

Research Article

Nutritional Quality, Lipid, Mineral Profiling and Antioxidant Activities of *Moringa Oleifera* Seeds from Senegal

Faye Mada² , Ait Bouzid Hasna¹ , Ahansal Chadia¹, Asdadi Ali¹ ,
Sakar El Hassan³ , Dramé Abdoulaye^{2,*} , Gharby Said¹ 

¹Polydisciplinary Faculty of Taroudant, University Ibn Zohr, Agadir, Morocco

²Faculty of Science and Technology, Cheikh Anta Diop University, Dakar, Sénégal

³Faculty of Sciences, Abdelmalek Essaadi University, Tetouan, Morocco

Abstract

Oilcakes are defined as by-products of oilseeds processing. They are usually considered as a primary source of protein in animal diets. This study aims to compare physicochemical characteristics of oils and oilcakes produced from *Moringa oleifera* seeds (MOS) in order to better understand their diverse properties. These characteristics govern their nutritional profiles, stability and functional attributes, thus impacting the sensory qualities and shelf-life of food products. The roasted seeds were subjected to a traditional pressing to produce *M. oleifera* seed oil (MOSO) and its residual oilcake (MOOC) left after extraction process. MOS, MOSO, and MOOC were subjected to analysis of mineral elements, protein content, fatty acid composition, total polyphenols, total flavonoids, condensed tannins, and antioxidant activity. Mineral profiling revealed higher levels of phosphorus, potassium, calcium, magnesium, and iron in MOOC to the MOS. The total protein content of the MOS and MOOC was respectively $7.74 \pm 0.01\%$ and $5.96 \pm 0.01\%$. For bioactive compounds, the MOS and MOOC showed a notable flavonoids content, with values respectively of 17.64 ± 0.55 mg QE/g DM and 14.86 ± 0.23 mg QE/g DM. While for total phenolic content, it was around 1.43 ± 0.06 mg GAE/g DM for the MOS and 2.65 ± 0.04 mg GAE/g DM for the MOOC. Similarly, high FRAP and DPPH activities were recorded, with values of 17.38 ± 0.88 mg AAE/g DM and 6.08 ± 3.82 mg AAE/g DM, respectively. The MOSO was characterized by high amount of monounsaturated fatty acids, such as oleic acid with a value reaching $69.56 \pm 0.1\%$ (cis). The results of this study showed that MOS and MOOC are a rich source of nutrients such as minerals, oil and fatty acids. The high content of unsaturated fatty acids, mainly oleic acid, makes the MOSO a valuable food for human consumption with a real impact on health and well-being.

Keywords

Moringa Oleifera, Press Cake, Fatty Acids, Protein, Antioxidant Activity

1. Introduction

Moringa oleifera, commonly known as the "miracle tree," is used for its important industrial, medicinal and nutritional

applications [1]. It presents a variety of biological activities due to its active components, such as anti-inflammatory,

*Corresponding author: abdoulay.drame@ucad.edu.sn (Dramé Abdoulaye)

Received: 1 August 2025; Accepted: 25 August 2025; Published: 19 September 2025



Copyright: © The Author(s), 2025. Published by Science Publishing Group. This is an **Open Access** article, distributed under the terms of the Creative Commons Attribution 4.0 License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution and reproduction in any medium, provided the original work is properly cited.

anti-oxidation, anti-diabetic, and anti-bacterial [2]. A considerable attention was devoted to this plant as “natural nutrition in the tropics” due to its rich nutritive value. It is a perennial tropical deciduous tree from the Moringaceae family, native to India and has been widely cultivated in Africa, Asia, tropical and subtropical regions of central America [3]. *M. oleifera* can improve household food security, nutrition, mitigate climate change, and participate to sustainable goals development [4, 5]. The *M. oleifera* seeds (MOS) are particularly known for their oil's richness in monounsaturated fatty acids which can serve as an essential ingredient in food products, cosmetics, and various industrial formulations [6].

For many reasons such as the excessive use of global resources and the increased demand for animal-source food, there is an increase interest in alternative nutrients sources. Among these, the by-products of oil extraction, referred to as oilcakes, are of significant interest. They can be used as livestock feed, for their proteins and also as sources of essential minerals and bioactive compounds [7]. Considering their nutritional and functional properties, the press cakes of *M. oleifera* seeds (MOOC) could be used as animal feed or for some other applications in human health and nutrition [8].

Although numerous studies have been carried on *M. oleifera*, there is a lack of a comprehensive research of the physicochemical properties of its seed oils (MOSO), seeds (MOS),

and oilcakes (MOOC). Understanding this composition is essential for optimizing the plant's potential applications across various sectors, including food, nutrition, medicine, and industry [9].

The objective of this work was to analyze the physicochemical properties of *M. oleifera* seeds (MOS), oil and oilcake (MOOC). It focuses on the investigation of mineral content, protein levels, fatty acid composition, and the presence of bioactive compounds (total polyphenols, flavonoids, and tannins) in the seeds and press cakes of *Moringa oleifera*.

2. Bibliometric Analysis

The bibliometric analysis was based on data about international publications related to *M. oleifera*, found in the Scopus database (<https://www.Scopus.com/search>) for the years from 1997 to 2024. To compile comprehensive information on various aspects of *M. oleifera*, the following search string was used:

TITLE (("Moringa oleifera*") AND ("Chemical*" OR "Oxidative Stability*" OR "Phytochemistry*" OR "Physicochemical*" OR "Biological Activity*" OR "Proximate*" OR "Biochemical*") AND ("seed*" OR "oil*" OR "cake*"))

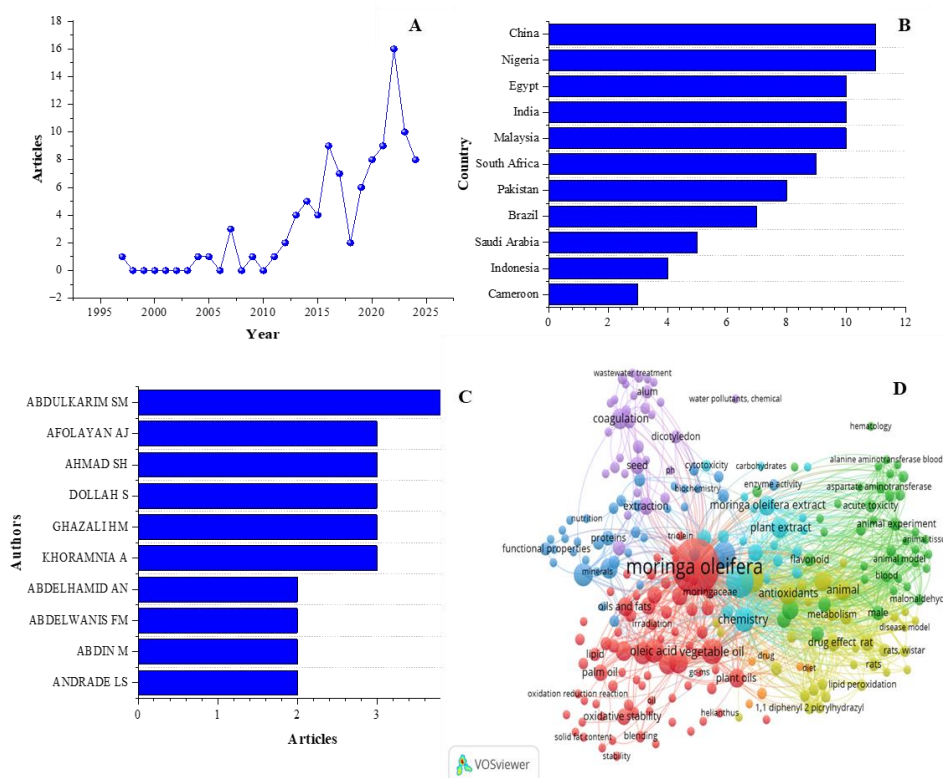


Figure 1. Bibliometric data analysis for the main subject between 1997 and 2024. A: Annual Volume of International Publications. B: Research Output by Country. C: Number of documents per author. D: Co-occurrence of keywords related to *Moringa oleifera*.

