C_{18:1}$	11.43	11.56	16.48	22.24
$C_{18:2\ Trans}$	ND	ND	ND	ND
$C_{18:2}$ (ω-6)	78.46	77.93	71.47	54.17
$C_{18:3}$ (ω-3)	0.083	0.039	0.26	6.37
$C_{20:0}$	0.34	0.33	0.32	0.36
$C_{20:1}$	0.215	0.17	0.166	0.15
$C_{22:0}$	0.25	0.24	0.711	0.44
ΣSFA	9.602	10.091	11.502	15.928
ΣUSFA	90.281	89.805	88.496	83.09
ΣMUFA	11.738	11.836	16.766	22.55
ΣPUFA	78.543	77.969	71.73	60.54
ΣUSFA/ΣSFA	9.402	8.9	7.694	5.217

ND: non detectable – SBO: soybean oil – SFO: sunflower oil – SSO: safflower oil

World Health Organization (CODEX STAN 210-1999, 2019).

Refractive index is related to unsaturated fatty acids; a higher refractive index corresponds to more unsaturated fatty acids. Peroxide value (peroxides and hydroperoxides), acidity (measure of rancidity with formation of free fatty acids), and saponification value (measure of molecular weight of triacylglycerols and free fatty acids) are related to the quality of an edible oil. Tocopherols inhibit the oxidation of polyunsaturated fatty acids by reducing free radical reactions to improve oil stability (Hou et al., 2024). As it will be shown in Table 4, the order of increasing unsaturated fatty acids coincides with the order of increasing refractive index (SSO-Giza1 > SSO – Kharga1 > SFO > SBO). From Table 3, the specific gravity recorded for all oils is similar with negligible differences. There are significant differences among the color measurements, UV-K_{232}/K_{270}, the peroxide value, the

Table 5. Lipid nutritional indices of SSO, SFO, and SBO

№	Lipid nutritional indices	SSO Giza1	SSO Kharga1	SFO Giza120	SBO (RBD)
1	PUFA/SFA	8.18	7.73	6.24	3.8
2	ω-6/ω-3 ($C_{18:2}$/ $C_{18:3}$)	945.3	1998.2	274.9	8.5
3	Atherogenicity Index (AI)	0.077	0.081	0.075	0.126
4	Thrombogenicity Index (TI)	0.198	0.211	0.232	0.261
5	Hypo cholesterol /hyper cholesterol (HH)	13.477	12.789	13.759	8.084
6	Health-promoting index (HPI)	12.964	12.302	13.421	7.951
7	Unsaturation index (UI)	168.907	167.813	160.486	150
8	Iodine value (IV calculated)	129.65	128.83	130.96	115.08
9	Peroxidability index (PI)	78.92	78.34	72.67	73.84
10	Allylic Position equivalent (APE)	179.946	179.058	176.42	165.56
11	Bis-Allylic position equivalent (BAPE)	78.626	78.008	71.99	66.91
12	Oxidative Stability Index (OSI)	0.37183	0.39964	0.67045	0.89905
13	Oxidizability value (COX)	8.2136	8.1508	7.5824	7.1778

SBO: soybean oil – SFO: sunflower oil – SSO: safflower oil oxidative stability as induction period (hrs.), the total polar compounds (TPC), and the α-tocopherol content of the studied oils. All recorded values for the various tests were within the range specified by the Codex standard for Named Vegetable Oils (CODEX STAN 210 – 1999, 2019). Furthermore, the obtained values were consistent with those reported by other researchers for soybean and sunflower oils (Almoselhy et al., 2020; Almoselhy et al., 2021, Ayouaz et al., 2022), and safflower oil (Ghiasy-Oskoee & AghaAlikhani, 2023; Song et al., 2023; Stojanović et al., 2023).

3.3 Fatty acid composition of SSO, SFO, and SBO

The fatty acid compositions as very important indices to evaluate the nutritional values of the edible oils under study are tabulated in Table 4, and there were significant differences among the fatty acid profiles of the four kinds of oils, from which there were two varieties of safflower (Giza1-Kharga1) with sunflower (Giza120) seeds with their oils extracted by cold pressing, and the soybean oil was refined, bleached, and deodorized (RBD) oil.

3.4 Lipid nutritional indices of SSO, SFO, and SBO

Lipid nutritional indices are calculated from the fatty acid composition of the oils under investigation for the possible assessment of health-related benefits of oils as shown in Table 5.

The main fatty acids in all oils with their ranges were palmitic ($C_{16:0}$) 6.35 – 10.17%; stearic ($C_{18:0}$) 2.31 – 4.80%; oleic ($C_{18:1}$) 11.43 – 22.24%; linoleic or ω-6 ($C_{18:2}$) 54.17 – 78.46%; linolenic or ω-3 ($C_{18:3}$) 0.039 – 6.37%. Saturated fatty acids (SFA) ranged 9.602 – 15.928%; unsaturated fatty acids (USFA) ranged 83.09 – 90.281%; monounsaturated fatty acids (MUFA) ranged 11.738 – 22.55%; polyunsaturated fatty acids (PUFA) ranged 60.54 – 78.543%; and the ratio USFA/SFA ranged 5.127 – 9.402.

