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ORIGINAL PAPER

Characterization of *Chemlal* Olive pomace and its extracted oil: chemical composition, quality indices, and FTIR analysis

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Abstract
The reuse and valorization of solid by-products from olive oil mills are attracting growing interest in the food, pharmaceutical, and cosmetics sectors due to the recovery of vital bioactive compounds and residual oil, which can be incorporated into functional foods, cosmetics, and pharmaceuticals products. This study investigates, for the first time, the chemical composition, biological activities, and potential valorization of *Chemlal* olive pomace from Algeria, both fresh and dried. The pomace was showed standard compliant values for moisture, acidity, and pH, a high phenolic content (50.56 g GAE/kg before drying and 63.53 g GAE/kg after drying), with significant antioxidant activity (DPPH• inhibition of 78.34% before drying and 89.53% after drying). Fourier-transform infrared (FTIR) spectroscopy confirmed the presence of functional groups associated with phenolic compounds, triglycerides, and fatty acids, indicating strong potential for functional compounds recovery. The extracted oil had slightly elevated acidity and dominant oleic acid content (64.60%), consistent with conventional olive oil profiles. Notably, the oil also exhibited good antioxidant activity (87.43%), and a measurable phenolic content (30.98 g GAE/kg). These findings contribute to the existing body of knowledge on olive pomace and highlight its potential as a valuable resource for the agri-food and pharmaceutical industries. They also emphasize the importance of drying as a crucial pre-treatment for stabilization and optimal valorization.

Keywords Olive pomace oil · Soxhlet extraction · Gas chromatography · Antioxidant potential · FTIR spectroscopy

Introduction

Olives represent a major agricultural crop in the Mediterranean region. The total cultivated area covers approximately 9 million hectares, with an estimated annual production of 15 million tons. According to data from the International Olive Oil Council [1], around 3 million tons of olive oil are produced globally each year [2]. More than 98% of the world's olive oil production is concentrated in the Mediterranean basin, with Spain, Italy, Greece, and Portugal being the leading producers [3]. However, olive oil production generates various waste streams, such as olive pomace and olive wastewater [4]. These by-products are highly phytotoxic and can pose a significant threat to both terrestrial and aquatic ecosystems [5]. For this reason, research is focused on developing strategies to control these leftovers and reduce the pollution burden by reusing them in different contexts [6]. About 25% of the processed olives are made up of olive pomace (OP). Its main components are the olive's skin and crushed pulp, while it also contains a significant quantity of water and some fat, depending on the type of olive and particularly the extraction method. The moisture content of the pomace obtained from the pressure system is around 30%. On the other hand, pomace from continuous 3- and 2-phase centrifugal extraction methods is considerably wetter, with a moisture level of 45–65%. Reducing the water content of OP to levels between 5 and 10% is a prerequisite for the primary upgrading options, which include solvent extraction of the remaining oil, fuel, and animal feed additives. Therefore, a crucial step in its recovery process is the drying process [7]. OP has been primarily

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extracted from residual oil using hexane, and the resulting product is then refined and distilled. However, the extraction of oil from OP has been discontinued due to its unprofitability and management-related problems [8]. For these reasons, there have been multiple attempts to employ OP directly or for the extraction of chemicals with significant added value. To date, OP has been utilized in agriculture as a fertilizer and soil conditioner; in the manufacture of bioenergy; and for the extraction of hydroxytyrosol, tyrosol, oleuropein, caffeic acid, and squalene for application in the food, cosmetic, and pharmaceutical industries. However, there has been little documented evidence of the use of such a substance in human nutrition so far [9]. Olive pomace oil (OPO) is derived from OP, a solid by-product made up of pits, stones, pulp, and fragments of olive skin. This oil is distinguished by its high oleic acid concentration and its distinctive composition of minor constituents, primarily dialcohols and triterpenic acids, squalene, tocopherols, sterols, aliphatic fatty alcohols, and phenolic compounds [10]. The chemical composition of OPO can be effectively studied using a variety of analytical techniques, among which FTIR spectroscopy stands out due to its ability to provide valuable information on the functional groups and molecular interactions that are present in the oil. FTIR spectroscopy works by measuring the absorption of infrared (IR) light by the sample, resulting in a spectrum that reveals the vibrational frequencies of the chemical bonds within the molecules [11]. This technique is particularly useful for identifying key nutritionally valuable molecules in OPO, such as phenolic compounds, tocopherols, squalene, and other minor components that contribute to its antioxidant and anti-inflammatory properties [12]. In the context of the circular economy, olive oil production generates large amounts of by-products, and OP represents both an environmental challenge and an opportunity for valorization. This study provides a detailed examination of the characterization and properties of OP from the Bejaia region in Algeria. It focuses on an in-depth physicochemical assessment, evaluation of antioxidant potential, analysis of the lipid fraction and fatty acids, and determination of oil quality indices. To achieve these objectives, advanced Spectrometric, chromatographic, and colorimetric techniques were utilized. The results highlight the valorization potential of this agro-industrial by-product, particularly its antioxidant properties and fatty acid composition, and its potential applications in the food, pharmaceutical, and cosmetic sectors, contributing to sustainable utilization.

Materials and methods

Raw material

The OP studied in this research was produced during the 2023/2024 olive harvest. It was collected from the technical institute of fruit of Takeriet, located in Sidi-Aich, in the Bejaia region, Algeria. After collection, the pomace was air-dried at room temperature for a month, then crushed, sieved, and stored in sealed bags in a refrigerator at 4 °C until use.