This search string targets a broad spectrum of research concerning *M. oleifera*, focusing on its chemical properties, oxidative stability, phytochemistry, physicochemical characteristics, biological activity, proximate analysis, and biochemical aspects. The search encompasses different parts of the plant, including seeds, oil, and cake, and covers literature published from 1997 to 2024, providing an in-depth view of recent advancements and research trends in the study of *M. oleifera*.

2.1. International Publication Volume

Figure 1A displays the volume of international publications from 1997 to 2024. Initially, from 1997 to 2006, publication numbers were quite low, with most years having 0 or 1 article. There was a noticeable increase starting in 2007, reaching 3 articles and rising steadily to 4 articles by 2013. The period from 2014 to 2022 experienced significant growth, culminating in a peak of 16 articles in 2022. In the recent years, 2023 and 2024, the volume remained high but showed a slight decrease, with 10 articles in 2023 and 8 articles in 2024.

2.2. Performance of Publications by Countries

The data reveals the number of publications by country (Figure 1B), showcasing varying levels of research output. China and Nigeria lead with 11 publications each, indicating significant research activity. Egypt, India, and Malaysia each have 10 publications, reflecting robust research contributions from these countries. South Africa follows with 9 publications, showing strong research engagement. Pakistan has 8 publications, demonstrating notable research productivity. Brazil contributes with 7 publications, while Saudi Arabia has 5, indicating moderate research activity. Indonesia and Cameroon show smaller contributions, with 4 and 3 publications respectively, highlighting emerging and less extensive research outputs.

2.3. Research Authorship

The Figure 1C shows the number of articles published by various authors. ABDULKARIM SM leads with 4 articles, indicating the highest level of publication among the listed authors. AFOLAYAN AJ, AHMAD SH, DOLLAH S, GHAZALI HM, and KHORAMNIA A each have 3 articles, reflecting a strong contribution to the research field. ABDELHAMID AN, ABDELWANIS FM, ABDIN M, and ANDRADE LS each have 2 articles, showing a significant but slightly lower level of output compared to the others. This distribution highlights the varying levels of research activity among the authors, with some contributing more extensively to the body of work.

2.4. Keywords Occurrences

For advanced bibliometric analysis, the "full records and cited references" were exported to VOSviewer software (version 1.6.18, 2022). This software analyzes words and terms used in publication abstracts and titles, presenting the results as a bubble map using either a term map with default settings or a density map (Figure 1D). To simplify the bubble map, only words and terms extracted from the Scopus database that appeared at least 5 times in the publications were included in the analysis. Out of 1187 keywords, 252 met the selected threshold.

The map elements were categorized into seven distinct clusters, each represented by a different color, to enhance the visualization of relationships between related terms within the same research domain. Notable keywords on the visual network map include "*Moringa oleifera*", "seeds," and "plant seed," which appear most frequently and have strong connections. These terms highlight the primary research topics addressed in the studies, reflecting their close association with various research axes.

3. Material & Methods

3.1. Protein Content (PC)

PC determination was evaluated following DUMAS method, it is based on the combustion of the matter to determine the total nitrogen using a LECO FP628 protein analyzer (LECO Corp., MI, USA) [10]. The total nitrogen content was then converted to PC using a factor of 6.25 and expressed as a percentage of sample dry matter (g/100g, DM).

3.2. Minerals Profiling

Mineral analysis was determined according to method described by [11]. 1 g of the sample powder was incinerated at 500 °C for 2 h. Then, 4 mL of 65% HNO₃ was added with 25 mL of ultrapure water. The solution was injected into a Perkin Elmer Optima 8000 DV spectrometry to quantify the concentrations of minerals zinc (Zn), iron (Fe), boron (B), manganese (Mn), copper (Cu), magnesium (Mg), calcium (Ca), sodium (Na), potassium (K) and phosphorus (P).

3.3. Extraction of Phenolic Compounds

The extraction of bioactive components followed the procedure described by [12]. The powder from each matrix was macerated in 80% methanol under stirring for 24 hours. After filtering the mixture through Whatman filter paper, the liquid obtained was stored at +4 °C until further use. The phenol, flavonoid and condensed tannin content and antioxidant activity were assessed on the extracts obtained.

3.4. Determination of Total Phenolic Content (TPC)

The content of total polyphenols was determined by the Folin-Ciocalteu reagent method following the protocol described by [13]. 0.5 mL of the diluted extract solution was mixed with 2.5 mL of Folin-Ciocalteu (1/10), then 4 mL of sodium carbonate Na_2CO_3 (7.5%) was added and the mixture was incubated at 45 °C for 30 minutes before measuring absorbance at 765 nm. Results were expressed as mg gallic acid equivalent per g of dry matter (mg GAE/g DM) from the calibration curve using gallic acid as the standard.

3.5. Determination of Total Flavonoids Content (TFC)

Total flavonoid content (TFC) was assessed by the aluminum chloride colorimetric method according to [14]. Briefly, 1 mL of the diluted extract solution was placed in a volumetric flask (10 mL) and then 4 mL of distilled water was added to each flask and 0.3 mL of 5% NaNO_2 was also added to the mixture. This was left to stand for 5 minutes before adding 0.3 mL AlCl_3 (10%). Next, 1 mL of 2M NaOH was added to the flask after 6 minutes and made up to 10 mL with distilled water. Absorbance was measured at 415 nm after the mixture had been incubated for 30 minutes. The TFC was expressed as mg quercetin equivalent per g of dry matter (mg QE/g DM) calculated from the equation of the calibration curve using quercetin as a standard.

3.6. Determination of Condensed Tannins (CT)

Vanillin method was used to determine the content of condensed tannins [15]. Briefly, 2 mL of a freshly prepared solution of vanillin in methanol (1% w/v) was added to 2 mL of sulfuric acid solution in methanol (25%, v/v). 0.5 mL of diluted sample was added. The mixture was then incubated in the dark for 15 min until a red coloration was developed. The absorbance was measured at 500 nm using a SCIOGEX SP-UV1100 UV-Vis spectrophotometer (USA, Rocky Hill) and compared with the control tube containing vanillin, sulfuric acid, and methanol. The condensed tannins (CT) content was expressed as mg of catechin equivalents per gram of dry matter of plant material (mg CE/g DM).

3.7. Antioxidant Activities

3.7.1. Determination of Antioxidant Activity by FRAP

The antioxidant power of the samples, an indicator of their reduction capacity, was assessed using the method described by [16]. Briefly, 2.5 mL of 0.2 M sodium phosphate buffer (pH 6.6) and 2.5 mL of 1% (w/v) potassium ferricyanide solution ($\text{K}_3\text{Fe}(\text{CN})_6$) were mixed with 1 mL of the extract solution.

