RESEARCH PAPER

Physicochemical Characterization, Proximate Composition, and Quality Assessment of Seed Oil and Press Cake Derivatives from *Ricinus communis* L.

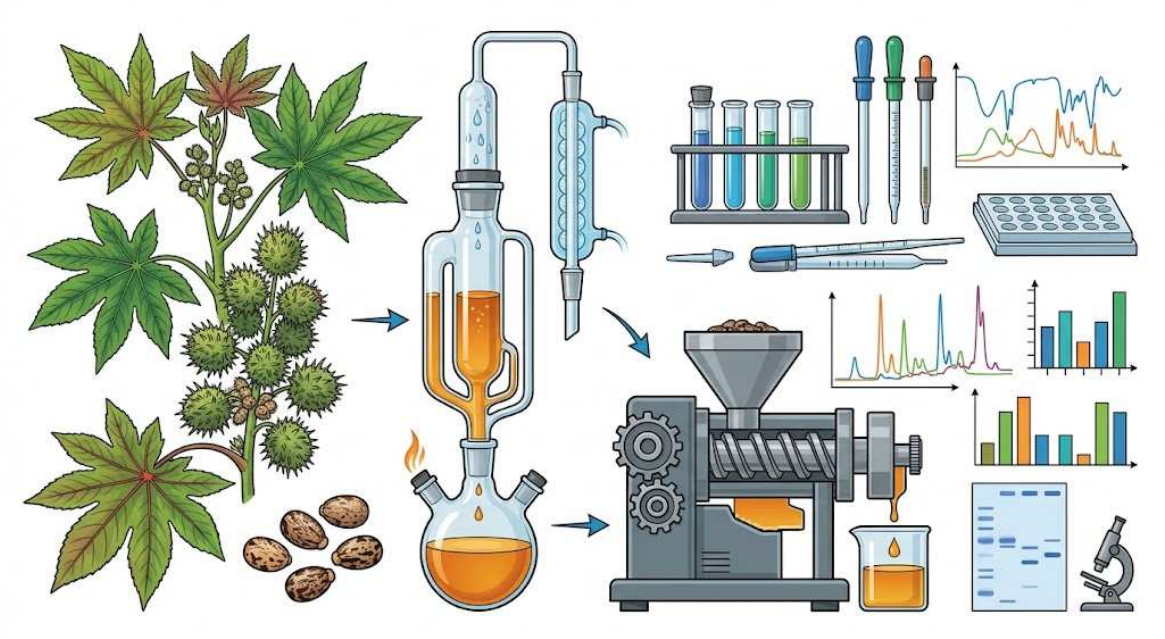
Souad HAMIMED[1], Hanène ZATER[1,2*], Lamia ALIOUCHE[2], Abderrezzeq CHEBOUT[3] ,Sana ZAMA[1]
[1]Department of Matter Sciences, Faculty of Exact Sciences and Natural and Life Sciences, Larbi Ben M'hidi University of Oum El Bouaghi, Constantine Road, P.O. Box 358, 04000 Oum El Bouaghi, Algeria.
[2]Research Unit for the Valorization of Natural Resources, Bioactive Molecules, and Physicochemical and Biological Analyses (VARENBIOMOL), Department of Chemistry, Faculty of Exact Sciences, University of Constantine 1 Frères Mentouri, Chaabet Ersas Campus, Aïn El Bey Road, 25000 Constantine, Algeria.
[3]Functional Ecology and Environment Laboratory (LEFE),Faculty of Exact Sciences and Natural and Life Sciences, Larbi Ben M'hidi University of Oum El Bouaghi, Constantine Road, P.O. Box 358, 04000 Oum El Bouaghi, Algeria.

***Corresponding author*: zater.hanene@gmail.com; zater.hanene@univ-oeb.dz**
Received: 15th July, 2026 **Revised:** 21st September, 2026 **Accepted:** 25th October, 2026 **Available online**: 02nd November, 2026

ABSTRACT

Ricinus communis L. (castor bean, Euphorbiaceae) is an economically important oilseed crop that provides industrially valuable oil and protein-rich solid residues. This study characterized commercially sourced *R. communis* seeds (S), press cake (Pc), de-oiled seeds (DS), and their corresponding oils. Lipids were recovered using three procedures: direct Soxhlet extraction with *n*-hexane (Do), Soxhlet extraction with petroleum ether following hydrochloric acid pretreatment (Indo), and mechanical cold pressing (Cpo). Oil yields were 49.00% (Do), 26.50% (Indo), and 32.50% (Cpo). Aqueous soluble protein concentrations determined by the Biuret method were 1.754 ± 0.083 g/L in S, 1.386 ± 0.012 g/L in DS, and 1.043 ± 0.000 g/L in Pc. Crude protein contents determined by the Kjeldahl method (N × 6.25) reached 9.07% in S, 41.32% in Pc, and 70.52% in DS. Total soluble sugar concentrations were similar in S and Pc (0.282 and 0.288 mg/mL, respectively). The extracted oils exhibited acid values of 4.20–4.92 mg KOH/g, saponification values ranging from 81.36 mg KOH/g (Cpo) to 173.94 mg KOH/g (Indo), peroxide values of 1.40–2.00 meq O_2/kg, and refractive indices of 1.4665–1.4687. UV spectrophotometry revealed absorption maxima at 272–275 nm, with ΔK values of 0.007–0.019. FTIR spectra displayed characteristic lipid bands at 2992–2880 cm^{-1} (C–H), 1740 cm^{-1} (ester C=O), and 1264 cm^{-1} (C–O). However, the absence of a detectable hydroxyl band near 3300 cm^{-1} and the comparatively low saponification values raise questions regarding oil identity and composition. Although the low peroxide values indicate limited primary oxidation at the time of analysis, chromatographic characterization is required to establish fatty acid composition and clarify the atypical analytical profile. These findings provide preliminary data for assessing the potential valorization of *R. communis* oil and protein-rich residues, subject to appropriate detoxification and toxicological validation.

Keywords: *Ricinus communis* L.; cold pressing; Soxhlet extraction; physicochemical properties; seed proteins
How to cite this article: Souad HAMIMED1 Hanène ZATER. Physicochemical Characterization, Proximate Composition, and Quality Assessment of Seed Oil and Press Cake Derivatives from Ricinus communis L.. Int J Drug Deliv Technol. 2026;16(8):102-114. DOI: 10.25258/ijddt.16.8.8.



HIGHLIGHTS

- Direct Soxhlet extraction yielded 49.00% castor seed oil.
- Extraction procedures produced different physicochemical profiles in castor oil.
- De-oiled seeds contained up to 70.52% crude protein, as determined by the Kjeldahl method.
- Principal component analysis (PCA) discriminated cold-pressed (Cpo), indirect-extraction (Indo), and direct-extraction (Do) oils.
- Physicochemical characterization supports the potential valorization of castor oil and residual seed fractions.

Abbreviations:

Ap : % percentage alteration; **ATR:** attenuated total reflectance; **AV**: acid value; **BSA**: bovine serum albumin ;**Cp**: cold pressing; **Cpo**: cold-pressed oil; **Do**, direct oil with Soxhlet extraction; **DS** : de-oiled seeds; **EV**: ester value; **Fc :** Fat content ; **FTIR** : Fourier-transform infrared spectroscopy; **H :** humidity level; **Indo** : indirect oil (acid-assisted) with Soxhlet extraction; $\mathbf{K_{232}}$, $\mathbf{K_{266}}$, $\mathbf{K_{270}}$, $\mathbf{K_{274}}$: specific extinction coefficients at 232, 266, 270, and 274 nm; **Pc** : press cake; **PV** : peroxide value; **RI**: refractive index; **S** : seeds; **Sd** : seeds extracted directly; **Sind** : seeds extracted indirectly; **SV**: saponification value; **Ts**: test sample concentration; **UV-Vis** : ultraviolet–visible spectroscopy; **ΔK**: specific extinction variation.