Characterization of OP

Moisture content was determined from 5 g samples of OP using a ventilated oven (WTB Binder, 120 Tuttlingen, Germany) at 105 °C for 48 h until constant weight. Ash content was obtained by combustion of 5 g of OP in a muffle furnace (Nabertherm GmbH, Germany) at 550±5 °C for 4 h. Titratable acidity, expressed as a percent free fatty acid on the basis of oleic acid, was determined by titrating with NaOH solution (0.1 N) [13]. The pH and electrical conductivity (EC) were determined in an aqueous suspension prepared by homogenizing 2 g of sample in 5 mL of distilled water (1:2.5 w/v ratio) for pH and the ratio 1:5 (w/v) for EC. Measurements were performed using a pH meter and conductivity meter (HANNA Instruments), previously calibrated with standard solutions. The analyses were carried out at room temperature (23±2 °C). FTIR analyses were performed using a Perkin Elmer Spectrum Two spectrometer equipped with a universal ATR accessory (attenuated total reflectance accessory). For transmission analysis, 0.002 g of the sample was combined with 0.008 g of spectroscopic-grade anhydrous KBr (1:4 ratio), ground in an agate mortar, and compressed under 10 tons for 5 min to form a transparent pellet. The spectrum was recorded in the range of 4000–500 cm^{-1} [14].

Evaluation of antioxidant potential of OP

Extraction of phenolic compounds

The OP extracts were prepared according to [15], with some modifications, by extracting 0.3 g of OP with 15 mL of 60% ethanol (v/v). The mixture was macerated and stirred in a water bath at 60 °C for 10 min. Afterward, it was centrifuged at 5000 rpm for 20 min and filtered through filter paper with a pore size of 0.18 mm. The obtained extract was stored in a refrigerator at 4 °C until further analysis.

Determination of total phenolic content

Folin-Ciocalteu colorimetric method described by [16], was used for the determination of total phenolic content (TPC) present in the OP extracts against a calibration curve made with gallic acid as a standard with an R^2 value of 0.99 and an equation of $y=3.5835x$. For this assay, a volume of 200 µL of extract was combined with 1 mL of Folin-Ciocalteu reagent and 800 µL of a sodium carbonate solution (7.5%). The mixture was stirred thoroughly and allowed to incubate

for 30 min. After incubation, the absorbance was measured at 765 nm using a UV-visible spectrophotometer (Uvimini1234, Shimadzu, Suzhou, China).

Antiradical scavenging activity

The ability of the tested OP to reduce the radical DPPH• (2,2-diphenyl-1-picrylhydrazyl) was assessed using the method described by [17]. A volume of 900 µL of 60 µM DPPH• solution was added to 100 µL of OP extract. After vortexing, the mixture was incubated for 30 min in the dark. The absorbance was measured at 517 nm, and the DPPH• radical scavenging activity was expressed as the percentage of inhibition.

Analysis of the oleic fraction in OP

Olive pomace oil extraction

The lipid fraction of OP was extracted using the Soxhlet apparatus (Behr Labor Technik, Germany), with hexane as the solvent. The process involved placing 20 g previously dried in the Soxhlet extractor. The extraction was performed for approximately 4 h at 60 °C, with 170 mL of hexane circulating through the pomace to dissolve the lipids. As a solvent evaporated, it was condensed and recycled into the apparatus, ensuring continuous extraction. After completion, the hexane-oil mixture was recovered, and the solvent was removed using a rotary evaporator, yielding crude OPO. This technique is widely employed due to its high efficiency and ability to achieve substantial oil recovery from OP, resulting in a high extraction yield [18].

Extraction yield

The extraction yield is determined as the percentage ratio of the weight of the dried extract obtained to the initial dry weight of the sample used for extraction, as shown in the following equation:

$$\text{Extraction yield}\% = \frac{\text{masse of dry extract}}{\text{masse of dry matter}} \times 100$$

Determination of quality indices

Acidity was determined according to Regulations EC/1989/2003 (EEC, 2003) and expressed as a percent free fatty acid on the basis of oleic acid. Saponification index was measured according to EEC (2003), by reflex boiling of a sample with an ethanolic solution of potassium hydroxide (KOH). 25 mL of KOH (0.5 N) and 2 g of pomace olive oil were placed in a glass flask and boiled for 1 h (reflux boiling). The solution was then titrated with HCl (0.5 N) in the presence of phenolphthalein. Refractive index of the oil was measured by refractometer at a constant temperature; according to the standard EEC (2003), 1 g of crude oil was spread over the refractometer blade until it was completely covered. The refractometer temperature was set at 20 °C. The result was read directly on the device. Peroxide index was carried out following the EN ISO 3960:2017 and expressed as a value in milliequivalents of free oxygen per kilogram of oil (meq O_2/kg).

Fatty acid composition

The fatty acid profile of pomace olive oil was identified using gas chromatography (GC). The preparation of the extract for analysis involved dissolving 5 g of OPO in 5 mL of hexane, to which 0.5 mL of methanolic KOH was added. The mixture was stirred for 30 s and centrifuged at 300 rpm for 5 min. The supernatant was introduced into a chromatography vial and then injected into the apparatus.

Fourier-transform infrared spectroscopy

The FTIR analyses were performed using a Perkin Elmer Spectrum Two spectrometer equipped with a universal ATR accessory (attenuated total reflectance accessory). A few milligrams of oil were put into ATR cells, and the samples were pressed slightly with a system tip in order to maximize the surface of contact. All spectra were recorded in the wavenumber range between 4000 and 500 cm^{-1} [18].

Evaluation of antioxidant potential of OPO

Preparation of extract

The preparation of OPO extract was conducted according to the method described by [19], using a C18 octadecyl column. Briefly, 1 g of oil was dissolved in 10 mL of hexane and introduced into a pre-activated column. The procedure involved three rinses with 5 mL of hexane to remove the apolar phase, followed by two rinses with 4 mL of methanol to elute the polar phase containing phenolic compounds. The extract was recovered during the final rinse.