After 20 minutes incubation at 50 °C, 2.5 mL of 10% (w/v) trichloroacetic acid was added to the mixture. Ferric chloride (FeCl_3) (0.5 mL at 0.1% w/v) and demineralized water (2.5 mL) were combined with the supernatant of the solution (2.5 mL). After 30 minutes of incubation, the solution was measured at λ_{max} 700 nm against a blank. The reducing power of the extract was expressed as milligram equivalents of standard ascorbic acid in grams of dry matter (mg AAE/g DM).

3.7.2. Determination of Antioxidant Activity by DPPH

The free radical DPPH (2, 2-diphenyl- 1-picrylhydrazyl) is used to calculate the percent inhibition of extracts. A 0.2 mM ethanolic DPPH solution was prepared, and 0.5 mL was added to 2.5 mL of diluted extract. After 30 min of standing in dark at room temperature, the absorbance of the combination was measured at 517 nm [17]. The percentage of inhibition, also known as radical scavenging activity (RSA), corresponds to the mixture's discoloration was estimated using the following formula:

$$\text{Inhibition of DPPH\%} = \frac{A_c - A_s}{A_c} \times 100$$

Where, "Ac" represents the absorbance of the control (0.2 mM DPPH ethanolic solution), and "As" represents the sample absorbance.

3.8. Oil Content

A Soxhlet extraction was used to determine oil content (OC). 10 g of powder was extracted with hexane for 8 h. Following that, the solvent was eliminated at 45 °C in a rotary vacuum evaporator (R-200, Buchi, Zurich, Switzerland) [18]. OC was calculated gravimetrically using the following formula:

$$\text{Oil content (\%)} = (\text{weight of oil (g)} / \text{Sample weight (g)}) \times 100$$

3.9. Fatty Acids Composition Determination

Fatty acid (FA) profiling was evaluated following the official analytical method [19]. FAs were then converted into their corresponding methyl esters and injected into a gas chromatograph (Agilent 6890; Santa Clara, CA 95051, USA) on a CPWAX 52CB column (30 m × 0.25 mm i.d., 0.25 µm film thickness) coupled to a flame ionization detector (GC-FID). Helium (He) was used as a carrier gas (flow rate was 1 mL/min), and through a flame ionization detector (FID) 1 µL of each sample was injected at 220 °C (split ratio of 1/50). Oven temperature was programmed at 180 °C for 5 minutes and was raised to 220 °C with a slope of 15 °C/min. Detection was performed at 230 °C. Results were presented as the relative percentage of each individual fatty acid peak area.

3.10. Iodine and Saponification Values

Iodine value was determined based on the fatty acid composition using equation (1), as outlined in the method [20]. The saponification value (SV) was calculated using equations (2). Initially, the fractional molecular weight (FMW) of each

$$IV = (\%C16:1 \times 1.001) + (\%C18:1 \times 0.899) + (\%C18:2 \times 1.814) + (\%C18:3 \times 2.737) \quad (1)$$

$$SV \text{ (mg KOH per g of oil)} = 3 \times n \times 56 \times 1000 \quad (2)$$

$$\text{With, } n = \frac{1}{M_{TG}} \text{ and } M_{TG} = (\text{mean molecular weight} \times 3) + 92.09 - (3 \times 18)$$

3.11. Induction Time

The oxidative stability (OS) of the oil sample was assessed using the Rancimat test, following the ISO 6886:2016 standard [22]. This method measures OS as the oxidative induction time (hours). Briefly, 3 g of oil sample (moringa seeds oil) were placed in the Rancimat instrument (Metrohm, Herisau, Switzerland) reaction vessel. The vessel was then heated at 383 °K with an air flow of 20 L/h. Volatile compounds released during oil degradation were collected in a flask containing 60 mL of distilled water. The conductivity of this solution, which increases with oxidation, was continuously

measured and recorded by the Rancimat software. The OS of the oil sample was determined by analyzing the resulting conductivity curves using the software's extrapolation method.

3.12. Oxidizability Index (COX) and Oxidative Susceptibility (OS)

Oxidizability index (COX) and oxidative susceptibility (OS) were calculated based on the percentage of UFAs according to the following formulas [21]:

$$COX = \frac{1 \times (C16:1 + C18:1 + C20:1) + 10.3 \times (C18:2) + 21.6 \times (C18:3 + C20:3)}{100}$$

$$OS = \%MUFA + (\%C18:2 \times 45) + (\%C18:3 \times 100)$$

The values presented correspond to the mean $\pm$ standard deviation obtained from two to three repetitions. The study used an ANOVA to assess significant variations between mean values. A Tukey test was performed, with a significance threshold set at a p -value < 0.05 . All statistical analyses were performed using Origin Lab software.

4. Results and Discussion

4.1. Oil Content

The economic value of oilseeds is dependent on its oil content [23]. The yield of *Moringa oleifera* seed oil extracted in this study was found to be $41.92 \pm 0.91\%$. This yield was similar to that of Tunisian *Moringa oleifera* seeds ($41.7 \pm 3.71\%$). However, it was substantially higher than the yields reported in Algerian (27-39%), Egyptian (36.7%), Chinese (25.5%), Nigerian (28.75%), and Indian *Moringa oleifera* seeds (39.9%). It was only slightly lower than the yield of Sudanese *Moringa oleifera* seeds (42.87%). This variation may be due to geographical differences.

4.2. Proximate Composition of *M. Oleifera* Seeds and Cake

The nutritional composition of seeds and cake of *M. oleifera* is displayed in the Table 2. The obtained results showed that the seeds have a high energy value of 553.68 kcal/100g since they contain 41.92 g of oil per 100g, the oil content is lower than the reported values for almond kernels (51.12-56.26 g/100 g) [32]. Furthermore, seeds have a considerable carbohydrate content of 44.57 g/100g, along with moderate quantities of Ash (2.92 g/100g), moisture (4.63 g/100g), and protein (7.74 g/100g). *Moringa oleifera* presented a high content of carbohydrates and oil compared to black cumin seeds [33]. The cake, presented a high content of carbohydrates (82.16 g/100 g) and contained medium of proteins (5.96 g/100 g). In addition, the cake had high levels of moisture (6.05 g/100g) and ash (4.03 g/100g), but its energy value (365.37 kcal/100g) is substantially lower than that of the seeds. This composition emphasizes how the nutritional profile changes during oil extraction.

Table 1. Some solvent-extracted oil-yields from *Moringa oleifera* Seed Oil of different countries.

Country	Oil Yield (%)	Reference
Senegal	41.92 ± 0.91	This study
India	39.9	[24]
Algeria	27.0 to 37.4	[25]
Egypt	36.7	[26]
Tunisia	41.7 ± 3.71	[27]
China	25.5	[28]
Nigeria	28.75 ± 0.00	[29]
Sudan	42.87	[30]
Mexico	29.40 ± 0.14	[31]

Table 2. Proximate composition of *Moringa oleifera* seeds and cake. (Results are expressed as mean values ± standard deviation of percentage of moisture content (Moisture C.) (g/100g), ash content (Ash C.) (g/100g), protein content (Protein C.) (g/100g), oil content (Oil C.) (g/100g), carbohydrate content (Carbohydrate C.) (g/100g) and energy value (Energy V.) (kcal/100g)).