1. INTRODUCTION

The Euphorbiaceae is a large and taxonomically diverse family of angiosperms whose classification and generic relationships have been extensively investigated [1]. Among its members, *Ricinus communis* L. (castor bean) is of considerable agronomic and industrial importance owing to its high seed-oil content and distinctive fatty acid composition [2]. The species has also attracted interest as a potential crop for drought-prone and saline environments, although its performance depends on genotype and environmental conditions [2]. Previous studies by members of our research group have investigated the chemical constituents and biological activities of Algerian plant species [3, 4], particularly members of the genera *Centaurea* and *Serratula* [5-12]. The present study extends this research interest to the physicochemical characterization of *R. communis* and the potential valorization of its oil and processing residues.

Different parts of *R. communis*, including its roots, leaves, and seeds, have been used in traditional medicine for various purposes, including purgative applications [13]. However, traditional use should not be regarded as evidence of established clinical efficacy or safety. Castor seeds and inadequately detoxified castor-derived materials present significant toxicological concerns, particularly because of the presence of ricin [14]. From an industrial perspective, castor seeds are an important source of vegetable oil, with reported oil contents commonly approaching or exceeding 45–50%, depending on genotype, growing conditions, and extraction method [2]. Castor oil is distinguished by its high proportion of ricinoleic acid, a hydroxylated monounsaturated fatty acid that typically accounts for approximately 85–90% of its fatty acid composition [15]. The hydroxyl group and carbon–carbon double bond of ricinoleic acid, together with the ester functionality of the oil, contribute to its distinctive chemical reactivity and physicochemical properties. These characteristics make castor oil a valuable renewable feedstock for the production of polyurethanes, lubricants, coatings, and other industrial chemicals [15].

The solid residues generated during castor-oil processing, including press cake and de-oiled seeds, may retain proteins and other organic constituents that could be investigated for potential valorization. Possible applications include soil amendment, organic fertilizer production, and protein recovery; however, their suitability for these purposes depends on their composition, processing history, and safety. Raw castor residues may contain ricin and allergenic 2S albumins, making appropriate detoxification and toxicological assessment essential before their use in applications involving agricultural or biological exposure, particularly animal feed [16 and 2]. Assessing the potential valorization of these materials therefore requires an understanding of how extraction procedures affect oil recovery, residual solid composition, and the physicochemical characteristics of the extracted oil [17 , 2]. Cold pressing avoids the use of organic solvents during the pressing operation, whereas solvent-based extraction relies on lipid solubilization and mass-transfer processes to recover oil from the seed matrix [17, 18]. Comparing these approaches can help clarify their respective extraction performance and the characteristics of the resulting oils and solid residues.

Although castor-oil extraction and physicochemical characterization have been widely investigated, further comparative assessments can help clarify the relationships between extraction procedures, oil recovery, residual solid composition, and oil quality. In particular, evaluating direct Soxhlet extraction, acid-assisted indirect Soxhlet extraction, and cold pressing within the same experimental framework, together with the proximate composition of whole seeds, press cake, and de-oiled seeds, allows these complementary aspects to be examined collectively. Combining conventional physicochemical indices with ultraviolet-visible (UV-Vis) and Fourier-transform infrared (FTIR) spectroscopy further broadens the characterization of the extracted oils. The contribution of the present study lies in integrating extraction-yield assessment, proximate analysis of the solid matrices, and physicochemical and spectroscopic characterization of the oils obtained from *R. communis* samples sourced from the Oum El Bouaghi region of Algeria. This integrated assessment provides comparative data relevant to understanding the effects of the investigated extraction procedures and evaluating potential valorization pathways for the resulting materials.

Accordingly, this study aimed to: (i) compare oil yields obtained by direct Soxhlet extraction, acid-assisted indirect Soxhlet extraction, and cold pressing; (ii) determine the proximate composition of whole seeds, press cake, and de-oiled seeds; and (iii) characterize the extracted oils using physicochemical parameters, including acid value (AV), saponification value (SV), peroxide value (PV), ester value (EV), the percentage alteration (Ap%), and refractive index (RI), complemented by UV-Vis and FTIR spectroscopy. By integrating extraction yield, proximate composition, conventional oil-quality indices, and spectroscopic characterization, this study provides a comparative assessment of the investigated castor-oil extraction procedures and the composition of their associated solid residues, contributing to the evaluation of their potential valorization.

2. MATERIALS AND METHODS

2.1. Plant Material and Sample Preparation

Ricinus communis L. seeds (S) and press cake (Pc) were procured from local commercial agro-botanical suppliers in the Oum El Bouaghi region, Algeria, in January 2025. The cold-pressed oil (Cpo) was produced in-house using a mechanical laboratory press. The seeds were authenticated macroscopically using the Flora of Algeria taxonomic keys [19], and a voucher specimen (RC-01-2025) was deposited at the herbarium of Larbi Ben M'hidi University. They were sorted manually to remove foreign matter and damaged hulls, washed with deionized water and dried in a forced-air oven at a set temperature of 65 °C for 12 h to constant mass. After cooling in a desiccator over activated silica gel, the seed coats were manually removed, and the kernels were milled to a homogeneous powder and stored in airtight amber glass containers at 4 °C. Moisture content was determined gravimetrically using 5.0 g of milled seeds dried at 105 °C until constant weight and expressed as a percentage of the initial wet mass.

2.2. Reagents and Reference Standards

All solvents and chemical reagents utilized were of analytical or spectroscopic grade. *n*-Hexane (≥ 99.0%) and petroleum ether (40-60 °C) were supplied by Sigma-Aldrich (St. Louis, MO, USA). Digestion catalysts and titrimetric reagents, including concentrated H_2SO_4, HCl, NaOH, phenol, $CuSO_4 \cdot 5H_2O$, and K_2SO_4, were sourced from Merck KGaA (Darmstadt, Germany). And D-glucose were utilized as calibration standards (Sigma-Aldrich).

2.3. Moisture levels

Humidity level was calculated using the following equation:

$$H\% = \frac{m_{humid} - m_{dried}}{m_{dried}} \times 100$$

2.4. Lipid Extraction Methodologies

Extractions were performed in triplicate.

Direct Soxhlet extraction (Do): Seed powder (20.0 g) was placed in a cellulose thimble and extracted with 500 mL of *n*-hexane at 68 °C for 6 h. The oil extraction yield (Fc%) was calculated as :

$$Fc\% = \frac{m_{\text{Oil}}}{m_{\text{sample}}} \times 100$$

Indirect acid-assisted Soxhlet extraction (Indo): Seed powder (20.0 g) was first digested with 100 mL of 4 M HCl at 80 °C for 30 min to disrupt the cellular matrix. The residue was filtered, washed to neutral pH, dried at 60 °C and extracted with 500 mL of petroleum ether for 3 h.

Cold pressing (Cpo): Mechanical extraction was carried out using a laboratory-scale hydraulic press with 500 g of seeds subjected to a pressure of 30 MPa, without external heating or solvent. Solvent phases were concentrated under reduced pressure at 60 °C using a rotary evaporator, and oil yields were determined gravimetrically and expressed on a dry-weight basis relative to the initial seed mass.

2.5. Proximate composition

Soluble proteins (Biuret assay). Soluble proteins were extracted from the samples (S, Pc, and DS) by cold maceration (24 h, 4 °C) with deionized water, 50 mM phosphate buffer (pH 7.4), or 0.5 M NaCl at a 1:10 (w/v) sample-to-solvent ratio, following established approaches for plant-protein extraction [20].