Determination of total phenolic content

The determination of the total phenolic compounds in OPO was carried out according to the method described by [16], as explained above.

Table 1 Chemical composition analysis of Chemlal olive pomace before 729 and after dryingChemical composition analysis of Chemlal olive pomace before and after drying

Parameters	Before	After
Moisture (%)	58.52±0.93[a]	1.28±0.5[b]
Dry matter (%)	41.39±0.58[b]	98.11±0.43[a]
Ash (%)	2.075±0.17[a]	5.20±0.1[b]
Acidity (%)	3.32±0.05[a]	1.53±0.06[b]
pH	4.88±0.22[a]	4.73±0.23[b]
Conductivity (mS/cm)	4.76±0.24[a]	4.53±0.1[b]
TPC (g GAE/kg)	50.56 ± 0.03[b]	63.53±0.03[a]
DPPH• (%)	78.34±0.13[b]	89.53±0.21[a]

Chemical composition analysis of chemlal Olive pomace before and after drying. The values are presented as mean ± sd of three sample replicates. Lowercase letters indicate significant differences ($p < 0.05$) between the analyzed samples (a-b)

Determination of antioxidant activity

The evaluation of the antioxidant capacity in OPO extracts was made by the DPPH• test described by [17], as explained above.

Statistical analysisStatistical analysis

The data were statistically analyzed using the t-Student test, conducted with the software JMP Pro 14 (Statistical Analysis System Inc., SAS) at a 95% confidence level (p-value < 0.05). The experiments and analytical measurements were performed in triplicate.

Results and discussion

Characterization of OP

The characterization of *Chemlal* OP before and after drying allows for the assessment of the impact of drying on its chemical and functional properties. The experimental data for fresh and dried samples were presented in Table 1.

The statistical analysis of the physicochemical parameters, both before and after drying the OP were presented in Table 2. The results indicate that the treatment significantly affects the physicochemical and bioactive properties of the sample (p-value < 0.05). Before drying, the OP sample presented a high moisture content of 58.52 ± 0.93%, which is characteristic of fresh plant materials. This high moisture content left only a fraction of 41.39 ± 0.58% of dry matter. OP is produced within a limited time frame and is highly prone to microbial degradation due to its high moisture content, which can reach 60–70% [2]. The moisture level of OP varies depending on the extraction method employed. In the case of the two-phase extraction process, OP can contain up to 70% water [5]. Consequently, its disposal presents a significant challenge with notable environmental consequences [2]. Other studies have reported similar moisture content values; Pontes et al., [20] found a moisture content of 67.34%, while Antónia Nunes et al., [21] reported a value of 61.10%, and Lafka et al., [22] recorded a moisture content of 65.10%. The moisture content significantly decreased after drying. After drying, the elimination of the majority of the water led to a drastic reduction in moisture content, down to 1.28 ± 0.50%, thus increasing the concentration of non-volatile compounds to 98.11 ± 0.43% dry matter. Zhao et al., [23] reported a similar moisture content after drying, measured at 2.83 ± 0.08%.

Mineral analysis revealed an ash content of 2.075 ± 0.17%, indicating the presence of minerals and inorganic elements in the OP. Comparable studies have documented different ash contents, including 1.797% [24], 5.8% [25], and 9.02% [23]. These discrepancies suggest that ash content can vary depending on the extraction method, the ripeness of the olives, and other processing factors [26]. After drying, dehydration led to the concentration of mineral elements, increasing the ash content to 5.20 ± 0.10%. This significant rise in ash content confirms the concentration effect of the drying process on the inorganic components of the pomace.

At the physicochemical level, fresh OP exhibits relatively high acidity, with a titratable acidity index of 3.32 ± 0.05% and a slightly acidic pH of 4.88 ± 0.22, typical of acidic plant products such as olive by-products. Lafka et al., [22] reported a similar pH value of 5.8. The measured electrical

Table 2 Statistical analysis of *Chemlal* OP before and after drying

	Moisture (%)	Dry matter (%)	Ash (%)	Acidity (%)	pH	Conductivity (mS/cm)	TPC (g GAE/kg)	DPPH• (%)
Difference	57.2400	−56.7130	−3.1317	1.7900	0.1533	0.2267	−12.9700	−11.1870
Std Err Dif	0.3237	0.7250	0.4373	0.1707	0.1272	0.1621	0.2440	0.2540
Upper CL Dif	58.4534	−54.5670	−1.2526	2.5228	0.6819	0.7141	−11.9200	−10.0960
Lower CL Dif	56.0266	−58.8600	−5.0108	1.0572	−0.3753	−0.2607	−14.0200	−12.2770
Confidence	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
t Ratio	176.8150	−78.2660	−7.1611	10.4872	1.2055	1.3983	−53.0975	−44.0892
DF	2.3459	3.4438	2.0028	2.0046	2.0756	3.3403	2.0022	2.0021
Prob > |t|	< 0.0001*	< 0.0001*	0.0189*	0.0089*	0.3474	0.2477	0.0004*	0.0005*
Prob > t	< 0.0001*	1.0000	0.9906	0.0045*	0.1737	0.1238	0.9998	0.9997
Prob < t	1.0000	< 0.0001*	0.0094*	0.9955	0.8263	0.8762	0.0002*	0.0003*

conductivity of 4.76 ± 0.24 mS/cm indicates a significant presence of dissolved ionic species. After drying, a decrease in titratable acidity to 1.53 ± 0.06% and a slight reduction in pH to 4.73 ± 0.23 were observed, bringing these values closer to those typically found in vegetable oils. Electrical conductivity decreased slightly to 4.53 ± 0.10 mS/cm, likely due to partial precipitation of dissolved salts. Statistical analyses show that acidity exhibited a significant difference after drying, while pH and conductivity did not show significant variation.