	Oil C.	Protein C.	Ash C.	Moisture C.	Carbohydrate C.	Energy V.
Seeds	41.92 ± 0.91	7.74 ± 0.01 ^a	2.92 ± 0.01 ^b	4.63 ± 0.01 ^b	44.57 ± 1.24 ^b	553.68 ± 5.50 ^a
Cake	-	5.96 ± 0.01 ^b	4.03 ± 0.01 ^a	6.05 ± 0.01 ^a	82.16 ± 0.01 ^a	365.37 ± 0.06 ^b

Results are presented as means ± SD, Different letters (a, b) indicate significant differences between means within the same column (p < 0.05)

4.3. Mineral Composition of *Moringa oleifera* Seeds and Cake

Minerals are essential elements that are needed to maintain overall health and wellness [34]. Ten minerals were examined in this work; five macro-elements (K, Ca, P, Mg, and Na) and five microelements (Fe, Cu, Mn, B, and Zn) were examined in *Moringa oleifera* seeds and cake. Table 3 summarizes the findings.

The mineral composition of moringa cake and seeds shows notable variations in important elements following oil extraction. Potassium (9026.3 mg/kg vs. 7239.1 mg/kg) was the

most abundant element in the two parts followed by calcium (3160.9 mg/kg vs. 2622.9 mg/kg), and magnesium (3095.5 mg/kg vs. 2447.5 mg/kg) in the third position. The same order was reported for the cumin seeds [33]. Iron (138.1 mg/kg vs. 35.5 mg/kg), and zinc (62.2 mg/kg vs. 55.4 mg/kg) are among the minerals that are more concentrated in moringa cake than in seeds. In addition, the cake has a higher phosphorus content (23069.6 mg/kg as opposed to 15391.1 mg/kg), which makes it a superior supply of this vital element. In contrast to the seeds (18.4 mg/kg), the cake has slightly lower copper levels (14.6 mg/kg), but boron levels are essentially unchanged. The cake's sodium and manganese contents have slightly increased, to 916.9 mg/kg and 24.6 mg/kg, respectively.

Table 3. Analysis of minerals (mg/kg) of *Moringa oleifera* seeds and cake.

Element	MOS	MOOC
Ca	2622.9 ± 27.7 ^b	3160.9 ± 4.1 ^a
Na	903.1 ± 4.5 ^a	916.9 ± 6.5 ^a
K	7239.1 ± 16.0 ^b	9026.3 ± 281.8 ^a
Mg	2447.5 ± 7.4 ^b	3095.5 ± 20.3 ^a

Element	MOS	MOOC
Fe	35.5 ± 0.6 ^b	138.1 ± 1.5 ^a
Mn	20.0 ± 0.1 ^b	24.6 ± 0.2 ^a
Cu	18.4 ± 0.0 ^a	14.6 ± 0.0 ^a
Zn	55.4 ± 0.2 ^b	62.2 ± 0.0 ^a
B	6.9 ± 0.0 ^a	6.5 ± 0.1 ^a
P	15391.1 ± 67 ^b	23069.6 ± 588 ^a

Results are presented as means ± SD, Different letters (a, b) indicate significant differences between means within the same column ($p < 0.05$)

4.4. Phenolic Compounds Content and Antioxidant Activities

Seeds are rich in various nutrients, such as proteins, carbohydrates and lipids. They are also good sources of various bioactive compounds, such as carotenoids (vitamin A), tocopherols (vitamin E), xanthophylls and polyphenols. Phenolic compounds such as phenolic acids, flavonoids, stilbenes and lignans are powerful antioxidant compounds [35]. The analysis of phenolic compounds in seeds is of great importance. The results of polyphenols content and antioxidant activities of seeds and cake of *Moringa oleifera* are presented in Table 4. As can be seen, *Moringa oleifera* cake has higher phenolic, condensed tannins contents and antioxidant activities (FRAP and ABTS). This suggests that the cake (the by-product of oil extraction) retains more phenolic compounds, which may provide stronger antioxidant effects. The total phenolic content (TPC), in seeds of *Moringa oleifera* is lower than that found in different fractions of *Moringa oleifera* seeds from Mexico (218.5 mg GAE/100g - 386.9 mg GAE/100 g) but that found in cake is within the previous range. The high content was found in the shell, followed by kernel, wings then the whole seed [31]. These results are consistent with other studies of TPC in *Moringa oleifera* leaves (161.98 ± 1.44 mg GAE/100 g) [36], but smaller than the values of seeds from Malaysia (10.179 ± 2.894 mg GAE/g DM) and Bangladesh [37, 38]. *Moringa oleifera* cake contains almost twice the amount of condensed tannins compared to the seeds (0.026 ± 0.002 mg CE/g DM and 0.050 ± 0.006 respectively for seeds and cake) (Table 4). These values are smaller than those found in the different fractions of *Moringa*

oleifera seeds [31, 38]. The seed and cake of *Moringa oleifera* are rich in flavonoids (17.64 ± 0.55 and 14.86 ± 0.23 mg QE/g DM respectively). These values are close to that found in *Moringa oleifera* stem bark methanolic extract from Nigeria but are very smaller than the values found in the other extracts from the different parts of *Moringa oleifera* (bark, flower, food powder, stalk, leaf, and root) [39]. Another study recorded low flavonoids content in *Moringa oleifera* seeds than that in our samples [38]. The low amount of flavonoids in cake than in seeds may be explained as they are either heat-sensitive or soluble in the extracted oil.

The MOOC shows over twice the antioxidant power (FRAP) compared to the seeds (Table 4). While DPPH antioxidant assay showed low percentages for both seeds and cake of *Moringa oleifera*. Similar results were obtained for seeds from Bangladesh, the extracts of methanol and acetone showed low percentages of inhibition of DPPH even at high concentration (500 µg/mL), compared to water extract that showed an IC₅₀ of 36.89 ± 0.15 [37].

Several studies have identified a variety of specific molecules responsible for this activity of *Moringa Oleifera* seeds, such as phenolics (ferulic acid, caffeic acid, chlorogenic acid, coumaric acid, and gallic acid) as well as flavonoids (catechin and quercetin) (Tariq et al., 2022) [40, 41]. All of these bioactive compounds, demonstrated significant antioxidant activity, including free radical scavenging capabilities. These antioxidant activities vary depending on soils, extraction methods, plant tissues and harvest season. The results indicated the importance of *moringa oleifera* seed extracts in the treatment of oxidative stress related diseases.

Table 4. Analysis of phenolic compounds and antioxidant activity.

Moringa	TPC (mg GAE/g DM)	TFC (mg QE/g DM)	CT (mg CE/g DM)	FRAP (mg AAE/g DM)	DPPH (%)
Seeds	1.43 ± 0.06 ^b	17.64 ± 0.55 ^a	0.026 ± 0.002 ^b	8.00 ± 0.44 ^b	4.73 ± 0.95 ^a
Cake	2.65 ± 0.04 ^a	14.86 ± 0.23 ^b	0.050 ± 0.006 ^a	17.38 ± 0.88 ^a	6.08 ± 3.82 ^a

Results are presented as means ± SD, Different letters (a, b) indicate significant differences between means within the same column ($p < 0.05$)