Protein quantification was performed using the Biuret method. Gornall's reagent was prepared by dissolving 3 g of copper sulfate and 9 g of sodium potassium tartrate (double tartrate salt) in 500 mL of 0.2 M sodium hydroxide (NaOH) solution, followed by the addition of 5 g of potassium iodide [21].

For the assay, 2 mL of the respective sample extracts (S, Pc, and DS) were mixed with 3 mL of Gornall's reagent. Following a 30-minute incubation period, the absorbance was measured at a wavelength of 540 nm.

Protein concentrations were determined using a calibration curve generated from a bovine serum albumin (BSA) stock solution (10 g/L), prepared at dilutions of 1, 3, 5, 7, and 9 g/L. The variations in absorbance were plotted as a function of protein concentration, yielding a linear regression equation of $y = 0.0598x + 0.0636$ with a correlation coefficient of $R^2 = 0.981$.

Total nitrogen and crude protein (Kjeldahl assay). Aliquots (0.5 g) of S, Pc and DS (originating from the direct *n*-hexane Soxhlet extraction) were mineralized with concentrated H_2SO_4 and a $CuSO_4/K_2SO_4$ catalyst at 420 °C. The digest was made alkaline, the ammonia was steam-distilled into 4% boric acid and titrated with 0.1 N HCl. Crude protein was calculated using the nitrogen-to-protein factor of 6.25 [22].

Total soluble sugars. Samples were hydrolysed (2.5 N HCl, 100 °C, 3 h) and analysed by the phenol–sulfuric acid method with 5% phenol and concentrated H_2SO_4. Absorbance was read at 490 nm against a D-glucose calibration curve [23].

2.6. Physicochemical and spectroscopic analyses

The oils (DO, IndO, and CpO) were characterized using established analytical procedures based on relevant international standards [24-28] and previously published methods [29]. The acid value (AV) was determined by titrating oil samples dissolved in an ethanol–diethyl ether mixture (1:1, v/v) with 0.1 N ethanolic potassium hydroxide (KOH), using phenolphthalein as an indicator. The saponification value (SV) was determined by refluxing the oil samples with 0.5 N ethanolic KOH for 60 min, followed by back-titration of the excess KOH with 0.5 N hydrochloric acid (HCl). A blank determination was performed under the same conditions. The peroxide value (PV) was determined by iodometric titration. Briefly, the oil samples were dissolved in an acetic acid–isooctane mixture (3:2, v/v), and saturated potassium iodide (KI) solution was added. The liberated iodine was titrated with 0.01 N sodium thiosulfate. The ester value (EV) was calculated as the difference between the saponification and acid values ($EV = SV - AV$). The percentage alteration index (Ap, %) was calculated as the ratio of the acid value to the saponification value: $Ap\ (\%) = (AV/SV) \times 100$. The refractive index (RI) was measured at 20.0 ± 0.1 °C using a digital Abbe refractometer according to ISO 6320:2017 [26].

UV-Vis spectra were recorded over the wavelength range of 220–300 nm using quartz cuvettes with a 1 cm optical path length. The specific UV extinction coefficients at 232 and 270 nm (K_{232} and K_{270}, respectively) were determined following the procedure described by Meftah et al. [30]. Briefly, 0.100 g of each oil sample (DO, IndO, and CpO) was dissolved in cyclohexane and made up to a final volume of 10 mL to obtain a 1% (w/v) solution. Absorbance was measured against a cyclohexane blank at 232, 266, 270, and 274 nm. The specific extinction coefficient at each wavelength was calculated using the equation $K\lambda = [A\lambda / (c \times l)]$, where $A\lambda$ is the absorbance at wavelength λ, c is the sample concentration (g/100 mL), and l is the optical path length (cm). The specific UV extinction coefficients (K_{232} and K_{270}) were calculated using the following equations, where A_1 and A_2 represent duplicate absorbance measurements at the corresponding wavelength, and T_s denotes the concentration of the test sample.

$$\mathbf{\Delta K = K_{270} - [(K_{266} + K_{274}) / 2]}.$$

$$\Delta K = K_{270} - \frac{K_{266} + K_{274}}{2} \quad ;$$

$$K_{232} = \frac{\frac{A_1 + A_2}{2}}{T_s \times 10} \quad ;$$

$$K_{270} = \frac{\frac{A_1 + A_2}{2}}{T_s \times 10}$$

FTIR spectra were recorded over the range of 4000–400 cm^{-1} at a resolution of 4 cm^{-1} using a JASCO FT/IR-4700 spectrometer equipped with an attenuated total reflectance (ATR) accessory. Measurements were performed in triplicate (n = 3), and results were expressed as mean ± standard deviation (SD), calculated using Microsoft Excel.

2.7. Statistical Data Analysis

All statistical analyses were performed using R software (version 4.6.1). Data manipulation and visualization were conducted using *the dplyr, tidyr, and ggplot2* packages, respectively. Principal component analysis (PCA) was performed using the *FactoMineR* and *factoextra* packages to explore multivariate patterns among the samples and extraction methods. Pearson's correlation coefficients were calculated to assess the strength and direction of linear relationships between physicochemical parameters. Before PCA, the variables were centered and scaled to unit variance to reduce the influence of differences in measurement units and magnitudes. Correlation analysis and PCA were used as exploratory tools to identify associations and patterns in the dataset. The results were interpreted descriptively and were not considered evidence of causality or statistically significant differences.

Radar chart: Each axis was scaled from the minimum to the maximum observed value for the corresponding variable.

3. RESULTS

3.1. Moisture content and oil yields

Moisture contents of S and Pc were 2.66% and 3.37%, respectively, below the 14.5% maximum cited for safe storage [32]. The moisture levels recorded for the whole seeds and the press cake, demonstrating their compliance with safe storage standards, are illustrated below (Figure 1)

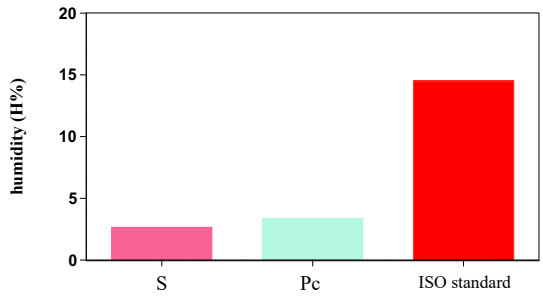


Figure 1: Variation of moisture content in *Ricinus communis* seeds and press cake.

Oil yield depended strongly on the procedure: direct extraction with *n*-hexane gave 49.00% (Do), whereas acid pretreatment followed by petroleum ether extraction gave 26.50% (Iindo). Both exceed the 20% minimum cited for oil seeds [33]. The cold-pressing yield was recorded at 32.50%. The lipid extraction yields obtained through the different methodologies (direct and indirect extraction) are compared in the following chart (Figure 2).

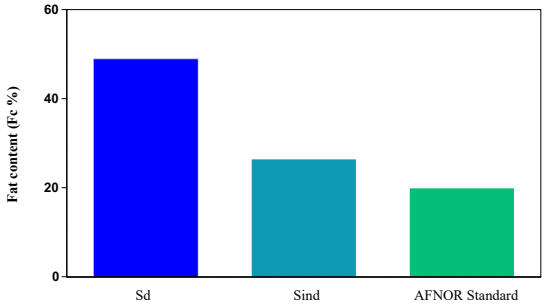


Figure 2: Evaluation of the fat content extracted from *Ricinus communis* seeds.

3.2. Proteins and sugars

In the Biuret assay, aqueous extraction gave the highest soluble protein concentrations in all samples, up to 1.754 g/L for whole seeds; NaCl and buffer extractions gave lower values. The soluble protein concentrations, determined by the *Biuret* method for each extract type (aqueous, buffer, and saline), are presented below (Figure 3).