The analysis of health-promoting compounds in fresh OP revealed a total phenolic content (TPC) of 50.56 ± 0.03 g GAE/kg OP and a DPPH• antioxidant activity of 78.34%, highlighting the functional properties of this by-product. These values are consistent with several studies; for instance, Pontes et al., [20] reported a higher TPC of 228.45 ± 0.03 g GAE/kg in a hydroacetonic extract, compared to 197.61 ± 0.02 g GAE/kg in a hydromethanolic extract. Lavecchia & Zuorro [2] also found differences based on the extraction solvent; a water-based extraction yielded 7.18 ± 0.25 g GAE/kg, while an ethanol-water (50:50 v/v) extraction resulted in 10.48 ± 0.42 g GAE/kg. These discrepancies can be attributed to variations in the extraction solvents and conditions used.

Interestingly, the bioactive properties were preserved or even slightly improved after drying, with a TPC of 63.53 ± 0.03 g GAE/kg OP and a DPPH• antioxidant activity of 89.53%. The phenolic contents obtained in our study are significantly higher than those reported for olive pomace from other Mediterranean regions. For example [27], observed levels between 35 and 38 g GAE/kg in Portuguese samples. Another study conducted by [28] on Spanish by-products reported a concentration approaching 29 g GAE/kg. Similarly [29], identified values ranging from 6.68 to 15.85 g GAE/kg in Turkish olive pomace, depending on the extraction methods employed. These differences can be explained by various factors, such as the cultivar used, geographical origin, agronomic conditions and extraction techniques applied. On the other hand, our results before and after drying suggests that the drying process employed effectively preserved the phenolic compounds and antioxidant properties of the OP, mainly due to the reduction of water activity, which limited enzymatic and microbial degradation. Furthermore, the removal of moisture increased the relative concentration of phenolics and may have facilitated their extraction by altering the cellular structure, thus enhancing their availability. Statistical analysis revealed that the increase in TPC after drying was statistically significant, with a p-value of 0.0004, indicating that the drying process led to a concentration of phenolic compounds. Additionally, the difference in antioxidant activity between fresh and dried OP was also statistically significant (p-value = 0.0005), suggesting that the drying process had a significant impact on the overall antioxidant potential. A study by [30] highlighted the influence of different drying methods on antioxidant activity, suggesting that the choice of drying technique can significantly affect the preservation of functional compounds. In a similar context [31], reported that drying olive pomace at high temperatures (up to 150 °C) resulted in a notable increase in total phenolic content and antioxidant capacity. This improvement was attributed to several mechanisms, including reduced water activity, improved extractability due to cell disruption, and thermal generation of new phenolic compounds via non-enzymatic reactions. In particular, they revealed that a two-fold increase in luteolin-7-O-glucoside content could be observed during prolonged drying, confirming the hypothesis that high-temperature drying effectively enhances the phenolic profile of olive pomace. These observations concur with the significant increases in TPC and antioxidant activity observed in our dried samples, underlining the dual role of thermal drying in preserving and enhancing the functional properties of olive pomace.

Therefore, drying is considered an essential step prior to any valorization technique to prevent alteration by microorganisms in Solid Olive Mill Waste (SOMW) due to its high water content. It not only reduces enzymatic reactions and microbiological spoilage but also decreases the weight and volume of the products, facilitating their transportation and storage [32]. This crucial stabilization process allows for a significant reduction in OP's water content while preserving its valuable chemical and functional characteristics [33].

FTIR spectroscopy of OP

FTIR spectroscopy is a vibrational spectroscopic technique widely used to characterize oils in all their aspects. FTIR spectroscopy involves the interaction between electromagnetic radiation in the IR region and the substances being analyzed, resulting in phenomena such as scattering, reflection, absorption, or transmission of this radiation [34], The resulting spectral fingerprints serve as powerful tools for quality control and the rapid characterization of the chemical profile of OP for industrial purposes [35]. Figure 1 illustrates the FTIR spectrum of an OP sample, displaying the absorption bands as a function of the wavenumber (cm^{-1}). Table 3 below provides an analysis of this spectrum, identifying the various bands and their corresponding functional groups according to Mohamed et al., [36]. The IR spectrum of OP reveals several characteristic bands corresponding to the different chemical bonds present in its compounds. A broad band around 3300 cm^{-1} indicates the presence of hydroxyl groups (O-H), typical of phenolic compounds, alcohols, or possible residual moisture [34]. The bands in