It is well-observed the high similarity in fatty acid composition between safflower and sunflower oils, with higher oleic acid ($C_{18:1}$) in sunflower oil and higher linoleic acid ($C_{18:2}$) in safflower oils. The fatty acid profile was consistent with the Codex standard (CODEX STAN 210 – 1999, 2019) and comparable to values reported in the literature for soybean and sunflower oils (Almoselhy et al., 2020; Almoselhy et al., 2021, Ayouaz et al., 2022), and safflower oil (Ghiasy-Oskoee & AghaAlikhani, 2023; Song et al., 2023; Stojanović et al., 2023).

Considering the important ratio between polyunsaturated fatty acids and saturated fatty acids, or_PUFA/SFA, it was ranged 3.8 – 8.18, with the highest values assigned for SSO, followed by SFO, then SBO, and it is considered an important index generally used to evaluate the effect of diet on the cardiovascular health (CVH), the higher PUFA/SFA, the healthier the effect on CVH besides the important ratio of ω-6/ω-3, or $C_{18:2}/C_{18:3}$, which was ranged 8.5 – 1998.2 for the edible oils under investigation, with the highest values for SSO, followed by SFO, then SBO with the lowest value.

The atherogenicity index, or AI, of the oils under investigation ranged from 0.075 – 0.126, which is considered an excellent value for a safe fatty acid profile, as AI demonstrates the relationship between SFA (which are considered proatherogenic, increasing cholesterol in blood with deposition on walls of arteries) and USFA (as an antiatherogenic agent). The lower the AI value, the healthier the edible oil, with the best minimum value assigned for SFO, followed by SSO, and SBO, with slight differences between SFO and SSO owing to the high similarity in fatty acid profile of the two oils.

The thrombogenicity index, or TI, of the studied oils ranged from 0.198 – 0.261, which is considered another excellent parameter confirming the healthy profile of fatty acids in the edible oils under examination, as TI exhibits the thrombogenic effect of fatty acids, with affinity to form accumulations or clots in blood vessels, with the best minimum value assigned for SSO, followed by SFO, and SBO.

It is noteworthy to mention that both AI and TI can be employed to evaluate the possible effects of fatty acid composition on CVH, where the fatty acid composition with lower values of AI and TI presents favorable nutritional quality, and its consumption can reduce the risk of coronary heart disease (CHD).

The hypocholesterolemic/hypercholesterolemic or HH index ranged from 8.084 – 13.759, which is an indicator of a healthy fatty acid profile, as the higher ratio demonstrates the relationship between the hypocholesterolemic fatty acid (*cis*-$C_{18:1}$ and PUFA) and the hypercholesterolemic fatty acids to evaluate the effect of the fatty acid composition on cholesterol. The evaluated HH index for all edible oils under study was higher than 1.0, suggesting the positive effect on CVDs (Stoyanova & Romova, 2024), with the highest values assigned for SFO, followed by SSO with small differences, and then SBO had the last order.

Considering the health-promoting index, or HPI, it was ranged from 7.951 to 13.421, and it is simply the inverse of the AI with the same indication to ensure the safety of these consumed edible oils for health. Overall, the abovementioned indices (AI, TI, HH) are well-known calculated indices from the fatty acid composition to be used in the evaluation of the

Table 6. Monitoring changes in FFA, PV, and TPC of SSO blends with SBO during frying

Parameter	Frying oil blend SSO+SBO	Frying hours					
		1	2	3	4	5	6
FFA%	**SSO (Pure 100%)**	0.39	0.47	0.50	0.58	0.63	0.78
	SSO: SBO (20:80)	0.32	0.35	0.40	0.45	0.53	0.57
	SSO: SBO (40:60)	0.34	0.40	0.43	0.48	0.55	0.59
	SSO: SBO (60:40)	0.35	0.42	0.45	0.52	0.58	0.62
	SSO: SBO (80:20)	0.37	0.45	0.47	0.55	0.60	0.64
	SSO: SBO (50:50)	0.30	0.35	0.38	0.42	0.50	0.55
PV	**SSO (Pure 100%)**	17.9	26.0	13.9	12.8	12.9	10.8
	SSO: SBO (20:80)	16.7	24.7	11.5	12.6	11.6	9.5
	SSO: SBO (40:60)	16.9	24.9	11.7	12.9	11.9	9.7
	SSO: SBO (60:40)	17.3	25.3	12.2	13.2	12.3	10.1
	SSO: SBO (80:20)	17.6	25.6	12.5	13.6	12.6	10.4
	SSO: SBO (50:50)	15.7	23.3	10.2	11.1	10.3	8.1
TPC	**SSO (Pure 100%)**	11.4	14.7	16.9	18.3	20.0	22.6
	SSO: SBO (20:80)	9.9	12.0	13.6	14.8	15.8	17.3
	SSO: SBO (40:60)	10.3	12.7	14.5	15.7	16.8	18.7
	SSO: SBO (60:40)	10.6	13.4	15.3	16.5	17.9	19.9
	SSO: SBO (80:20)	11.0	14.0	16.0	17.6	19.0	21.3
	SSO: SBO (50:50)	9.5	11.3	12.8	13.9	14.7	15.9