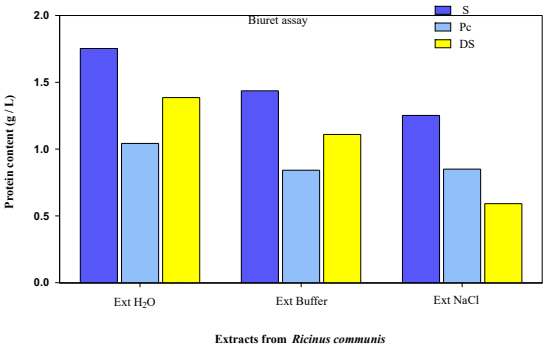


Figure 3: Variation of soluble protein content in different *Ricinus communis* extracts.

The Kjeldahl method, which measures total nitrogen, gave much higher crude protein contents: 9.065% in S, 41.318% in Pc and 70.517% in DS, are presented below (Figure 4).

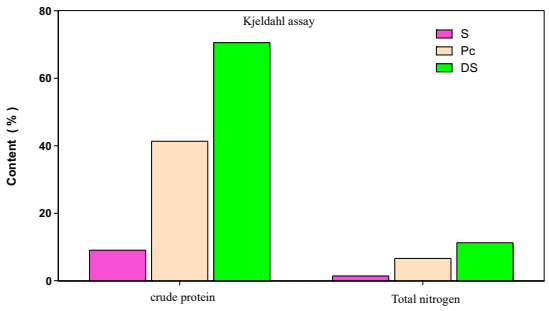


Figure 4: Content of Total nitrogen and crude protein in *Ricinus communis*.

Total soluble sugars were low and similar in S (0.282 mg/mL) and Pc (0.288 mg/mL).

3.3. Physicochemical Parameters of Extracted Oils

The physicochemical quality indices of the direct (Do), indirect (Indo), and cold-pressed (Cpo) oils were evaluated:

- **Acid Value (AV):** Values ranged between 4.204 and 4.923 mg KOH/g of oil, with direct extraction exhibiting the highest acidity.

The figure 5 below highlights the acid value measured for the three types of extracted oils, reflecting their free fatty acid content.

- **Saponification Value (SV):** Values demonstrated significant divergence, ranging from 81.359 mg KOH/g for Cpo to 173.941 mg KOH/g for Indo.

The saponification values, reflecting the average length of the fatty acid chains depending on the extraction method used, are illustrated here (Figure 5).

- **Peroxide Value (PV):** Primary oxidation markers ranged between 1.40 and 2.00 meq O_2/kg (Figure 5).
- **Ester Value (EV):** The ester values were calculated as the difference between the saponification and acid values, yielding 121.32, 169.74, and 76.45 mg KOH/g for Do, Indo, and Cpo, respectively.

The chemical indices of the extracted oils (Do, Indo) and the cold-pressed standard (Cpo) are summarized in Table 1. The calculated ester values, which indicate the amount of esterified fatty acids present in the extracted oils, are presented in Figure 5.

- **% Alteration (Ap %):** Values ranged from 2.417% to 6.028% across the samples.
- **Refractive Index (RI):** Values ranged from 1.4665 to 1.4687 across the samples.

Table 1. Physicochemical indices of *R. communis* oils obtained by direct Soxhlet extraction (Do), indirect acid-assisted Soxhlet extraction (Indo) and cold pressing (Cpo).

Chemical indices	Do	Indo	Cpo	Standard Limits
AV (mg KOH/g)	4.92 ± 0.05	4.20 ± 0.02	4.90 ± 0.03	2-4 [a]
SV (mg KOH/g)	126.24 ± 1.10	173.94 ± 1.25	81.35 ± 0.80	189–196[a]
PV (meq O_2/kg)	1.60 ± 0.05	1.40 ± 0.04	2.00 ± 0.06	Max 5[b]
EV(mg KOH/g)	121.32 ± 1.05	169.74 ± 1.22	76.45 ± 0.77	ND
Ap (%)	3.90 ± 0.05	2.42 ± 0.02	6.03 ± 0.08	ND
RI	1.4665	1.4674	1.4687	~1.466[c]

Legend :*Values are mean ± SD (n = 3). , except for refractive index (RI) Standard Limits derived from: [a] 34; 35 and 29 ; [b] 30 and 34; [c] 36. ND: Not determined.*

The comparative chemical profiles of the three oil samples (Do, Indo, and Cpo) exhibit distinct variations across all measured parameters, as shown in Figure 5.

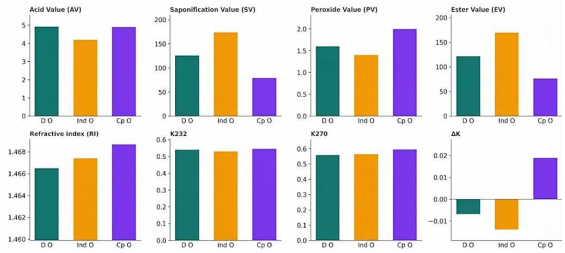


Figure 5: Chemical characteristics by sample

3.4. Chemical characteristics by sample

The figure 5, illustrates the comparative chemical profiles of three distinct oil samples (Do, Indo, and Cpo), revealing significant interspecific variability for all measured parameters. Ind o showed the highest saponification value (SV = 174 mg KOH/g) and ester value (EV = 170 mg KOH/g), followed by Do (SV = 126; EV = 121), whereas Cpo had the lowest values (SV = 79; EV = 77). AV was similar in Do and Cpo (approx 4.9 mg KOH/g) and lower in Indo (around 4.2 mg KOH/g), corresponding to free fatty acid contents of roughly 2.1-2.5% (as oleic acid). The refractive index increased in the order Do <Indo <Cpo (approximately 1.4665 < 1.4674 < 1.4687), consistent with a higher degree of unsaturation and/or longer chain length in Cpo, in agreement with its low SV. Cpo also had the highest peroxide index (around 2.0 vs. 1.6 for Do and 1.4 for Indo meq O_2/kg). The specific extinction coefficients support this pattern: K_{232} was nearly identical across samples (approximately 0.53–0.55), while K_{270} was slightly higher in Cpo (= 0.595 vs. =0.56–0.565). ΔK was negative for Do and Indo (about −0.007 and −0.014) and positive for Cpo (approx +0.019), indicating that secondary oxidation products are more pronounced in Cpo.

3.5. Pearson Correlation Matrix of the Physicochemical Parameters

Figure 6 illustrates the Pearson correlation matrix of the investigated physicochemical parameters, revealing distinct patterns of association among the measured variables. Saponification value (SV) and ester value (EV) exhibited strong negative correlations with several indicators of oil quality deterioration. Their perfect correlation (r = 1.00) is a direct consequence of their strict mathematical relationship, as EV is calculated by subtracting acid value (AV) from SV (EV = SV − AV), and the variance of AV across the samples is negligible compared to that of SV. Both SV and EV were strongly negatively correlated with peroxide value (PV; r = −0.98 for both), K232 (r = −0.97 and −0.98, respectively), ΔK (r = −0.94 for both), and AV (r = −0.86 and −0.87, respectively). SV was also negatively correlated with K270 (r = −0.78) and refractive index (RI; r = −0.57); identical coefficients were obtained for EV.

In contrast, PV, K_{232}, K_{270}, and ΔK exhibited predominantly positive correlations, with coefficients ranging from r = 0.63 to 0.99. The strongest associations within this group were observed between PV and ΔK (r = 0.99) and between K_{270} and ΔK (r = 0.95). PV was also strongly positively correlated with K_{232} (r = 0.91) and K_{270} (r = 0.90), indicating that these oxidation-related parameters varied in the same direction across the investigated samples. AV was strongly positively correlated with K_{232} (r = 0.95) and positively correlated with PV (r = 0.74) and ΔK (r = 0.65), whereas its correlation with K_{270} was weaker (r = 0.36). These findings indicate strong descriptive associations between the measured hydrolytic and oxidative quality indicators; however, correlation alone does not establish a causal relationship.