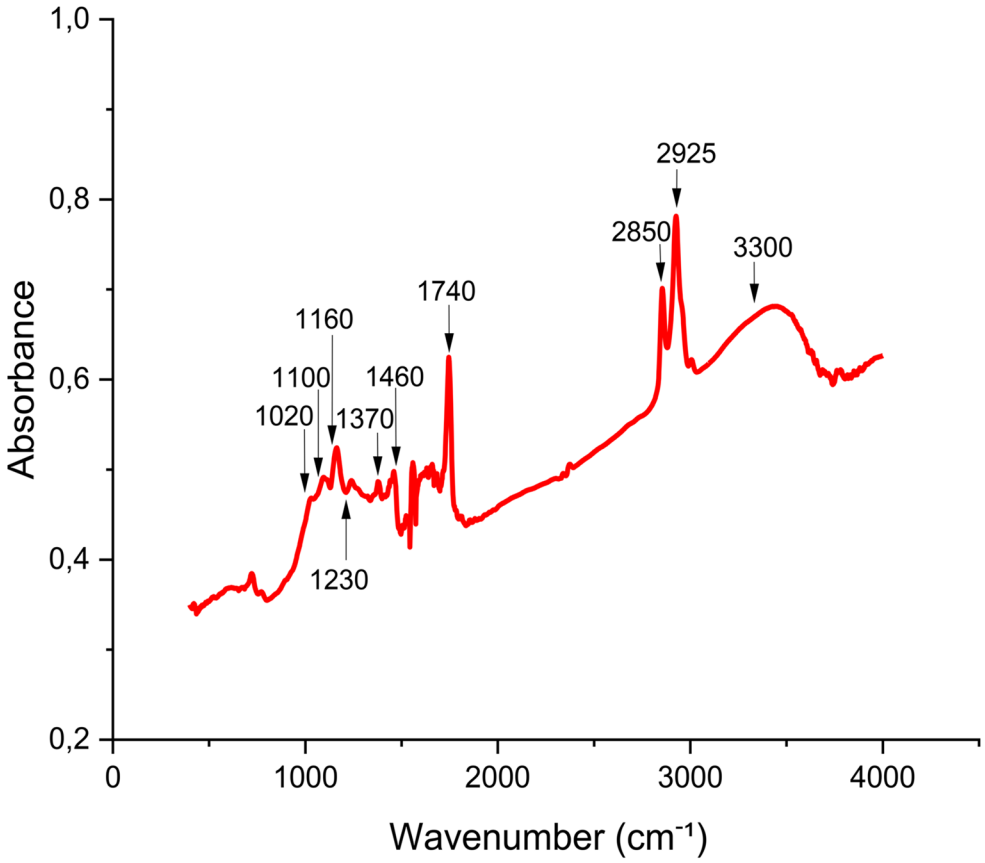

Fig. 1 FTIR spectrum of olive pomace at wavenumber of 4000–500 cm^{-1}

Table 3 Functional groups and modes of vibration in the FTIR spectrum

Wavenumber (cm^{-1})	Functional group assignment
3300	O-H (stretching, often wide) - Possible presence of water or phenolic compounds
2925 − 2850	C-H (stretching, aliphatic) - Asymmetrical and symmetrical stretching vibration of methylene ($-CH_2$) and methyl ($-CH_3$)
1740	C = O (stretching, ester) - Ester carbonyl functional group, indicating residual oil in olive pomace
1460 − 1370	C-H (bending vibrations) - Bending vibrations of CH_2 and CH_3 groups, typical of aliphatic chains
1230 − 1160	C-O (stretching, ester) -C-O bonding in triglycerides or esterified structures
1100 − 1020	C-O (stretching, ester) -C-O bonding vibrations in triglycerides or esterified structures

the region 2920–2850 cm^{-1} are associated with asymmetric and symmetric stretching vibrations of methylene ($-CH_2$) and methyl ($-CH_3$) groups, typical of aliphatic hydrocarbon chains abundant in fatty acids [37]. The intense peak at 1740 cm^{-1} corresponds to the stretching of the ester carbonyl (C = O) group, which is a key feature of triglycerides, signifying the presence of residual oil in the OP [38]. The region between 1600 and 1500 cm^{-1} is attributed to C = C vibrations, which could indicate the presence of aromatic compounds, such as phenolic substances, or the double bonds found in unsaturated fatty acids [36]. Furthermore, the bands between 1450 and 1375 cm^{-1} are linked to the bending vibrations of CH_2 and CH_3 groups, highlighting the aliphatic structure of fatty acids. The absorption in the range of 1230–1160 cm^{-1} and 1100–1020 cm^{-1} corresponds to C-O stretching vibrations, which are characteristic of triglycerides or other esterified structures [38]. The substantial presence of fatty acids, triglycerides, and perhaps beneficial substances in OP is confirmed by this IR spectrum analysis, which offers a thorough comprehension of the molecular structures and functional groups present in the material.

Extraction yield

In general, the yield of extraction processes is directly influenced by several parameters, such as the type of solvent, the method of extraction, the processing time and temperature, and the moisture content of the sample [32]. The polarity of the selected solvent significantly affects the solubility of the compounds in the sample and ultimately the extraction yield. Hexane is one of the most commonly used solvents for the recovery of oil from olive mill by-products, including OP, due to its non-polar nature and high affinity for lipids

[39]. Hexane's selectivity for triglycerides and its ability to minimize co-extraction of polar compounds make it an ideal choice for oil recovery in both laboratory and industrial settings. Regarding the method of extraction, conventional techniques, such as Soxhlet extraction, remain widely used for their reliability and efficiency in oil recovery. Soxhlet extraction involves continuous recycling of the solvent over the sample, ensuring exhaustive extraction of lipids [40]. The efficiency of oil extraction is strongly influenced by the duration and temperature of the Soxhlet process. Optimal temperatures for hexane-based extractions typically range between 50 °C and 70 °C, ensuring maximum solubility of the oil while preventing thermal degradation. Prolonged extraction times, usually around 4–8 h, are required to achieve exhaustive oil recovery from OP, although shorter times may suffice for pre-dried samples with higher oil content [40]. Moisture content is another critical factor affecting the extraction yield [41]. OP with high moisture content can hinder solvent penetration, reducing the efficiency of oil recovery. Pre-drying the pomace to a moisture content of less than 10% has been shown to enhance oil extraction by improving solvent access to the lipid-rich matrix [42].