FFA: free fatty acids – PV: peroxide value – SBO: soybean oil – SSO: safflower oil – TPC: total polar compounds

Table 7. Monitoring changes in FFA, PV, and TPC of SFO blends with SBO during frying

Parameter	Frying oil blend SFO+SBO	Frying hours					
		1	2	3	4	5	6
FFA%	**SFO (Pure 100%)**	0.52	0.59	0.68	0.75	0.81	0.87
	SFO: SBO (20:80)	0.33	0.36	0.41	0.45	0.51	0.55
	SFO: SBO (40:60)	0.43	0.47	0.50	0.55	0.60	0.64
	SFO: SBO (60:40)	0.53	0.59	0.62	0.67	0.70	0.74
	SFO: SBO (80:20)	0.62	0.69	0.72	0.76	0.80	0.83
	SFO: SBO (50:50)	0.44	0.49	0.55	0.61	0.65	0.68
PV	**SFO (Pure 100%)**	12.88	18.95	24.51	12.70	12.06	11.75
	SFO: SBO (20:80)	12.52	18.61	24.18	12.32	11.67	11.37
	SFO: SBO (40:60)	12.59	18.66	24.22	12.42	11.76	11.46
	SFO: SBO (60:40)	12.70	18.75	24.31	12.50	11.87	11.57
	SFO: SBO (80:20)	12.78	18.88	24.43	12.60	11.96	11.65
	SFO: SBO (50:50)	12.64	18.74	24.27	12.47	11.82	11.51
TPC	**SFO (Pure 100%)**	15.40	17.60	19.10	20.80	21.50	23.90
	SFO: SBO (20:80)	14.00	16.30	17.80	19.60	20.30	22.80
	SFO: SBO (40:60)	14.30	16.50	18.00	19.80	20.50	23.00
	SFO: SBO (60:40)	14.90	17.10	18.70	20.40	21.10	23.60
	SFO: SBO (80:20)	15.10	17.40	18.90	20.70	21.40	23.90
	SFO: SBO (50:50)	14.60	16.80	18.30	20.10	20.90	23.30

FFA: free fatty acids – PV: peroxide value – SBO: soybean oil – SFO: sunflower oil, TPC: total polar compounds

potential effects of fatty acids on cardiovascular diseases (Chen & Liu, 2020).

The unsaturation index (UI) for the edible oils under investigation ranged from 150 to 168.907, with the highest value for SSO, followed by SFO, and SBO in the last order of decreasing unsaturation. This is the same order of USFA, which was highest in SSO, followed by SFO, and SBO when calculating USFA directly from the fatty acid composition analysis without the sophisticated mathematical equations of UI, which resulted in a similar trend as in the calculation of USFA.

The iodine value (IV) ranged from 115.08 to 130.96, with the highest value for SFO followed by SSO, then SBO, which is greatly similar to the trend of the unsaturation index (UI), and the USFA percent with slight differences emerged from the variation in the source and variety of SFO, which made it preceding SSO in IV despite the superiority of SSO with higher USFA.

Peroxidability index (PI) evaluation based on fatty acid composition was found to range between 72.67 and 78.92 which is considered a good indicator for the good stability of oils under study according to the review of literature mentioning the measured values from 7.10 (olive oils) to 111.87 (perilla oils), where malondialdehyde (MDA), as the secondary product in the lipid oxidation process, was produced more in oils with higher PI without induced oxidative stress (Yun & Surh, 2012).

The rate of oxidation of fatty constituents depends on the double bond number and their relative positions per mole, as demonstrated by Stoyanova & Romova (2024), considering the allylic position equivalent, or APE (-H_2C=CH-CH_2-), and the bis-allylic position equivalent, or BAPE (R-CH=CH-CH_2-CH=CH-R). The APE value for the oils under study ranged from 165.56 to 179.946 and the BAPE value ranged from 66.91 to 78.626, which are expected due to their high-unsaturated composition. The higher the results for these two indices are, the higher the susceptibility of the oil to oxidation. The unsaturation index (UI), with its range ranging from 150 to 168.907, matches the PI, APE, and BAPE in the same tendencies.