RI was strongly positively correlated with K_{270} (r = 0.96) and also positively correlated with ΔK (r = 0.81) and PV (r = 0.73). Its association with K_{232} was comparatively weak (r = 0.38). Overall, the correlation matrix provides a valuable exploratory overview of the relationships among the physicochemical parameters. Given the descriptive nature of the dataset, these associations highlight coordinated variations across the extraction methods rather than inferential statistical significance.

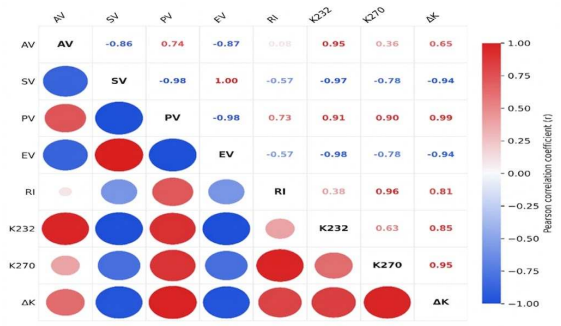


Figure 6: Exploratory Pearson correlation matrix of the physicochemical parameters of the investigated castor oils.

3.6. Multivariate discrimination of the samples by principal component analysis (PCA)

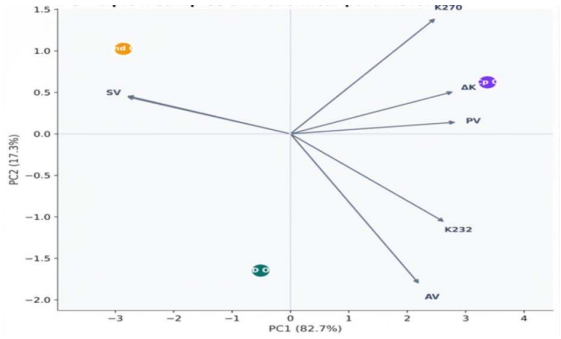


Figure 7: Principal component analysis (PCA) biplot of the evaluated physicochemical parameters across the three extraction methods.

As illustrated in the PCA biplot (Figure 7), the eight physicochemical parameters were represented by two principal components, which together accounted for 100% of the total variance (PC1 = 82.7%; PC2 = 17.3%). The first principal component (PC1) represented the dominant source of variation and clearly discriminated among the three extraction methods: Cpo was positioned at the positive extreme (PC1 ≈ +3.4), Indo at the negative extreme (PC1 ≈ −2.9), while Do occupied an intermediate position (PC1 ≈ −0.5).

The variable loading vectors exhibited a quasi-bipolar distribution along PC1. SV and EV pointed in the negative direction and were associated with Indo, whereas PV, ΔK, K_{270}, K_{232}, and AV projected towards the positive side of PC1, in the direction of Cpo. The second principal component (PC2) further differentiated Do from the other samples. Do was located in the lower quadrant of the biplot (PC2 ≈ −1.65), with its position associated primarily with AV and K_{232}. This distribution suggests a distinct physicochemical profile involving parameters related to hydrolytic degradation and primary oxidation.

By contrast, Indo and Cpo displayed positive PC2 scores (approximately +1.0 and +0.6, respectively), with their positions oriented towards K_{270} and ΔK, parameters associated with secondary oxidation and changes in oil quality. The acute angle between the PV and ΔK vectors suggested a positive association between these variables, whereas the opposing directions of the SV and EV vectors relative to the oxidation-related variables indicated contrasting patterns of variation. Furthermore, the orientation of the RI vector towards K_{270} was consistent with the reported Pearson correlation coefficient (r = 0.96), provided that this value is confirmed by the correlation matrix. Overall, the PCA revealed distinct multivariate profiles among the extraction methods, highlighting differences in the physicochemical characteristics of the resulting oils.

3.7. Multivariate Chemometric Profiling of Samples via Radar Chart Analysis

The radar chart (Figure 8), scaled between 0 and 1, visually summarizes the parameter distributions.

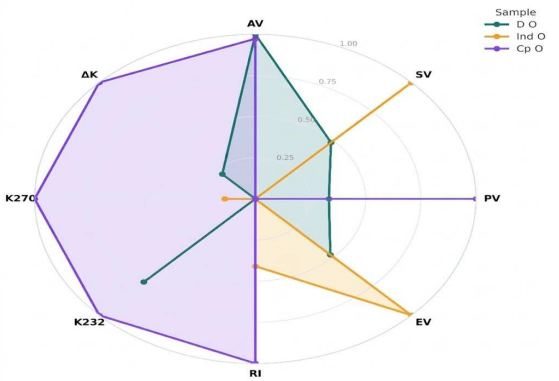


Figure 8: Multivariate Profiling of Samples via Radar Chart Analysis

The radar plot, which displays the 8 parameters scaled to a common range between 0 and 1, provides a concise visual representation of each sample. Cpo formed a large asymmetrical polygon that reached its maximum for PV, RI, K_{232}, K_{270}, and ΔK and was close to its maximum for AI (around 0.97) but plummeted to its minimum for SV and EV. Indo showed the opposite trend, with maximum values for SV and EV and minimum values for AV, PV, K_{232}, and ΔK, as well as a low K_{270} (approximately 0.14) and an intermediate RI (approx. 0.41). Do occupied an intermediate and more balanced position: it had the highest AI (1.00), intermediate values for SV and EV (around 0.48), a low PV (approximately 0.33), a high K_{232} (around 0.71), as well as minimal values for RI and K_{270}, with a low ΔK (approx. 0.21). The mirror-image arrangement of the SV/EV axes relative to the PV–K_{270}–ΔK sector illustrates the antagonistic structure of the dataset, consistent with the strong negative correlations between these groups. As each axis is scaled from minimum to maximum.

3.8. UV-Vis and FTIR spectra

The evaluation of the oxidation state and the comparison of the absorption profiles of the three extracted oils were performed by UV-visible spectrophotometry, the superimposed spectra of which are illustrated below (Figure 9).

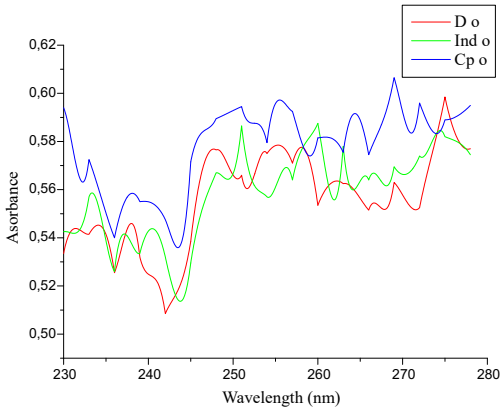


Figure 9: UV-visible absorption spectra of the different *Ricinus communis* oil samples (direct extraction, indirect extraction, and cold pressing).

UV spectra showed absorption maxima near 272-275 nm. ΔK was 0.007 for Do, 0.014 for Indo and 0.019 for Cpo.

FTIR spectra of the three oils were similar and showed bands at 2992–2880 cm^{-1} (aliphatic C–H stretching), 1740 cm^{-1} (ester C=O stretching) and 1264 cm^{-1} (ester C–O stretching). No broad hydroxyl band near 3300 cm^{-1} was observed.

The specific extinction variations measured in the UV spectrum at 232 nm and 270 nm, serving as indicators of the primary and secondary oxidation states of the oils, are summarized in this graph (Figure 5).