In this study, the extraction yield of OPO using hexane as a solvent and the Soxhlet technique was estimated at 20%. This yield demonstrates notable efficiency compared to other studies. For instance, a study conducted by Banat et al., [40] reported a yield of 10.6%, while another study by Amarni & Kadi [43] achieved only 7%. These variations highlight the importance of optimizing extraction parameters, such as the choice of solvent and the extraction technique, to maximize oil recovery while preserving its quality.

Quality indices determinations of OPO

The results of indices that demonstrate the quality of OPO extracted are shown in Table 4. The analysis of moisture content reveals a value of 1.85 ± 0.30%, which is relatively high compared to the optimal value, ideally below 1%. This elevated moisture content can promote triglyceride hydrolysis, thereby increasing acidity, and may potentially reduce the oil's shelf life.

Acidity is a crucial parameter for quality assessment and suitability for consumption of oil. It measures the level of free fatty acids resulting from the breakdown of triglycerides. The acidity level, measured at 1.93 ± 0.03%, is moderately high compared to the standard of ≤ 0.1% commission regulation (EC) No 1989/2003 (EEC, 2003) for refined OPO. This value suggests some triglyceride degradation through hydrolysis but remains acceptable for crude, unrefined pomace oil. The result obtained indicates that the oil analyzed is fresh and of good quality, and this is probably due to the method of extraction and the good conservation of the olives [44].

Table 4 Quality indices of Olive pomace oil (OPO)

Parameters	Content
Moisture (%)	1.85±0.3
Acidity (%)	1.93±0.03
Peroxide index (meq O_2/Kg)	1.5±0.25
Saponification index (mg/g)	190.44±0.03
Refractive index	1.4701
TPC (g GAE/kg)	30.98±0.25
DPPH• (%)	87.43±0.06

The peroxide index can also assess the quality of the oil by determining the amount of hydroperoxides present. The determination of this index has given a value of 1.5 ± 0.25 meq O_2/kg of oil, which is highly satisfactory, significantly below the maximum permitted limit of 15 meq O_2/kg. This low value indicates minimal primary oxidation, reflecting the oil's good oxidative stability. Studies conducted by Elkacmi et al., [45] and Sebban et al., [46] reported values of less than 11.26 meq O_2/kg oil and 9.6 meq O_2/kg oil, respectively. Therefore, the extracted oil is fresh and contains antioxidants that help to limit oxidation.

The saponification value representing the mass of potassium hydroxide (KOH) in mg required for neutralization of fatty acids contained in 1 g of fat is also an important parameter in the evaluation of the quality of the oil; this value provides information about the average chain length of fatty acids, indicating a standard fatty acid composition for olive oil. Based on the result of measuring this index, which gave a value of 190.44 ± 0.03 mg/g, which complies with the standards (184 mg/g −196 mg/g) established by the IOC (2019) and which is close to the value reported by Elkacmi et al., [45] in its study on the analysis of the lipid composition of acid oil of bagasse, which is 189 mg/g. It can be concluded that the bagasse oil analyzed did not oxidize. On the other hand, the refractive index is also an important parameter for estimating the purity of the oil. The measurement of this index gave a value of 1.4701, which is close to the reference value established by the IOC (2019), which ranges from 1.4677 to 1.4705, and that reported by Sebban et al., [46], which is 1.4618, and by [45] with a value of 1.4678. This measurement confirms the oil's purity and gives insight into the degree of unsaturation of the fatty acids present.

Oil quality is closely related to its concentration of phenolic compounds, which is generally influenced by the maturity stage of olives and phenolic environmental conditions [47]. Phenolic compounds are metabolites that play a crucial role in ensuring good oxidative stability and potential health benefits and organoleptic characteristics during oil storage. The result of the determination of phenolic compounds in the OPO analyzed is 30.98 ± 0.25 g GAE/kg. This shows that it contains a significant amount of phenolic compounds.

The evaluation of antioxidant activity provides information on the quality of the olive, the oil, and its richness or lack of antioxidants, especially phenolic compounds [5]. The study done by Paulo & Santos [48] on the valorization of phenolic compounds of olive oil by-products gave a 30% inhibition rate. Whereas ours shows an excellent inhibition percentage of 87.43%. This high value indicates strong antioxidant capacity, which is directly correlated with the significant phenolic compound content.

Overall, this pomace oil presents satisfactory quality parameters and a remarkable antioxidant potential. The measured moisture content (1.85%) is relatively low and appears to have had no significant effect on enzymatic alterations, particularly triglyceride hydrolysis, which typically leads to the formation of free fatty acids. This is supported by the observed acidity level of 1.93%, which is lower than that of standard crude olive pomace oil (COI, 2019) and aligns with values reported for oils extracted without intensive drying [49]. Such a combination of moderate moisture and low acidity suggests limited hydrolytic degradation and reflects the good initial quality of the sample. Nevertheless, these parameters should still be monitored, especially if the oil is to be used in artisanal, cosmetic, or food applications, where oxidative stability and product safety are essential. To further improve oil quality and preserve its functional properties, proper drying, refining steps, and adequate storage conditions are recommended [50].

Fatty acid composition

The results of gas chromatography are presented in Fig. 2; Fig. 3; and Table 5, providing important information on the fatty acid composition of the pomace olive oil sample that was extracted. The most representative fatty acids in percentage are oleic (C18:1), linoleic (C18:2), palmitic (C16:0), and linolenic (C18:3), which are the main ones representing 99% of the composition of total fatty acids in OPO from a variety of *Chemlal*. The most abundant fatty acid is oleic, representing more than 64.59%.