Oxidation Stability Index (OSI) can be used to predict the oil shelf life (Pinto et al., 2021). Oxidizability value (COX) calculated according to the formula mentioned by Fatemi & Hammond (1980) of the studied oils ranged 7.1778 – 8.2136. The OSI of the studied oil ranged from 0.37183 to 0.89905, which was found to be inversely correlated to the APE, BAPE, and COX values. The recorded values were in good agreement when compared with measurements performed by different authors for safflower oils (Longoria-Sanchez *et al.*, 2019).

3.5 Monitoring changes in FFA, PV, and TPC of oil blends during frying procedure

The effect of the deep-frying procedure on the quality of oil blends was studied by performing two frying schemes with different ratios of two oils to be carried out for safflowers with soybean oils and soybean with sunflower oils, in order to reach the best blends for deep frying through the exact monitoring of free fatty acid, peroxide value, and total polar compounds.

During the deep frying procedure, the oil comes into contact with air, moisture, and foodstuffs at a high temperature (180°C), where several changes occur, including oxidation, hydrolysis, polymerization, and thermal degradation for the oil through deteriorative reactions with the formation of multiple hazardous volatile and non-volatile components, which significantly reduce the nutritional value of the oil (Aşkın & Kaya, 2020; Kittipongpittaya et al., 2020). Peroxide levels (PV) were found to peak during frying and then fall at the end of the frying procedure. Oxidation is more likely to occur in linoleic acids. TPC measures directly the level of the degraded components in an oil. The maximum value of TPC for commercial frying oils is accepted as 24% in several European countries.

3.6 Monitoring changes in FFA, PV, and TPC of SSO blends with SBO during frying

For SSO blends with SBO, during the repeated frying, the deterioration of the frying oil blend was detected after 2 hours, as indicated by the increase in peroxide values, which exceeded the permitted range stipulated by the Codex standard for named vegetable oils (CODEX STAN 210 – 1999, 2019). Whereas, for SFO blends with SBO, during the repeated frying, the deterioration of the frying oil blend was detected after 3 hours, as indicated by the increase in peroxide values, which exceeded the permitted range stipulated by the Codex standard for named vegetable oils (CODEX STAN 210 – 1999, 2019). Therefore, it is recommended to avoid the repeated usage of these frying oil blends in deep frying processes after the end of the determined period of their validity for human consumption to avoid the health risks resulting from consumption of the deteriorated used oil. Also, it is noteworthy to mention that the cold-pressed safflower oil is characterized by superior quality and safety, as it does not involve additional refining, bleaching, and deodorizing (RBD) processes as numerous vegetable and seed oils (Almoselhy et al., 2020), as the refining processes at high temperatures are possibly accompanied by hazardous processing contaminants such as 3-MCPD (Almoselhy et al., 2021).

4 Novelty impact statement

The novelty of the current research can be summarized as a new approach to studying in-depth the physicochemical characteristics of safflower oil to validate its potential for expansion in production in Egypt. The significance of this study appears mainly in the sustainable economic utilization of safflower as a non-traditional oilseed crop capable of growing under high temperatures, drought, salinity, and marginal environments in order to bridge the edible oil gap accompanied by negative impacts of climate change on the agroecological settings for common oilseed crop productivity. A new innovative achievement is the detailed presentation of the lipid nutritional indices for the first time in this original research paper to reveal the great health benefits of safflower seed oil on a scientific basis, applying the evidence-based approach using all available information and mathematical equations to calculate the lipid nutritional indices from the fatty acids' composition. Therefore, this work should be of special value to researchers requiring up-to-date information on safflower seed oil, including physicochemical characteristics with lipid nutritional indices, in an informative and concise way.

5 Conclusions

Safflower seed oil, a sustainable and economically viable non-traditional edible oil, offer promise as a solution to the growing global demand for edible oil, particularly in regions affected by climate change. Its resilience to adverse conditions such as high temperatures, drought, salinity, and marginal environments makes it a valuable crop that needs to be expanded in cultivation in Egypt to help in bridging the edible oil gap. Safflower seed oil exhibits physicochemical characteristics and fatty acid profiles are comparable to sunflower oil, with slight variations. The most innovative are the lipid nutritional indices calculated from the fatty acid composition of safflower seed oil, signifying its medicinal benefits. Being a novel non-traditional edible oil of plant origin rich in ω-6 fatty acids with optimum atherogenicity indices (AI), thrombogenicity (TI), and hypocholesterolemic / hypercholesterolemic (HH) with the health-promoting index (HPI). Furthermore, its high α-tocopherol content contributes to its potent antioxidant properties. Given its nutritional profile and potential health benefits, safflower oil presents a promising opportunity to diversify the Egyptian edible oil market and enhance food security.

6 Recommendations for expansion in production of safflower oil

It is highly recommended that the expansion of safflower seed oil production be supported through various initiatives, including providing technical support and incentives to farmers to encourage safflower cultivation. Additionally, highlighting the economic and health benefits of safflower oil can further stimulate its adoption. A collaborative approach involving farmers, stakeholders, experts, industry leaders, policymakers, regulatory bodies, production companies, and scientific research institutions is essential to facilitate the successful cultivation of safflower and production of safflower oil in Egypt.