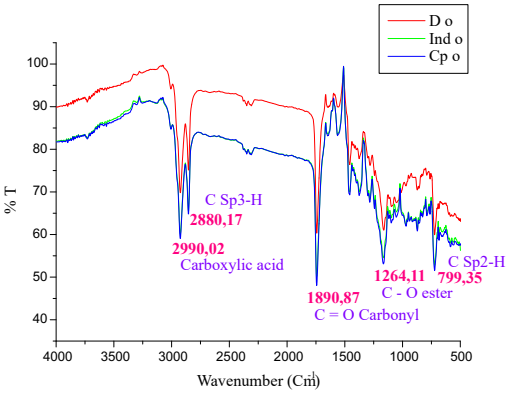


Figure 10: Fourier-transform infrared (FTIR) spectra of *Ricinus communis* oils.

FTIR spectra exhibited consistent, characteristic triglyceride bands across all extraction procedures.

Key absorptions included 2992–2880 cm^{-1} (aliphatic C–H stretching), 1740 cm^{-1} (ester carbonyl C=O stretching), and 1264 cm^{-1} (C–O ester stretching). No broad hydroxyl band near 3300 cm^{-1} was observed.The structural characterization of the lipids and the identification of their main functional groups (notably the C=O and C-O stretching characteristic of esters) were confirmed by the Fourier-transform infrared (FTIR) spectroscopic profiles, presented in the following figure 10.

4. DISCUSSION

4.1. Extraction Yield

The 49.00% yield from direct hexane extraction aligns with literature reporting the high oil content typical of castor seeds [37 and 15]. The significantly lower yield after acid pretreatment (26.50%) cannot be solely attributed to the structural integrity of cell barriers; differences in solvent polarity, extraction duration, or the potential for acid digestion (80 °C) to hydrolyze glycerides likely contributed to this reduction. The 32.50% cold-pressing yield reflects standard mechanical retention of residual oil in the press cake.

4.2. Proteins and Sugars

Differences between the Biuret and Kjeldahl results can be attributed to the distinct analytical principles of these methods. The Biuret assay estimates protein content through the colorimetric reaction of peptide bonds in the analyzed sample, whereas the Kjeldahl method determines total nitrogen, which is conventionally converted into crude protein using a factor of 6.25. This conversion assumes that proteins contain, on average, 16% nitrogen; consequently, crude protein estimates may overstate the actual protein content when non-protein nitrogen compounds are present. This limitation is relevant to *Ricinus communis*, whose seeds contain ricinine, a nitrogen-containing alkaloid. The high crude protein values recorded for the oilcake (Pc; 41.32%) and de-oiled seeds (DS; 70.52%) indicate that these materials are rich in nitrogen. However, these estimates should not be interpreted as equivalent to directly measured true protein content. Despite their potential as sources of nutrients, the use of castor-derived residues in animal feed requires appropriate detoxification and analytical verification of residual ricin and other toxic constituents before their safety can be established.

4.3. Quality Indices and Spectroscopic Profiles

The acid values exceeded the maximum limit of 2 mg KOH/g specified for castor oil by the FAO/JECFA, potentially indicating hydrolytic deterioration during seed storage or oil processing. However, this interpretation should be considered in light of the seed-handling and extraction conditions. The saponification values (SV) ranged from 81.36 to 173.94 mg KOH/g, remaining below the reference range of 176-185 mg KOH/g specified for castor oil (FAO/JECFA). The markedly low SV recorded for Cpo should be verified by checking the calculation, units, reagent concentration, and blank titration before attributing this difference to the extraction method.

The FTIR spectra showed no clearly distinguishable O–H absorption band around 3400 cm^{-1}, despite the presence of hydroxyl groups in ricinoleic acid, the predominant fatty acid in castor oil [38]. This observation alone does not demonstrate a reduction in ricinoleate content or a specific chemical transformation. Further fatty acid profiling would be required to confirm changes in the oil composition. Principal component analysis (PCA) associated Cpo with a higher oxidative burden and lower SV, whereas Indo displayed the opposite pattern. These associations indicate differences among the samples but do not establish causal relationships. Finally, the low peroxide values (1.40-2.00 meq O_2/kg) suggest limited accumulation of primary oxidation products at the time of analysis; nevertheless, peroxide values alone are insufficient to establish long-term oxidative stability [25].

4.4. Chemical characteristics by sample

The variation in saponification value (SV) among the samples may reflect differences in the average molecular characteristics of the saponifiable lipid fraction. However, fatty acid profiling is required to determine whether these differences are associated with variations in fatty acid chain length. The ester value (EV) closely followed the SV across the samples, as expected because EV is calculated as the difference between SV and acid value (AV). The relatively small contribution of AV to this difference indicates that the observed EV pattern was primarily driven by variations in SV. Differences in AV may reflect variations in free fatty acid content and the extent of hydrolysis, although these parameters should be interpreted in relation to the extraction and storage conditions. The peroxide values were low in all three samples, suggesting limited accumulation of primary oxidation products at the time of analysis. Nevertheless, these values alone do not establish overall oxidative stability. Taken together, the results indicate distinct physicochemical profiles among Cpo, Indo, and Do. Although Cpo exhibited the lowest SV and a higher oxidative burden according to the investigated parameters, whereas Indo showed comparatively favorable acidity and primary oxidation indices, these differences require confirmation through fatty acid composition analysis and complementary oxidation measurements.

4.5. Correlation Analysis of the Physicochemical Parameters

The strong correlation between ΔK and K_{270} is partly expected because ΔK is calculated from UV

absorbance measurements at wavelengths surrounding 270 nm. Consequently, this association reflects, at least in part, the mathematical dependence between the variables rather than an independent physicochemical relationship. Correlations between acidity-related and oxidation-related parameters may indicate the coexistence of hydrolytic and oxidative changes in the investigated samples; however, correlation analysis alone cannot establish a causal relationship between these processes. The refractive index (RI) may be influenced by several compositional factors, including fatty acid composition, degree of unsaturation, and the formation of oxidation-related products. Therefore, its correlations with other physicochemical parameters should be interpreted as potential compositional or quality-related associations rather than direct evidence of hydrolysis or advanced oxidation. Overall, the correlation matrix provides a descriptive overview of the relationships among the measured parameters. These relationships should be interpreted cautiously, taking into account mathematical dependencies between variables and the number of independent observations included in the analysis.

4.6. Multivariate Discrimination of the Samples by Principal Component Analysis (PCA)

The PCA provided a multivariate overview of the physicochemical differences among the investigated oil samples and was broadly consistent with the correlation analysis. The first two principal components, PC1 and PC2, explained 82.7% and 17.3% of the total variance, respectively, accounting for 100% of the variance represented in the dataset. Cpo was associated with lower saponification and ester values and comparatively elevated oxidation-related parameters. These associations indicate a distinct physicochemical profile for Cpo relative to Indo and Do. Nevertheless, PCA identifies patterns of covariation rather than causal chemical mechanisms. The interpretation of sample discrimination therefore depends on the variables included, their scaling, and the structure of the dataset. In particular, the explained variance and sample separation should be interpreted cautiously if the analysis is based on a limited number of independent samples.

4.7. Multivariate Chemometric Profiling of Samples Using Radar Chart Analysis

The radar chart provided a complementary visualization of the physicochemical profiles of the three oil samples. To account for differences in measurement units and numerical scales, all physicochemical parameters were normalized before graphical representation. Cpo displayed comparatively elevated values for oxidation-related parameters and refractive index, together with lower saponification and ester values. In contrast, Indo exhibited the lowest acidity and peroxide values, alongside the highest saponification value. Do showed comparatively higher acid value (AV) and UV absorbance at 232 nm (K_{232}), without the elevated K_{270}, ΔK, and refractive index observed for Cpo. Overall, the radar chart illustrates differences among the samples across multiple quality indices. These patterns should be interpreted descriptively and alongside the underlying numerical results, as radar charts do not independently establish the mechanisms responsible for the observed differences.