4.5. Fatty Acids Composition of *Moringa oleifera* oil Seeds

The fatty acids (FAs) found in *Moringa oleifera* seed oil are known to reduce the risk of cardiovascular diseases and stroke [42]. The Table 5 shows the fatty acid profiles of four vegetable oils: Moringa, Cactus, Olive and Argan. C14:0 levels are similar in all oils, ranging from 0.08 to 0.1 g/100 g, indicating that this fatty acid is relatively low in these oils. There is significant variation in C16:0 levels. Argan oil has the highest concentration (13.1 ± 0.2), while Moringa oil contains the least (5.54 ± 0.1 g/100 g). C16:1 is highest in Moringa oil (1.38 ± 0.1 g/100 g), and significantly lower in the other oils. Moringa oil also showed the highest concentration of C18:0 (7.19 ± 0.1 g/100 g) compared to other oils, particularly olive oil, which has the lowest concentration (2.5 ± 0.1 g/100 g). Olive oil has the highest concentration of C18:1 (74.5 ± 0.1 g/100 g), closely followed by Moringa oil (65.96 ± 3.60 cis ± 0.1 g/100 g), while cactus oil showed a much lower level (20.5 ± 1.5 g/100 g). This indicates that olive oil is a rich source of oleic acid. Cactus oil has the highest concentration of C18:2 (62.3 ± 1.5 g/100 g), indicating its potential as a good source

of this essential fatty acid. Conversely, Moringa oil has the lowest concentration (0.64 ± 0.01 g/100 g). C18:3 levels are relatively low in all oils, with argan oil showing the highest concentration (0.7 ± 0.1). Moringa and cactus oils also show comparable levels (0.14 ± 0.01 and 0.3 ± 0.1 g/100 g, respectively). Both C20:0 and C20:1 are significantly higher in Moringa oil than in other oils. The highest concentration of C22:0 is noted in Moringa oil (6.82 ± 0.1 g/100 g), while no data is available for the other oils, suggesting a distinctive feature of Moringa oil.

The analysis revealed significant differences in the fatty acid profiles of the oils examined, indicating that each oil possesses distinct nutritional benefits. Moringa oil stands out for its higher levels of certain fatty acids, while cactus oil is notable for its linoleic acid content. This information could be beneficial when choosing oils according to dietary needs and health benefits. C16:0 and C16:1 found in Moringa oil are similar to that reported for *Moringa oleifera* (*Moringaceae*) (5.88 and 1.13 g/100 g, respectively) [43]. The C18:1 content is similar to that of solvent-extracted Moringa oil, which contains 65.0 g/100 g [29].

Table 5. Analysis of the fatty acid composition (g/100g) of moringa seed oil compared with other vegetable oils.

Analyte	Moringa	Cactus	Olive	Argan
C14:0	0.08 ± 0.01^a	0.1 ± 0.1^a	0.1 ± 0.1^a	0.1 ± 0.1^a
C16:0	5.54 ± 0.1^d	12.0 ± 0.2^b	10.5 ± 0.2^c	13.1 ± 0.2^a
C16:1	1.38 ± 0.1^a	0.7 ± 0.1^b	0.7 ± 0.1^b	0.1 ± 0.1^c
C18:0	7.19 ± 0.1^a	3.3 ± 0.1^c	2.5 ± 0.1^d	5.8 ± 0.1^b
C18:1	69.56 ± 0.1^b	20.5 ± 1.5^d	74.5 ± 0.1^a	47.7 ± 0.1^c
C18:2	0.64 ± 0.01^d	62.3 ± 1.5^a	10.2 ± 0.5^c	32.1 ± 0.1^b
C18:3	0.14 ± 0.01^c	0.3 ± 0.1^b	0.7 ± 0.1^a	0.3 ± 0.1^b
C20:0	4.55 ± 0.1^a	0.3 ± 0.1^b	0.2 ± 0.1^b	0.3 ± 0.1^b
C20:1	2.33 ± 0.1^a	0.1 ± 0.1^b	0.1 ± 0.1^b	0.2 ± 0.1^b
C22:0	6.82 ± 0.1	ND	ND	ND
Other peaks	1.64 ± 0.1	-	-	-
IV	68.33	133.09	88.22	102.28
SV	190.23	193.40	192.67	192.83
COX	0.81	6.69	1.95	3.85
OS	116.07	2854.80	604.30	1522.50
IT (h)	17 ± 0.5	7 ± 1.5	21.5 ± 0.5	28 ± 2.5

Results are presented as means $\pm$ SD, Different letters (a, b) indicate significant differences between means within the same column ($p < 0.05$).

4.6. Saponification Value & Iodine Value

The saponification value (SV) is an indicator of the total amount of FAs. It gives insight into the average molecular weight of the FAs in the oil. A higher SV corresponds to a lower molecular weight of the FAs [44]. The SV shows slight differences between the oils, reflecting the average size of the FAs present. Cactus oil has the highest SV (193.40) (Table 5). In contrast, Moringa oil has the lowest SV (190.23). Olive (192.67) and Argan (192.83) oils fall between these two extremes. These SV variations are important, as they influence the saponification properties and uses of the oils, particularly in the production of soaps and cosmetics. The SV obtained in moringa seed oil was similar to the values for Indian *Moringa oleifera* seed oil (190.4 mg KOH/g oil) [24] and Yunnan-China *Moringa oleifera* seed oil (189.84 ± 0.35 mg KOH/g oil) [28].

The iodine value (IV) measures the amount of iodine that can bind to the double bonds of FAs, thus indicating the degree of unsaturation of oils. In the oil studied, Cactus oil has the highest iodine value (133.09 g I₂/100 g oil), suggesting a high concentration of UFAs, which may increase its susceptibility to oxidation. Argan oil follows with an IV of 102.28 g I₂/100 g oil, also indicating a good UFAs content. Olive oil has a moderate IV of 88.22 g I₂/100 g oil, while Moringa oil, with the lowest index at 68.33 g I₂/100 g oil (Table 5), reveals a lower proportion of UFAs, giving it better stability and a longer shelf life. These differences in iodine index influence not only the nutritional properties of the oils, but also their resistance to oxidation. The IV of moringa oil aligns with the IV of Pakistani Moringa seed oil, which was founded as 68.63 g I₂/100 g oil [45] and was reported by (Gharsallah et al., 2021) [27].

4.7. Induction Time (IT)

Oxidation is an unavoidable process that alters the nutritional quality of vegetable oils (VOs). Oxidation can lead to a whole series of negative consequences, such as a reduction in shelf-life and nutritional value deterioration, development of undesirable organoleptic characteristics, and may even lead to the formation of toxic substances [46]. Preservation of Moringa seed oil has never been investigated, so far. To get a complete picture of this seed oil oxidative stability, we decided to determine the induction period by Rancimat test. The oxidative stability of oil is evaluated using this technique, based on conductometric measurement of volatile degradation products produced by thermal oxidation of oil. Induction time of Moringa seed oil, evaluated by the Rancimat accelerated method, was found to be 17 ± 0.5 hours at 110 °C (Table 5). At the same temperature, we found the Rancimat induction time of 7 ± 1.5 ; 21.5 ± 0.5 and 28 ± 2.5 hours for Cactus, olive and argan oils, respectively. Our results show that the stability of Moringa seed oil to oxidation is higher than that of Cactus oil. However, cactus seed oil stability of

much lower than that of olive and argan oils.

4.8. Oxidizability Index (COX) and Oxidative Susceptibility (OS)

The oxidizability (COX) and oxidative susceptibility (OS) indexes assess the oxidative stability of the oil. To indicate that the fatty acids are less prone to oxidation, both the OS and COX indexes should be as low as possible, signifying that the oil is more resistant to oxidation [47]. The results show significant differences in oxidative stability between the oils studied (Table 5). Cactus oil has both the highest COX (6.69) and the highest OS (2854.80), indicating that it is the least stable to oxidation and is already highly degraded. Similarly, Argan oil shows high signs of oxidation (COX = 3.85) and compromised oxidative susceptibility (OS = 1522.50), although it is less degraded than Cactus. Olive oil, with a moderate COX (1.95) and high OS (604.30), shows more limited oxidation but remains relatively unstable. Moringa oil, on the other hand, has the lowest COX (0.81) and OS (116.07) values, indicating that it shows the best oxidative stability.