7 Future directions and challenges in harnessing the medicinal potential of safflower

7.1 Future directions

7.1.1 Clinical trials and standardization

To fully realize the therapeutic potential of safflowers, comprehensive clinical trials are necessary. Standardizing dosage regimens and administration protocols will be crucial to evaluate the efficacy and safety of safflower-based treatments across diverse patient populations.

7.1.2 Mechanistic understanding

A deeper understanding of the molecular mechanisms underlying safflower's medicinal is essential. Elucidating the precise mode of action will facilitate the development of targeted therapies for specific health conditions.

7.1.3 Formulation development

Examining innovative formulations and techniques of administration, such as liposomes, nanoparticles, and nano emulsions, can significantly enhance the stability and bioavailability of bioactive compounds derived from safflower, thereby optimizing their therapeutic efficacy.

7.1.4 Drug interactions and safety profile

Thorough investigations into potential drug interactions and long-term safety profiles are essential to ensure the safe and effective integration of safflower into traditional medicine.

7.2 Challenges

7.2.1 Regulatory variations

The varying regulatory statuses of safflower across different countries and regions pose a significant challenge. While some countries recognize safflower as a traditional medicine or pharmaceutical ingredient, may impose restrictions due to safety and efficacy concerns.

7.2.2 Quality control and standardization

The absence of standardized operating procedures for safflower cultivation, harvesting, and extraction presents a major obstacle to maintaining consistent quality and potency in safflower-based products.

7.2.3 Complex authentication and analytical techniques

The authentication procedures of safflower products can be challenging and costly, often requiring sophisticated analytical techniques such as GC, HPLC, and spectrometry.

Developing simpler, more affordable, and accessible authentication methods is essential for widespread adoption.

7.2.4 Geographical variation

The geographical origin of safflower cultivars significantly influences the characteristics of the final product. Developing consistent and trustworthy authentication techniques is hampered by the need to comprehend and account for this geographic heterogeneity.

7.2.5 Bioavailability issues

The therapeutic efficacy of safflower is often limited by the low bioavailability of its bioactive components. Innovative approaches to enhance the absorption and systemic delivery of these compounds are necessary to optimize their therapeutic potential.

7.2.6 Regulatory hurdles

Prior to commercialization, the establishment of robust regulatory frameworks and standards is essential to ensure the quality, safety, and efficacy of safflower-based products.

7.2.7 Global market dynamics

Navigating the global market presents significant challenges, as it requires compliance with international standards while simultaneously meeting diverse consumer demands. Striking a balance between traditional practices and modern market expectations is crucial to fully realizing safflower's potential.

7.2.8 Global awareness and accessibility

Increasing public awareness of safflowers' potential health benefits and ensuring its accessibility, particularly in resource-limited regions, remain major challenges.

7.2.9 Educational awareness

Educating consumers, producers, and healthcare professionals about the changing role of safflower from a traditional treatment to a pharmaceutical preparation, is crucial. Bridging the information gap is essential to ensure acceptance and informed decision-making.

7.2.10 Integration into pharmacopeia

Integrating safflower into pharmacopeias requires the establishment of precise administration guidelines, consistent dosages, and adherence to pharmacological standards. Overcoming these obstacles is essential for the approval and widespread use of safflower-based pharmaceutical products.

7.2.11 Maintaining therapeutic integrity

Preserving the medicinal value of safflower-based pharmaceutical formulations while ensuring standardization is a significant challenge. Balancing standardization with the inherent diversity of safflower's bioactive compounds is crucial to maintain its therapeutic efficacy.

Source of funding: None.

Acknowledgments: None.

Previous submissions: This study has not previously been submitted to another journal for publication.

Authors' Contribution: W.S.A. Conceptualization, Methodology, Resources, Investigation, Formal Analysis, Writing - review & editing; R.I.M.A. Conceptualization, Methodology, Investigation, Formal Analysis, Data Curation, Writing - original draft, Visualization; S.M.M.A. Conceptualization, Methodology, Investigation, Formal Analysis, Writing - review & editing.

Conflicts of Interest: The authors declare no conflict of interest.