The fatty acid composition suggests several positive nutritional and quality attributes. The high oleic acid content (64.591%) indicates superior nutritional value, good oxidative stability, and potential health benefits associated with monounsaturated fats. The balanced proportions of other fatty acids suggest an appropriate nutritional profile, authenticity of the oil, and conformity with typical olive oil characteristics [51]. Similar results showed that OPO was a monounsaturated fat with a 74.32% oleic acid (C18:1) content, followed by palmitic acid (C16:0) and linoleic acid (C18:2) with respective contents of 10.78% and 9.02% [10]. The results obtained from this analysis are similar to those reported by other studies on olive oil and pomace olive oil, such as the study conducted by [44], having demonstrated that the fatty acid composition of the oil of OP is almost identical to that of olive oil (palmitic acid with 14.93%, oleic acid with 66.78%, and linoleic acid with 11.67%), and that of Ducom et al., [52], which revealed that oleic acid is the most common acidic component of the residual oil in pomace.

The oleic/linoleic ratio is also a commonly used criterion for evaluating oil stability and characterizing olive oil varieties [51]. This ratio also allows the detection of virgin olive oil blends containing between 5 and 10% refined seed oils [53]. In our case, the oil from the *Chemlal* variety shows a

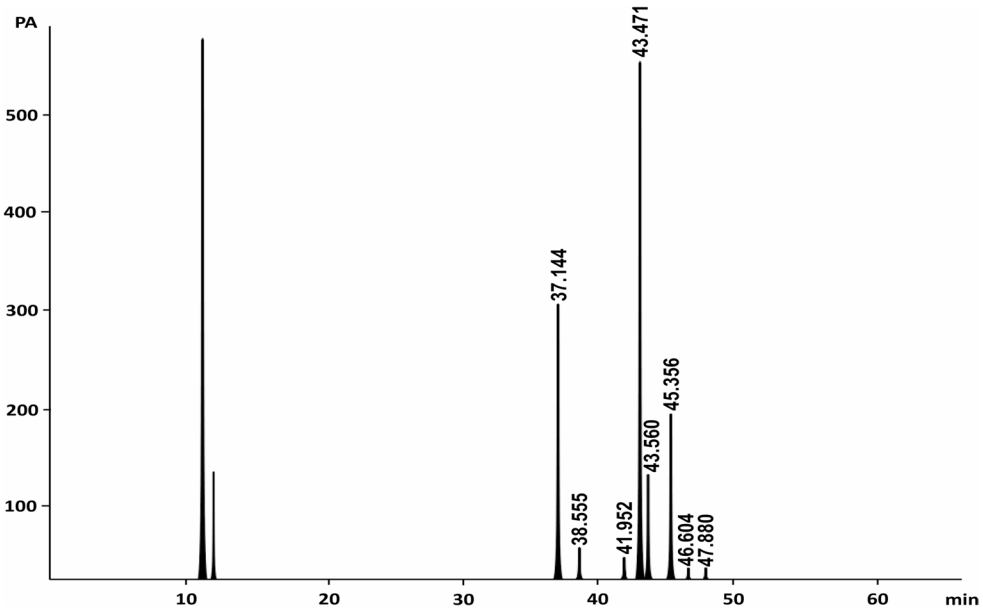

Fig. 2 Gas chromatography spectrum of olive pomace oil (OPO)

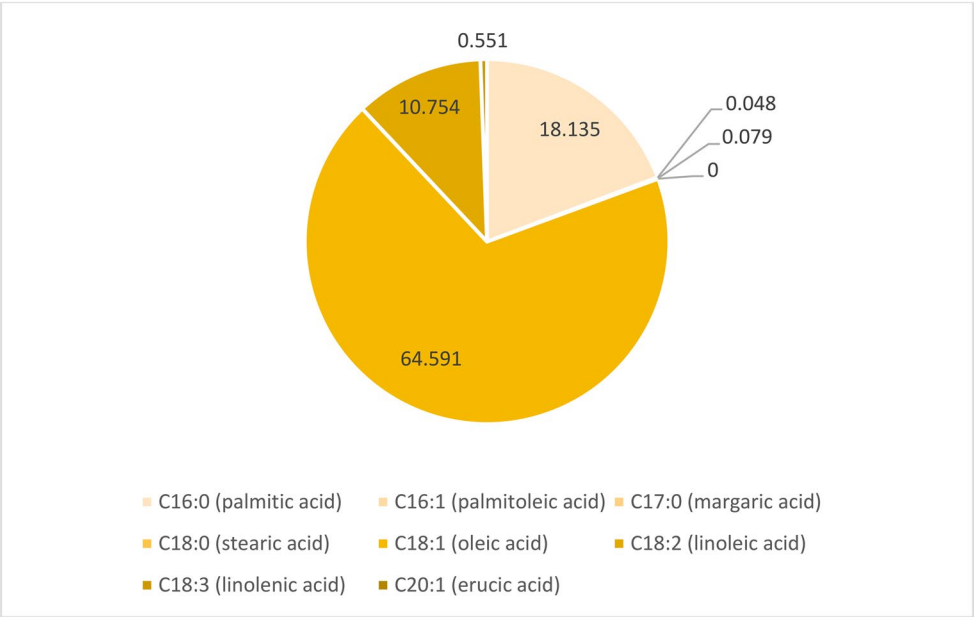

Fig. 3 Presentation of fatty acid contents in olive pomace oil (OPO)

Table 5 The main component of fatty acids in Olive pomace oil (OPO)

Fatty acids	Contents (%)
C16:0 (palmitic acid) *	18.135
C16:1 (palmitoleic acid) **	0.048
C17:0 (margaric acid) *	0.079
C18:0 (stearic acid) *	0.000
C18:1 (oleic acid) **	64.591
C18:2 (linoleic acid) ***	10.754
C18:3 (linolenic acid) ***	0.551
C22:1 (erucic acid) **	0.040

high oleic/linoleic ratio, indicating increased oxidative stability, with a ratio of about 21%. Several studies [54]; [55] have highlighted the importance of this ratio for the nutritional quality of the oil and its resistance to oxidation.