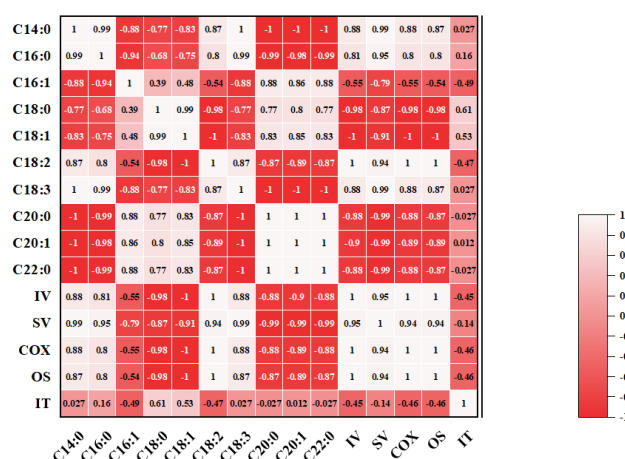


Figure 2. Pearson's correlation coefficient among fatty acids and oxidation indicators.

4.9. Correlation Analysis

The Figure 2 represents a correlation matrix between different variables as fatty acids and other indices (IV, SV, COX, OS, IT) that could correspond to oxidation indicators. C14:0 and C18:3 are perfectly correlated with a coefficient of 1, suggesting that they vary together in a similar way. The same trend was observed between C18:2 and (IV, COX, OS) ($r^2=1$), which could indicate a close relationship between these two variables. Other positive correlations also include C18:0 and C18:1 (0.99), C18:1 and C20:1 (0.85), IV and SV (0.95), and SV and COX (0.94). On the negative correlation side, there is a perfect inverse relationship between C14:0 and C20:0 ($r^2=-1$), C14:0 and C20:1 ($r^2=-1$), as well as C20:0 and C18:3

($r^2=-1$). Other notable negative correlations include C16:1 and C14:0 ($r^2=-0.88$), C16:1 and C16:0 ($r^2=-0.94$), C18:0 and C18:2 ($r^2=-0.99$), C18:1 and C18:2 ($r^2=-1$), and C20:1 and C16:0 ($r^2=-0.99$), indicating strong inverse trends between these fatty acids. The IV and SV indices also show a high positive correlation with IV and COX ($r^2=1$), as well as with IV and OS ($r^2=1$). The IT index shows generally low correlations with other variables, such as C14:0 ($r^2=0.03$), C16:0 ($r^2=0.16$), and with the C20:1 ($r^2=0.01$) and SV ($r^2=-0.14$). In summary, this matrix illustrates complex and significant interactions between the various fatty acids and indices, reflecting both positive and negative correlations.

5. Conclusion

This study focuses on the nutritional and phytochemical composition of Moringa seeds and cake. Moringa seeds have a high oil content. In terms of minerals, Moringa cake is rich in calcium and potassium. Phytochemical analysis reveals that, Moringa seeds have lower total phenol content and condensed tannins, the cake has high levels of total flavonoids and stronger antioxidant activity. The fatty acid profile of oils indicates a significant amount of oleic acid (C18:1) in Moringa seeds, suggesting potential benefits for cardiovascular health. The favorable iodine value of Moringa oil also supports its culinary use. Overall, Moringa seeds and cake are nutrient-rich and possess functional properties that make them valuable for food production and health applications, meriting further research into their benefits.

Abbreviations

MOS	Moringa Oleifera Seeds
MOSO	Moringa Oleifera Seeds Oil
MOOC	Moringa Oleifera Residual Oil Cake

Author Contributions

Faye Mada: Investigation, Project administration, Validation, Writing – review & editing

Ait Bouzid Hasna: Data curation, Formal Analysis, Investigation, Resources, Writing – original draft

Ahansal Chadia: Data curation, Formal Analysis, Resources

Asdadi Ali: Conceptualization, Data curation, Formal Analysis, Software, Validation

Sakar El Hassan: Conceptualization, Investigation, Project administration, Validation, Writing – review & editing

Dramé Abdoulaye: Conceptualization, Project administration, Resources, Supervision, Validation, Visualization, Writing – review & editing

Gharby Said: Project administration, Validation, Visualization, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] Pareek, A., Pant, M., Gupta, M. M., Kashania, P., Ratan, Y., Jain, V., Pareek, A., & Chuturgoon, A. A. (2023). *Moringa oleifera*: An Updated Comprehensive Review of Its Pharmacological Activities, Ethnomedicinal, Phytopharmaceutical Formulation, Clinical, Phytochemical, and Toxicological Aspects. *International Journal of Molecular Sciences*, 24(3), Article 3. <https://doi.org/10.3390/ijms24032098>
- [2] Cao, J., Shi, T., Wang, H., Zhu, F., Wang, J., Wang, Y., Cao, F., & Su, E. (2023). *Moringa oleifera* leaf protein: Extraction, characteristics and applications. *Journal of Food Composition and Analysis*, 119, 105234. <https://doi.org/10.1016/j.jfca.2023.105234>
- [3] Kumar, M., Selvasekaran, P., Kapoor, S., Barbhai, M. D., Lorenzo, J. M., Saurabh, V., Potkule, J., Changan, S., ElKelish, A., Selim, S., Sayed, A. A. S., Radha, Singh, S., Senapathy, M., Pandiselvam, R., Dey, A., Dhupal, S., Natta, S., Amarowicz, R., & Kennedy, J. F. (2022). *Moringa oleifera* Lam. seed proteins: Extraction, preparation of protein hydrolysates, bioactivities, functional food properties, and industrial application. *Food Hydrocolloids*, 131, 107791. <https://doi.org/10.1016/j.foodhyd.2022.107791>
- [4] Anwar, F., Latif, S., Ashraf, M., & Gilani, A. H. (2007). *Moringa oleifera*: A food plant with multiple medicinal uses. *Phytotherapy Research: PTR*, 21(1), 17-25. <https://doi.org/10.1002/ptr.2023>
- [5] Leone, A., Spada, A., Battezzati, A., Schiraldi, A., Aristil, J., & Bertoli, S. (2015). Cultivation, Genetic, Ethnopharmacology, Phytochemistry and Pharmacology of *Moringa oleifera* Leaves: An Overview. *International Journal of Molecular Sciences*, 16(6), Article 6. <https://doi.org/10.3390/ijms160612791>
- [6] Saini, R. K., Sivanesan, I., & Keum, Y.-S. (2016). Phytochemicals of *Moringa oleifera*: A review of their nutritional, therapeutic and industrial significance. *3 Biotech*, 6(2), 203. <https://doi.org/10.1007/s13205-016-0526-3>
- [7] Gopalakrishnan, L., Doriya, K., & Kumar, D. S. (2016). *Moringa oleifera*: A review on nutritive importance and its medicinal application. *Food Science and Human Wellness*, 5(2), 49-56. <https://doi.org/10.1016/j.fshw.2016.04.001>
- [8] Vergara-Jimenez, M., Almatrafi, M. M., & Fernandez, M. L. (2017). Bioactive Components in *Moringa oleifera* Leaves Protect against Chronic Disease. *Antioxidants*, 6(4), Article 4.
- [9] Bennett, R. N., Mellon, F. A., Foidl, N., Pratt, J. H., Dupont, M. S., Perkins, L., & Kroon, P. A. (2003). Profiling Glucosinolates and Phenolics in Vegetative and Reproductive Tissues of the Multi-Purpose Trees *Moringa oleifera* L. (Horseradish Tree) and *Moringa stenopetala* L. *Journal of Agricultural and Food Chemistry*, 51(12), 3546-3553. <https://doi.org/10.1021/jf0211480>