Preprint deposit: Authors shared this manuscript as a preprint deposit:

- At SSRN: https://dx.doi.org/10.2139/ssrn.4968250

- At Research Square https://doi.org/10.21203/rs.3.rs-5159596/v1

References

Almeida, O.P., de Freitas Marques, M.B., de Oliveira, J.P., da Costa, J.M.G., Rodrigues, A.P. *et al.* (2022). Encapsulation of safflower oil in nanostructured lipid carriers for food application. *Journal of Food Science and Technology*, *59*(2):805-814. https://doi.org/10.1007/s13197-021-05078-5 [Crossref] [Google Scholar] [PubMed] [Publisher]

Almoselhy, R.I.M., Eid, M.M., Abd El-Baset, W.S. & Aboelhassan, A.F.A. (2021). Determination of 3-MCPD in Some Edible Oils using GC-MS/MS. *Egyptian Journal of Chemistry*, *64*(3):1639-1652. https://doi.org/10.21608/ejchem.2021.64084.3373 [Crossref] [Google Scholar] [Publisher]

Almoselhy, R.I.M., Eid, M.M., Abd El-Mageed, S.M.M. & Youness, R.A. (2020). Using Nanotechnology in Bleaching Vegetable Oils. *Egyptian Journal of Chemistry*, *63*(7):2699-2706. https://doi.org/10.21608/ejchem.2020.23625.2407 [Crossref] [Google Scholar] [Publisher]

Aşkın, B. & Kaya, Y. (2020). Effect of deep-frying process on the quality of the refined oleic/linoleic sunflower seed oil and olive oil. *Journal of Food Science and Technology*, *57*(12):4716-4725. https://doi.org/10.1007/s13197-020-04655-4 [Crossref] [Google Scholar] [PubMed] [Publisher]

Ayouaz, S., Bensadia, D., Hamitri-Guerfi, F., Muhammad, D. R. A., Mouhoubi, K., Arab, R., Rahmani, Y., Guemouni, S., Hadjal, S., & Madani, K. (2022). Impact of incorporating sesame oil (*Sesamum indicum* L.) in an Algerian frying oil and margarine formulation. *The North African Journal of Food and*

Nutrition Research, 6(14):165–177. https://doi.org/10.51745/najfnr.6.14.165-177 [Crossref] [Google Scholar] [Publisher]

Badem, Ş. & Baştürk, A. (2023). Oxidative stability and characterization of oleogels obtained from safflower oil-based beeswax and rice bran wax and their effect on the quality of cake samples. *Journal of the American Oil Chemists' Society*, *100*(8):635–649. https://doi.org/10.1002/aocs.12694 [Crossref] [Google Scholar] [Publisher]

Benmeziane, F., Araba, K. & Belahcene, A. (2024). Impact of deep-frying process on the physicochemical characteristics of two edible vegetable oils marketed in Algeria. *The North African Journal of Food and Nutrition Research*, *8*(17):21 – 31. https://doi.org/10.51745/najfnr.8.17.21-31 [Crossref] [Google Scholar] [Publisher]

Botella-Martínez, C., Pérez-Álvarez, J.Á., Sayas-Barberá, E., Navarro Rodríguez de Vera, C., Fernández-López, J. *et al.* (2023). Healthier Oils: A new scope in the development of functional meat and dairy products: A review. *Biomolecules*, *13*(5):778. https://doi.org/10.3390/biom13050778 [Crossref] [Google Scholar] [PubMed] [Publisher]

Chen, J. & Liu, H. (2020). Nutritional indices for assessing fatty acids: A mini-review. *International Journal of Molecular Sciences*, *21*(16):5695. https://doi.org/10.3390/ijms21165695 [Crossref] [Google Scholar] [PubMed] [Publisher]

Cheng, H., Yang, C., Ge, P., Liu, Y., Zafar, M.M. *et al.* (2024). Genetic diversity, clinical uses, and phytochemical and pharmacological properties of safflower (*Carthamus tinctorius* L.): an important medicinal plant *Front. Pharmacol.*, *Sec. Ethnopharmacology*, *15* – 2024. https://doi.org/10.3389/fphar.2024.1374680 [Crossref] [Google Scholar] [PubMed] [Publisher]

Deliorman Orhan, D., Pekacar, S., Ulutaş, O.K., Özüpek, B., Sümmeoğlu, D. *et al.* (2022). Assessment of commercially safflower oils (Carthami Oleum raffinatum) in terms of European Pharmacopoeia Criteria and their weight control potentials. *Turkish Journal of Pharmaceutical Sciences*, *19*(3), 273–279. https://doi.org/10.4274/tjps.galenos.2021.84484 [Crossref] [Google Scholar] [PubMed] [Publisher]

Fatemi, S.H. & Hammond, E.G. (1980), Analysis of oleate, linoleate and linolenate hydroperoxides in oxidized ester mixtures. *Lipids*, *15*:379-385. https://doi.org/10.1007/BF02533555 [Crossref] [Google Scholar] [Publisher]

Ghiasy-Oskoee, M. & AghaAlikhani, M. (2023). Towards utilizing Asteraceae alternative oilseed species on marginal lands: Agronomic performance, fatty acid composition, oil biocompounds, and oil physicochemical properties of Asteraceae species. *Journal of Agriculture and Food Research*, *14*, 100799, https://doi.org/10.1016/j.jafr.2023.100799 [Crossref] [Google Scholar] [Publisher]