4.8. Spectroscopic Profile

The FTIR absorption bands observed at approximately 2992–2880, 1740, and 1264 cm^{-1} are consistent with characteristic vibrations of lipid structures, including aliphatic C–H stretching, ester carbonyl (C=O) stretching, and C–O-related vibrations, respectively. These features support the presence of ester-containing lipids, including triacylglycerols. However, no clearly distinguishable O–H absorption band was observed around 3400 cm^{-1}. This finding is noteworthy because ricinoleic acid, the predominant fatty acid in castor oil, contains a secondary hydroxyl group, and O–H absorption has been reported in castor-oil-related FTIR spectra [38]. Nevertheless, the absence of a clearly resolved band does not establish the absence of ricinoleate or hydroxyl-containing compounds, as the signal may be influenced by sample composition, band intensity, spectral acquisition conditions, and data processing.

Further characterization, particularly fatty acid profiling by GC-MS following appropriate derivatization, would help verify the fatty acid composition. However, this approach does not directly provide a comprehensive characterization of intact triacylglycerol molecular species. If detailed triacylglycerol profiling is required, complementary techniques such as liquid chromatography coupled with mass spectrometry (LC-MS) may be appropriate.

Regarding UV absorption, ΔK is calculated from absorbance measurements around 270 nm and is commonly used in olive-oil quality assessment. In the absence of a validated acceptance threshold for castor oil, the ΔK values obtained (0.007–0.019)

should be treated as comparative measurements among the investigated samples rather than as definitive evidence of minimal secondary oxidation. Their significance should be evaluated alongside K_{270}, K_{232}, peroxide values, and other relevant oxidation indicators.

4.9. Limitations and Valorization Potential

Despite the botanical authentication of the plant material, its commercial origin limits traceability with respect to cultivation conditions, geographical provenance, and genetic background. The absence of a detailed fatty acid profile also restricts the interpretation of the oil's molecular composition. Furthermore, differences in the principles and operating conditions of the extraction procedures may limit the direct comparability of the resulting oil yields.

The reported crude protein contents and the unusually low saponification values require independent analytical verification. In addition, complementary compositional analyses are needed to substantiate interpretations of the FTIR spectra and to clarify the chemical basis of the observed differences among the oil samples. Accordingly, the present findings provide a preliminary basis for evaluating the potential valorization of castor oil and its processing residues but do not establish their suitability for specific applications. Future studies should include comprehensive fatty acid profiling, validation of physicochemical measurements, characterization of the lipid fraction using appropriate chromatographic techniques, and standardized comparisons of extraction methods. Importantly, any proposed use of castor-derived residues, particularly in feed or other applications involving biological exposure, must be preceded by validated detoxification procedures and appropriate toxicological assessment to address ricin and other potentially hazardous constituents.

5. Conclusion

This study revealed differences in oil recovery and physicochemical characteristics among the investigated extraction procedures for *Ricinus communis* seeds. Direct Soxhlet extraction using *n*-hexane yielded the highest oil recovery (49.00%), compared with mechanical cold pressing (32.50%) and acid-assisted indirect extraction (26.50%). The residual matrices also exhibited high crude protein contents, reaching 70.52% in de-oiled seeds and 41.32% in the press cake. These results indicate that the residues may warrant further investigation as nitrogen-rich raw materials for potential agricultural or industrial applications. However, their actual suitability depends on confirmation of protein quality, characterization of non-protein nitrogen and other constituents, and effective control of toxic components, particularly ricin, where relevant.

The oils exhibited low measured peroxide values (1.40-2.00 meq O_2/kg), indicating limited accumulation of primary oxidation products at the time of analysis. Nevertheless, the absence of a clearly resolved O–H band in the FTIR spectra and the unusually low saponification values (81.36–173.94 mg KOH/g) require further investigation. These observations cannot, on their own, establish structural modification of the acylglycerols or a direct effect of extraction conditions on molecular composition. Verification of the analytical results and complementary chromatographic characterization are therefore essential. Overall, this study provides a preliminary physicochemical basis for evaluating the combined valorization of castor oil and its protein-rich processing residues, while highlighting the need for compositional validation, standardized process comparisons, and toxicological assessment before application-specific recommendations or industrial scale-up can be justified.

DECLARATIONS AND ADMINISTRATIVE STATEMENTS

ACKNOWLEDGEMENTS

Not applicable.

FUNDING

This research received no specific grant from any funding agency in the public, commercial, or non-profit sectors.

CONFLICT OF INTEREST

The authors declare that they have no competing financial or personal interests that could have influenced the work reported in this article.

ETHICS STATEMENT

Not applicable. This study did not involve human participants or animal models.

AUTHOR CONTRIBUTIONS

S.H. (SouadHamimed): Supervision.

H.Z. (HanèneZater): Methodology, Writing original draft, Writing, review and editing.

L.A. (Lamia Aliouche): Data curation, review and editing.

A.C. (AbderrezzeqChebout): Validation, Formalanalysis.

S.Z. (Sana Zama): Resources.

REFERENCES

1. Webster GL. Classification of the Euphorbiaceae. Annals of the Missouri Botanical Garden. 1994; 81(1):3-32. https://doi.org/10.2307/2399908
2. Severino LS, Auld DL, Baldanzi M, Cândido MJD, Chen G, Crosby W, et al. A review on the challenges for increased production of castor. Agronomy Journal. 2012;104(4):853-880. https://doi.org/10.2134/agronj2011.0210
3. López-Rodríguez M, García VP, Zater H, Benayache S, Benayache F. Cynaratriol, a

sesquiterpene lactone from *Centaurea musimomum*. Acta Crystallographica Section E. 2009;65(8):o1867-o1868. https://doi.org/10.1107/S1600536809026701