- [10] Keller, D., & Schäfer, S. (2020). Application of Dumas combustion method for rapid protein analysis in food and feed samples. *Journal of Analytical Methods in Chemistry*, 2020, 1-8. <https://doi.org/10.1155/2020/1234567>
- [11] Ibourki, M., Gharby, S., Guillaume, D., Sakar, E. H., Laknifli, A., El Hammadi, A., & Charrouf, Z. (2021). Profiling of mineral elements and heavy metals in argan leaves and fruit by-products using inductively coupled plasma optical emission spectrometry and atomic absorption spectrometry. *Chemical Data Collections*, 35, 100772. <https://doi.org/10.1016/j.cdc.2021.100772>
- [12] Ait Bouzid, H., Oubannin, S., Ibourki, M., Bijla, L., Hamdouch, A., Sakar, E. H., Harhar, H., Majourhat, K., Koubachi, J., & Gharby, S. (2023). Comparative evaluation of chemical composition, antioxidant capacity, and some contaminants in six Moroccan medicinal and aromatic plants. *Biocatalysis and Agricultural Biotechnology*, 47, 102569. <https://doi.org/10.1016/j.bcab.2022.102569>
- [13] Ismaili, S. A., Marmouzi, I., Sayah, K., Harhar, H., Faouzi, M. E. A., Gharby, S., Himmi, B., Kitane, S., & Belghiti, M. A. E. (2016). Chemical analysis and anti-oxidation activities of the Moroccan Milk Thistle. *Moroccan Journal of Chemistry*, 4(3), Article 3. <https://doi.org/10.48317/IMIST.PRSM/morjchem-v4i3.4845>
- [14] Bouzid, H. A., Bijla, L., Ibourki, M., Oubannin, S., Elgadi, S., Koubachi, J., Sakar, E. H., & Gharby, S. (2023). Ziziphus lotus (L.) Lam. almonds nutritional potential: Evidence from proximate composition, mineral, antioxidant activity, and lipid profiling reveals a great potential for valorization. *Biomass Conversion and Biorefinery*. <https://doi.org/10.1007/s13399-023-03984-6>
- [15] Benabderrahim, M. A., Yahia, Y., Bettaieb, I., Elfalleh, W., & Nagaz, K. (2019). Antioxidant activity and phenolic profile of a collection of medicinal plants from Tunisian arid and Saharan regions. *Industrial Crops and Products*, 138, 111427. <https://doi.org/10.1016/j.indcrop.2019.05.076>
- [16] Aryal, S., Baniya, M. K., Danekhu, K., Kunwar, P., Gurung, R., & Koirala, N. (2019). Total Phenolic Content, Flavonoid Content and Antioxidant Potential of Wild Vegetables from Western Nepal. *Plants*, 8(4), Article 4. <https://doi.org/10.3390/plants8040096>
- [17] Abdel Azeem, S. M., Al Mohesen, I. A., & Ibrahim, A. M. H. (2020). Analysis of total phenolic compounds in tea and fruits using diazotized aminobenzenes colorimetric spots. *Food Chemistry*, 332, 127392. <https://doi.org/10.1016/j.foodchem.2020.127392>
- [18] Mohammed, A. S., & Elshiekh, M. I. (2022). Determination of oil content in seeds using Soxhlet extraction and comparison with other extraction methods. *Journal of Food Measurement and Characterization*, 16(4), 1234-1242. <https://doi.org/10.1007/s11694-022-00989-0>
- [19] ISO 12966-2. (2017). *Animal and vegetable fats and oils—Gas chromatography of fatty acid methyl esters—Part 2: Preparation of methyl esters of fatty acids*. ISO. <https://www.iso.org/standard/72142.html>
- [20] Nid Ahmed, M., Gagour, J., Asbbane, A., Hallouch, O., Atrach, L., Giuffrè, A. M., Majourhat, K., & Gharby, S. (2024). Advances in the Use of Four Synthetic Antioxidants as Food Additives for Enhancing the Oxidative Stability of Refined Sunflower Oil (*Helianthus annuus* L.). *Analytica*, 5(2), Article 2. <https://doi.org/10.3390/analytica5020018>
- [21] Asbbane, A., Hallouch, O., Oubannin, S., Gagour, J., Ait Bouzid, H., & Gharby, S. (2024). Lipid oxidation of argan compared to virgin olive, and cactus oils: Rancimat test for kinetic and thermodynamic analysis. *Chemical Papers*. <https://doi.org/10.1007/s11696-024-03688-9>
- [22] ISO 6886. (2016). *Corps gras d'origines animale et végétale—Détermination de la stabilité à l'oxydation (essai d'oxydation accéléré)*. ISO. <https://www.iso.org/fr/standard/69594.html>
- [23] Taoufik, F., Zine, S., El Hadek, M., Idrissi Hassani, L. M., Gharby, S., Harhar, H., & Matthäus, B. (2015). Oil content and main constituents of cactus seed oils *Opuntia Ficus Indica* of different origin in Morocco. *Mediterranean Journal of Nutrition and Metabolism*, 8(2), 85-92. <https://doi.org/10.3233/MNM-150036>
- [24] Ogunsina, B. S., Indira, T. N., Bhatnagar, A. S., Radha, C., Debnath, S., & Gopala Krishna, A. G. (2014). Quality characteristics and stability of *Moringa oleifera* seed oil of Indian origin. *Journal of Food Science and Technology*, 51(3), 503-510. <https://doi.org/10.1007/s13197-011-0519-5>
- [25] Boukandoul, S., Casal, S., Cruz, R., Pinho, C., & Zaidi, F. (2017). Algerian *Moringa oleifera* whole seeds and kernels oils: Characterization, oxidative stability, and antioxidant capacity. *European Journal of Lipid Science and Technology*, 119(10), 1600410. <https://doi.org/10.1002/ejlt.201600410>
- [26] Mohamed, M. A., Ibrahim, M. T., Abdel-Azim, N. S., & El-Missiry, M. M. (2021). Chemical and biological studies on *Moringa oleifera* L. cultivated in Egypt. *Egyptian Pharmaceutical Journal*, 20(1), 33-41. https://doi.org/10.4103/epj.epj_37_20
- [27] Gharsallah, K., Rezig, L., Msaada, K., Chalh, A., & Soltani, T. (2021). Chemical composition and profile characterization of *Moringa oleifera* seed oil. *South African Journal of Botany*, 137, 475-482. <https://doi.org/10.1016/j.sajb.2020.11.014>
- [28] Fu, X., Su, J., Hou, L., Zhu, P., Hou, Y., Zhang, K., Li, H., Liu, X., Jia, C., & Xu, J. (2021). Physicochemical and thermal characteristics of *Moringa oleifera* seed oil. *Advanced Composites and Hybrid Materials*, 4(3), 685-695. <https://doi.org/10.1007/s42114-021-00302-4>
- [29] Nebolisa, N. M., Umeyor, C. E., Ekpunobi, U. E., Umeyor, I. C., & Okoye, F. B. (2023). Profiling the effects of microwave-assisted and soxhlet extraction techniques on the physicochemical attributes of *Moringa oleifera* seed oil and proteins. *Oil Crop Science*, 8(1), 16-26. <https://doi.org/10.1016/j.oesci.2023.02.003>
- [30] Idris, A., Nour, A., Ishag, O., Ali, M., Erwa, I., & Nour, A. (2020). Physicochemical Properties and Fatty Acids Composition of Sudanese *Moringa oleifera* Seed Oil. *Journal of the Turkish Chemical Society Section A: Chemistry*, 7(3), 911-920. <https://doi.org/10.18596/jotcsa.771260>