Han, L., Chen, M., Li, Y., Wu, S., Zhang, L., Tu, K., Pan, L., Wu, J., & Song, L. (2022). Discrimination of different oil types and adulterated safflower seed oil based on electronic nose combined with gas chromatography-ion mobility spectrometry. *Journal of Food Composition and Analysis: An Official Publication of the United Nations University, International Network of Food Data Systems*, *114*(104804), 104804. https://doi.org/10.1016/j.jfca.2022.104804 [Crossref] [Google Scholar] [Publisher]

Hou, N.-C., Gao, H.-H., Qiu, Z.-J., Deng, Y.-H., Zhang, Y.-T., Yang, Z.-C., Gu, L.-B., Liu, H.-M., Zhu, X.-L., Qin, Z., & Wang, X.-D. (2024). Quality and active constituents of safflower seed oil: A comparison of cold pressing, hot pressing, Soxhlet extraction and subcritical fluid extraction. *Lebensmittel-Wissenschaft Und Technologie [Food Science and Technology]*, *200*(116184), 116184. https://doi.org/10.1016/j.lwt.2024.116184 [Crossref] [Google Scholar] [Publisher]

Iskakov, B., Kakimov, M., Kudelski, R., Mursalykova, M., Kassenov, A., Satayeva, Z., Kardenov, S., Kalibekkyzy, Z., Mustafayeva, A., Igenbayev, A., & Bembenek, M. (2023). Improving the technology of primary purification of the safflower oil using secondary products of processing on a biological basis. *Foods (Basel, Switzerland)*, *12*(17). https://doi.org/10.3390/foods12173275 [Crossref] [Google Scholar] [PubMed] [Publisher]

Jeong, E. H., Yang, H., Kim, J.-E., & Lee, K. W. (2020). Safflower seed oil and its active compound acacetin inhibit UVB-induced skin photoaging. *Journal of Microbiology and Biotechnology*, *30*(10), 1567–1573. https://doi.org/10.4014/jmb.2003.03064 [Crossref] [Google Scholar] [PubMed] [Publisher]

Kang, Z.L., Xie, J.J., Hu, Z.L., Li, Y.P. & Ma, H.J. (2023). Effect of safflower oil and magnetic field-modified soy 11S globulin on rheological and emulsifying properties of oil-in-water emulsions. *Food Hydrocolloids*, *142*, 108775, https://doi.org/10.1016/j.foodhyd.2023.108775 [Crossref] [Google Scholar] [Publisher]

Khan, A., Nadeem, M., Ullah, R., Gulzar, N., Al-Asmari, F., Imran, M., Rahim, M. A., Zongo, E., Hussain, I., Tayyab, M., & Almalki, R. S. (2024). Fatty acid composition, phenolic compounds, phytosterols, and lipid oxidation of single- and double-fractionated olein of safflower oil produced by low-temperature crystallization. *ACS Omega*, *9*(6), 6787–6796. https://doi.org/10.1021/acsomega.3c08099 [Crossref] [Google Scholar] [PubMed] [Publisher]

Khémiri, I., Essghaier, B., Sadfi-Zouaoui, N., & Bitri, L. (2020). Antioxidant and antimicrobial potentials of seed oil from Carthamus tinctorius L. in the management of skin injuries. *Oxidative Medicine and Cellular Longevity*, *2020*, 4103418. https://doi.org/10.1155/2020/4103418 [Crossref] [Google Scholar] [PubMed] [Publisher]

Kittipongpittaya, K., Panya, A., Prasomsri, T., & Sueaphet, P. (2020). Tropical oil blending and their effects on nutritional content and physicochemical properties during deep fat frying. *Journal of Nutritional Science and Vitaminology*, *66*(Supplement), S206–S214. https://doi.org/10.3177/jnsv.66.s206 [Crossref] [Google Scholar] [PubMed] [Publisher]

Kyriakidis, N. B., & Katsiloulis, T. (2000). Calculation of iodine value from measurements of fatty acid methyl esters of some oils: Comparison with the relevant American Oil Chemists Society method. *Journal of the American Oil Chemists' Society*, *77*(12), 1235–1238. https://doi.org/10.1007/s11746-000-0193-3 [Crossref] [Google Scholar] [Publisher]

Longoria-Sanchez, A., Morales, M. V., Oomah, B. D., Ochoa-Espinoza, X. M., Góngora-Gómez, A. M., & Espinosa-Alonso, L. G. (2019). Characteristics and Antioxidant Properties of Cold Pressed High Oleic and Linoleic Oils from Mexican Safflower Varieties. *Emirates Journal of Food and Agriculture*, *31*(9):679-687. https://doi:10.9755/ejfa.2019.v31.i9.1999 [Crossref] [Google Scholar] [Publisher]

Mursalykova, M., Kakimov, M., Kassenov, A., Iskakov, B., Sergibayeva, Z., Kaspakov, E., Zhumadilova, G., Shulenova, A., Kokayeva, G., & Suychinov, A. (2023). Mathematical modeling of screw press configuration for processing safflower oil. *Applied Sciences (Basel, Switzerland)*, *13*(5), 3057. https://doi.org/10.3390/app13053057 [Crossref] [Google Scholar] [Publisher]