4. Hamimed S, Boulebda N, Laouer H, Belkhiri A. Bioactivity-guided isolation of alkamides from a cytotoxic fraction of the ethyl acetate extract of *Anacyclus pyrethrum* (L.) DC. roots. Current Issues in Pharmacy and Medical Sciences. 2018;31(4):180-185. https://doi.org/10.1515/cipms-2018-0033
5. Aliouche L, Zater H, Zama D, Bentamene A, Seghiri RR, Mekkiou R, et al. Flavonoids of *Serratula cichoracea* and their antioxidant activity. Chemistry of Natural Compounds. 2007;43(5):618-619. https://doi.org/10.1007/s10600-007-0208-9
6. Boudjerda A, Zater H, Benayache S, Chalchat JC, González-Platas J, León F, et al. A new guaianolide and other constituents from Achillealigustica. Biochemical Systematics and Ecology. 2008;36(5-6):461-466. https://doi.org/10.1016/j.bse.2007.11.006
7. Zater H, Boudjerda A, Huet J, Oliveira Ribeiro S, Benayache S, Fontaine V, et al. Antimicrobial effects of aerial parts from Algerian centaury (abstract P1L96). Planta Medica. 2014;80(16):1442. https://doi.org/10.1055/s-0034-1394753
8. Zater H, Huet J, Fontaine V, Benayache S, Stévigny C, Duez P, et al. Chemical constituents, cytotoxic, antifungal and antimicrobial properties of *Centaurea diluta* Ait. subsp. *algeriensis* (Coss. & Dur.) Maire. Asian Pacific Journal of Tropical Medicine. 2016;9(6):554-561.https://doi.org/10.1016/j.apjtm.2016.04.016
9. Zater H, Rebbas K, Bicha S, Bensaid SO. Discovery of *Centaurea hyalolepis*Boiss. (Asteraceae) in the region of Djelfa. Acta Botanica Malacitana. 2019;44:67-69. https://doi.org/10.24310/abm.v44i0.5334
10. Zater H, Rebbas K, Bicha S, Bensaid SO. The discovery of the species *Centaurea hyalolepis*Boiss. (Asteraceae) has been added in the site CABI. CABI Invasive Species Compendium. 2019. Availablefrom: https://www.cabi.org/isc/datasheet/113063 .
11. Zater, H., Aliouche, L., Benayache, S., Chalchat, J.-C., Chalard, P., Figueredo, G., & Benayache, F. (2021). Chemical composition & *in vitro* evaluation of the antibacterial activity of the essential oil of the aerial parts of *Centaurea* (Desf.) (Asteraceae) from the North-East region of Algeria. Advances in Bioresearch, 12(6), 1-9. https://doi.org/10.15515/abr.0976-4585.12.6.109
12. Aliouche, L., Zater, H., Bicha, S., Benayache, S., Bensouici, C., Seghiri, R., & Benayache, F. (2022). In Vitro Antioxidant, AntiAlzheimer and Antidiabetic Activities, Phenolic and Flavonoid Contents of Different Polarity Extracts from *Serratula cichoracea* (DC.) (Asteraceae) Aerial Parts. Advances in Bioresearch, 13(2), 25–35. https://doi.org/10.15515/abr.0976-4585.13.2.2535
13. Jena J, Gupta AK. *Ricinus communis* Linn: a phytopharmacological review. International Journal of Pharmacy and Pharmaceutical Sciences. 2012;4(4):25-29.
14. Worbs S, Köhler K, Pauly D, Avondet MA, Schaer M, Dorner MB, Dorner BG. *Ricinus communis* intoxications in human and veterinary medicine: a summary of real cases. Toxins. 2011;3(10):1332–1372. https://doi.org/10.3390/toxins3101332
15. Mutlu H, Meier MAR. Castor oil as a renewable resource for the chemical industry. European Journal of Lipid Science and Technology. 2010;112(1):10-30. https://doi.org/10.1002/ejlt.200900138
16. Anandan S, Kumar GK, Ghosh J, Ramachandra KS. Effect of different physical and chemical treatments on detoxification of ricin in castor cake. Animal Feed Science and Technology. 2005;120(1-2):159-168.https://doi.org/10.1016/j.anifeedsci.2004.10.002
17. Kumar SPJ, Prasad SR, Banerjee R, Agarwal DK, Kulkarni KS, Ramesh KV. Green solvents and technologies for oil extraction from oilseeds. Chemistry Central Journal. 2017;11:9. https://doi.org/10.1186/s13065-017-0238-8
18. Savoire R, Lanoisellé JL, Vorobiev E. Mechanical continuous oil expression from oilseeds: A review. Food and Bioprocess Technology. 2013;6(1):1-16. https://doi.org/10.1007/s11947-012-0947-x
19. Quézel P, Santa S. Nouvelle flore de l'Algérie et des régions désertiques méridionales. Vol. 2. Paris: Centre National de la Recherche Scientifique; 1963. p. 596.
20. Buyel JF. Strategies for efficient and sustainable protein extraction and purification from plant tissues. Methods in

Molecular Biology. 2022;2480:127-145. https://doi.org/10.1007/978-1-0716-2241-4_9

21. Gornall AG, Bardawill CJ, David MM. Determination of serum proteins by means of the biuret reaction. Journal of Biological Chemistry. 1949;177(2):751-766. https://doi:10.1016/S0021-9258(18)57021-6
22. Bireche M, Bakchiche B, Maatallah M, Gherib A. Physicochemical properties of lipid and quantification of proteins of *Citrullus colocynthis* seed oil. *International Journal of Innovation and Applied Studies*. 2014;9(4):1944–1948. http://www.ijias.issr-journals.org/abstract.php?article=IJIAS-14-272-08
23. DuBois M, Gilles KA, Hamilton JK, Rebers PA, Smith F. Colorimetric method for determination of sugars and related substances. *Analytical Chemistry*. 1956;28(3):350–356. https://doi.org/10.1021/ac60111a017
24. International Organization for Standardization. ISO 3656:2011. Animal and vegetable fats and oils. Determination of ultraviolet absorbance expressed as specific UV extinction. Geneva: ISO; 2011. Available from: https://www.iso.org/standard/51008.html.
25. International Organization for Standardization. ISO 3960:2017. Animal and vegetable fats and oils. Determination of peroxide value. Iodometric (visual) endpoint determination. Geneva: ISO; 2017. Available from: https://www.iso.org/standard/71267.html.
26. International Organization for Standardization. ISO 6320:2017. Animal and vegetable fats and oils . Determination of refractive index. Geneva: ISO; 2017. Available from: https://www.iso.org/standard/71267.html
27. International Organization for Standardization. ISO 660:2020. Animal and vegetable fats and oils. Determination of acid value and acidity. Geneva: ISO; 2020. Available from: https://www.iso.org/standard/75594.html.
28. International Organization for Standardization. ISO 3657:2023. Animal and vegetable fats and oils. Determination of saponification value. Geneva: ISO; 2023. Available from:https://www.iso.org/standard/85171.html.
29. Diakite K, Diagouraga S, Diawara M, Fane M. Étude des paramètres physico-chimiques des huiles de graines de coton produites en zone CMDT au Mali. International Journal of Biological and Chemical Sciences. 2022;16(3):1320-1330. https://doi.org/10.4314/ijbcs.v16i3.33ifgdg
30. Meftah H, Latrache H, Hamadi F, Hanine H, Zahir H, El Louali M. Comparaison des caractéristiques physicochimiques des huiles d'olives issues de différentes zones de la région de Tadla-Azilal (Maroc). Journal of Materials and Environmental Science. 2014;5(2):641-646. Available from: http://www.jmaterenvironsci.com/Document/vol5/vol5_N2/69-JMES-628-2014-Meftah.pdf.
31. Tanouti K, Elamrani A, Serghini-Caid H, Khalid A, Bahetta Y, Benali A, et al. Caractérisation d'huiles d'olive produites dans des coopératives pilotes (Lakrarma et Kenine) au niveau du Maroc oriental. Les Technologies de Laboratoire. 2010;5(18):18-26.
32. International Organization for Standardization. ISO 665:2020. Oil seeds: Determination of moisture and volatile matter content Geneva: ISO; 2020. https://www.iso.org/standard/77995.html
33. FAO/WHO Expert Committee on Food Additives (JECFA). Castor Oil. Rome: Food and Agriculture Organization of the United Nations (FAO); 2004. Available from: https://www.fao.org/fileadmin/user_upload/jecfa_additives/docs/Monograph1/Additive-120.pdf
34. Codex Alimentarius Commission. Standard for Quick-Frozen Vegetables. CXS 320-2015. Rome: FAO/WHO; 2015. Available from: https://www.fao.org/input/download/standards/13928/CXS_320e_2015.pdf
35. Novidzro KM, Wokpor K, Amoussou F, Koudouvo K, Dotse K, Osseyi E, Koumaglo KH. Étude de quelques paramètres physicochimiques et analyse des éléments minéraux, des pigments chlorophylliens et des caroténoïdes de l'huile de graines de *Griffoniasimplicifolia*. International Journal of Biological and Chemical Sciences. 2019;13(4):2360-2373. https://doi.org/10.4314/ijbcs.v13i4.39
36. Codex Alimentarius Commission. Recommended Methods of Analysis and Sampling. CXS 234-1999. Rome: FAO/WHO; 1999. Available from: https://www.fao.org/fao-who-codexalimentarius/codex-texts/all-standards/en/

37. Ogunniyi DS. Castor oil: A vital industrial raw material. Bioresource Technology. 2006;97(9):1086-1091. https://doi.org/10.1016/j.biortech.2005.03.028
38. Yeboah A, Ying S, Lu J, Xie Y, Amoanimaa-Dede H, Boateng KG, et al. Castor oil (*Ricinus communis*): A review on the chemical composition and physicochemical properties. Food Science and Technology. 2021;41(Suppl 2):399-413. https://doi.org/10.1590/fst.19620