- [31] Cuevas-Rodríguez, E. O., León-López, L., Escobar-Zúñiga, Y., Milán-Carrillo, J., Domínguez-Arispuro, D. M., & Gutiérrez-Dorado, R. (2020). Chemical proximate composition, antinutritional factors content, and antioxidant capacity of anatomical seed fractions of *Moringa oleifera*. *Acta Universitaria*, 30, 1-11. <https://doi.org/10.15174/au.2020.2892>
- [32] Ibourki, M., Bouzid, H. A., Bijla, L., Aissa, R., Sakar, E. H., Ainane, T., Gharby, S., & Hammadi, A. E. (2022). Physical fruit traits, proximate composition, fatty acid and elemental profiling of almond [*Prunus dulcis* Mill. DA Webb] kernels from ten genotypes grown in southern Morocco. *OCL*, 29, 9. <https://doi.org/10.1051/ocl/2022002>
- [33] Oubannin, S., Jadouali, S. M., Atifi, H., Bijla, L., Ibourki, M., Gagour, J., Bouzid, H. A., Aabd, N. A., Bouyahya, A., Harhar, H., Goh, K. W., Ming, L. C., Razi, P., & Gharby, S. (2024). Antioxidant activity, physico-chemical properties, and bioactive compounds of *Nigella sativa* seeds and oil impacted by microwave processing technique. *Heliyon*, 10(18). <https://doi.org/10.1016/j.heliyon.2024.e37603>
- [34] Ibourki, M., Hallouch, O., Ahmed, M. N., Sabraoui, T., Devkota, K., Sakar, E. H., Jadouali, S., Bouyahya, A., Santanatoglia, A., Caprioli, G., Majourhat, K., & Gharby, S. (2024). Minerals and heavy metals profiling of Moroccan saffron (*Crocus sativus* L.): A comparative study across diverse agro-ecological areas. *Journal of Food Composition and Analysis*, 135, 106651. <https://doi.org/10.1016/j.jfca.2024.106651>
- [35] Sahu, P. K., Cervera-Mata, A., Chakradhari, S., Singh Patel, K., Towett, E. K., Quesada-Granados, J. J., Martín-Ramos, P., & Rufián-Henares, J. A. (2022). Seeds as Potential Sources of Phenolic Compounds and Minerals for the Indian Population. *Molecules*, 27(10), Article 10. <https://doi.org/10.3390/molecules27103184>
- [36] Ezz El-Din Ibrahim, M., Alqurashi, R. M., & Alfaraj, F. Y. (2022). Antioxidant Activity of *Moringa oleifera* and Olive *Olea europaea* L. Leaf Powders and Extracts on Quality and Oxidation Stability of Chicken Burgers. *Antioxidants*, 11(3), Article 3. <https://doi.org/10.3390/antiox11030496>
- [37] Jahan, I. A., Hossain, M. H., Ahmed, K. S., Sultana, Z., Biswas, P. K., & Nada, K. (2018). Antioxidant activity of *Moringa oleifera* seed extracts. *Oriental Pharmacy and Experimental Medicine*, 18(4), 299-307. <https://doi.org/10.1007/s13596-018-0333-y>
- [38] Sulaiman, M., & Abd Manan, F. (2015). Analysis of Total-phenolics, Tannins and Flavonoids from *Moringa oleifera* Seed Extract. *Journal of Chemical and Pharmaceutical Research*, 2015, 132-135.
- [39] Nwidu, L. L., Elmorsy, E., Aprioku, J. S., Siminialayi, I., & Carter, W. G. (2018). In Vitro Anti-Cholinesterase and Antioxidant Activity of Extracts of *Moringa oleifera* Plants from Rivers State, Niger Delta, Nigeria. *Medicines*, 5(3), Article 3. <https://doi.org/10.3390/medicines5030071>
- [40] Tarik, S., Umbreen, H., Noreen, H., Noreen R., Petitbois, C., Aftab, K., Alasmay, F. A., Almaki, A. S., Abdul, M. M. (2022). Comparative Analysis of Antioxidants Activity of Indigenously Produced *Moringa Oleifera* Seeds Extracts. *BioMed Research International* 2022 Oct 15: 2022: 4987929. <https://doi.org/10.1155/2022/4987929>
- [41] Yameogo, C. F., Savadogo, A., & Zongo, C. (2023). Phenolic profiles and antioxidant capacities of *Moringa oleifera* seed oils extracted by different methods. *Food Chemistry Advances*, 14, 100250. <https://doi.org/10.1016/j.fca.2023.100250>
- [42] Magalhães, E. R. B., Fonseca De Menezes, N. N., Silva, F. L., Alves Garrido, J. W., Angélica Dos Santos Bezerra Sousa, M., & Santos, E. S. D. (2021). Effect of oil extraction on the composition, structure, and coagulant effect of *Moringa oleifera* seeds. *Journal of Cleaner Production*, 279, 123902. <https://doi.org/10.1016/j.jclepro.2020.123902>
- [43] De Sousa, E. O., Brito, A. D. S., Feitoza, D. M. A., Ribeiro, A. D. A., Tavares, V. H. N. D., Costa, M. G. M., Nobre, C. D. A., Oliveira-Tintino, C. D. D. M., Borges, J. A. D. O., De Araújo, G. A., Moura, T. F., De Lima, J. P. M., Florencio, S. G. L., Coutinho, H. D. M., De Menezes, I. R. A., & Tintino, S. R. (2024). Chemical analysis of *Moringa oleifera* (Moringaceae) seed oil and potentiation of antibiotic activity against standard and multidrug-resistant bacterial strains. *Food Chemistry Advances*, 5, 100765. <https://doi.org/10.1016/j.focha.2024.100765>
- [44] Cervera-Chiner, L., Pageo, S., Juan-Borrás, M., García-Mares, F. J., Castelló, M. L., & Ortolá, M. D. (2024). Fatty Acid Profile and Physicochemical Properties of *Moringa oleifera* Seed Oil Extracted at Different Temperatures. *Foods*, 13(17), Article 17. <https://doi.org/10.3390/foods13172733>
- [45] Anwar, F., & Rashid, Ts. Dr. U. (2007). Physiochemical characteristics of *Moringa oleifera* seeds and seed oil from a wild provenance of Pakistan. *Pak. J. Bot*, 39, 1443-1453.
- [46] Gharby, S., Oubannin, S., Ait Bouzid, H., Bijla, L., Ibourki, M., Gagour, J., Koubachi, J., Sakar, E. H., Majourhat, K., Lee, L.-H., Harhar, H., & Bouyahya, A. (2022). An Overview on the Use of Extracts from Medicinal and Aromatic Plants to Improve Nutritional Value and Oxidative Stability of Vegetable Oils. *Foods*, 11(20), Article 20. <https://doi.org/10.3390/foods11203258>
- [47] Belhoussaine, O., El Kourchi, C., Amakhmakh, M., Ullah, R., Iqbal, Z., Goh, K. W., Gallo, M., Harhar, H., Bouyahya, A., & Tabyaoui, M. (2024). Oxidative stability and nutritional quality of stored *Linum usitatissimum* L. and *Argania spinosa* L., oil blends: Chemical compositions, properties and nutritional value. *Food Chemistry: X*, 101680. <https://doi.org/10.1016/j.fochx.2024.101680>