Pinto, T. I., Coelho, J. A., Pires, B. I., Neng, N. R., Nogueira, J. M., Bordado, J. C., & Sardinha, J. P. (2021). Supercritical carbon dioxide extraction, antioxidant activity, and fatty acid composition of bran oil from rice varieties cultivated in Portugal. *Separations*, *8*(8), 115. https://doi.org/10.3390/separations8080115 [Crossref] [Google Scholar] [Publisher]

Potdar, S., Bagale, U., Potoroko, I., Hakke, V. S., Maralla, Y., Sivakumar, M., & Sonawane, S. (2022). Sonochemical approach for the synthesis of safflower oil based low fat emulsion: Effect of ultrasonic parameters. *Materials Today: Proceedings*, *57*, 1619–1625. https://doi.org/10.1016/j.matpr.2021.12.232 [Crossref] [Google Scholar] [Publisher]

Ruyvaran, M., Zamani, A., Mohamadian, A., Zarshenas, M. M., Eftekhari, M. H., Pourahmad, S., Abarghooei, E. F., Akbari, A., & Nimrouzi, M. (2022). Safflower (Carthamus tinctorius L.) oil could improve abdominal obesity, blood pressure, and insulin resistance in patients with metabolic syndrome: A randomized, double-blind, placebo-controlled clinical trial. *Journal of Ethnopharmacology*, *282*(114590), 114590. https://doi.org/10.1016/j.jep.2021.114590 [Crossref] [Google Scholar] [PubMed] [Publisher]

Shahid, M., Jaradat, A. & Rao, N.K. (2020). Safflower: A Multipurpose Crop for the Marginal Lands. In: Hirich, A., Choukr-Allah, R., Ragab, R. (eds) Emerging Research in Alternative Crops. *Environment & Policy*, 58. Springer, Cham., Switzerland, 58, 279-294. https://doi.org/10.1007/978-3-319-90472-6_12 [Crossref] [Google Scholar] [Publisher]

Song, L., Geng, S. & Liu, B (2023). Characterization of Wei Safflower Seed Oil Using Cold-Pressing and Solvent Extraction. *Foods*, *12*(17):3228. https://doi.org/10.3390%2Ffoods12173228 [Crossref] [Google Scholar] [PubMed] [Publisher]

Stojanović, Z. S., Uletilović, D. D., Kravić, S. Ž., Kevrešan, Ž. S., Grahovac, N. L., Lončarević, I. S., Đurović, A. D., & Marjanović Jeromela, A. M. (2023). Comparative Study of the Nutritional and Chemical Composition of New Oil Rape, Safflower and Mustard Seed Varieties Developed and Grown in Serbia. *Plants*, *12*(11):2160. https://doi.org/10.3390/plants12112160 [Crossref] [Google Scholar] [PubMed] [Publisher]

Stoyanova, L.S., & Romova, M.Y.A. (2024). Bioactive Compounds and Nutritive Composition of Waste Seeds from *Nicotiana tobacum* L. (Solanaceae). *Current Research in Nutrition and Food Science, 12*(1):374-383. http://dx.doi.org/10.12944/CRNFSJ.12.1.30 [Crossref] [Google Scholar] [Publisher]

Wang, R., Wang, D., Yu, J., Wang, T., Yu, D., & Elfalleh, W. (2024). Conjugated safflower seed oil and its oleogels stabilization properties: Thermodynamic properties, rheology, oxidative stability. *Food Bioscience*, *59*(104203), 104203. https://doi.org/10.1016/j.fbio.2024.104203 [Crossref] [Google Scholar] [Publisher]

Wong, M. L., Timms, R. E., & Goh, E. M. (1988). Colorimetric determination of total tocopherols in palm oil, olein and stearin. *Journal of the American Oil Chemists' Society*, *65*(2), 258. https://doi.org/10.1007/BF02636412 [Crossref] [Google Scholar] [Publisher]

Yun, J.-M., & Surh, J. (2012). Fatty acid composition as a predictor for the oxidation stability of Korean vegetable oils with or without induced oxidative stress. *Preventive Nutrition and Food Science*, *17*(2), 158–165. https://doi.org/10.3746/pnf.2012.17.2.158 [Crossref] [Google Scholar] [PubMed] [Publisher]

Zou, Z., Wang, Q., Li, M., Zhen, J., Yuan, D., Zhang, Q., Cui, Q., Li, M., Zhou, M., Yin, S., & Xu, L. (2024). Combination of gas chromatography-mass spectrometry and hyperspectral imaging for identification of adulterated Safflower seed oil. *Journal of Food Composition and Analysis: An Official Publication of the United Nations University, International Network of Food Data Systems*, *135*(106593), 106593. https://doi.org/10.1016/j.jfca.2024.106593 [Crossref] [Google Scholar] [Publisher]