FTIR spectroscopy of OPO

Figure 4 shows a FTIR spectrum representing the absorption bands of an OPO sample as a function of the wavenumber (cm^{-1}). Table 2 below presents the analysis of this spectrum, identifying the different bands.

The IR spectrum of OPO reveals several characteristic bands associated with the functional groups present in fatty acids and triglycerides. The band around 3450 cm^{-1} corresponds to O-H stretching, often broad, indicating the possible presence of trace water or phenolic compounds containing hydroxyl groups. The band located around 2925 cm^{-1} and 2850 cm^{-1} corresponds to the asymmetric and symmetric elongation vibrations of the C-H bonds of the methylene groups (-CH_2-) of the aliphatic chains of the fatty acids. An intense band around 1740 cm^{-1} is attributed to the elongation vibrations of the C=O bond of the esters, indicating the presence of triglycerides, the main component of the oil. Between 1460 and 1370 cm^{-1}, bending vibrations of -CH_2 and -CH_3 groups are observed, characteristic of the aliphatic structures in saturated and unsaturated fatty acids. Bands in the 1230–1160 cm^{-1} and 1100–1000 cm^{-1} regions are associated with vibrations of C-O bonds, characteristic of esters and alcohols present in lipids. Finally, the absence of significant bands in the 3300 cm^{-1} region confirms the absence of free hydroxyl compounds, which is typical for non-oxidized oils. This IR spectrum thus provides a detailed analysis of the chemical composition of OPO, highlighting key functional groups and molecular structures.

The results align with those of Yang & Irudayaraj [56], although some bands present in our study are not found in theirs. For instance, the band around 3450 cm^{-1} may explained by the presence of traces of water or phenolic compounds.

The primary differences in the IR spectra of OPO and OP are the decreased intensity of bands linked to triglycerides (C=O, C-O) and the increased intensity of bands linked to hydrophilic chemicals (O-H, C=C). According to these findings, OP has residual oil and bioactive phenolic chemicals, which present encouraging prospects for value-adding in the pharmaceutical and agri-food industries.

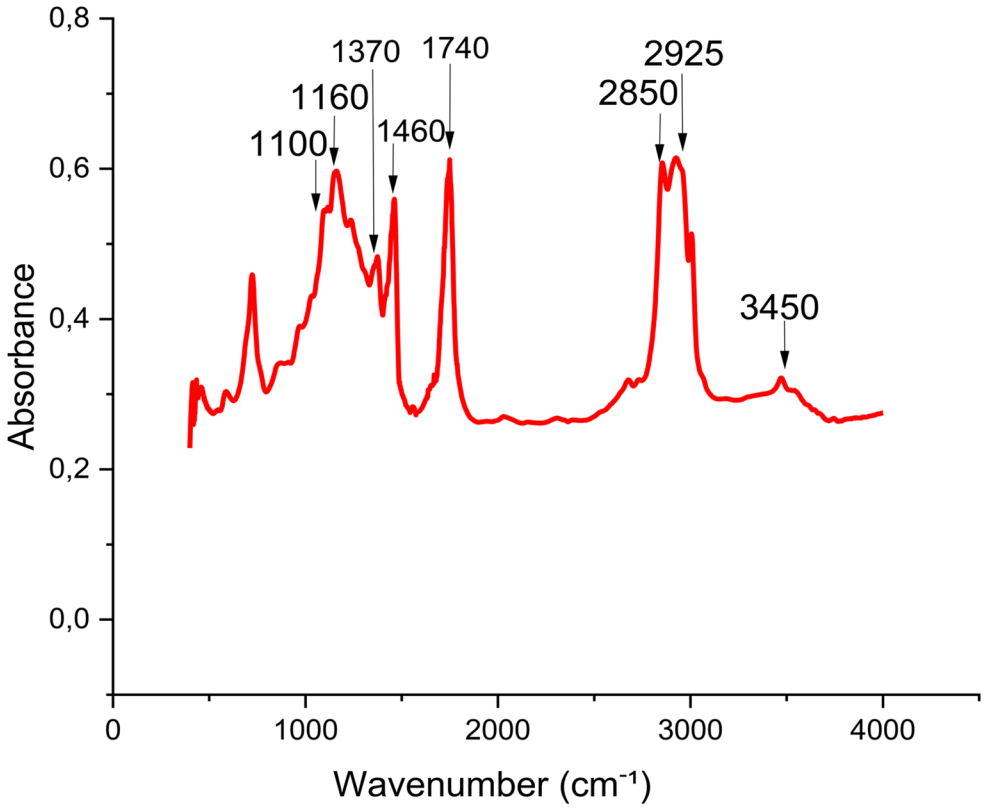

Fig. 4 FTIR spectrum of olive pomace oil at wavenumber of 4000–500 cm^{-1}

Conclusion

This study, conducted for the first time on Algerian *Chemlal* olive pomace, characterized its chemical and bioactive properties before and after drying, while also assessing the quality of the extracted oil. The findings highlight that drying is a critical step in stabilizing OP, significantly reducing its moisture content while preserving and enhancing its bioactive properties, particularly total phenolic compounds (TPC) and antioxidant activity (DPPH•).

Oil extracted from pomace showed satisfactory quality indices, with low acidity and peroxide values reflecting good oxidative stability. The fatty acid composition is dominated by oleic acid (64.60%), giving this oil interesting nutritional and functional qualities. However, improvements in drying processes and storage conditions could further optimize its properties.

Analysis by FTIR spectroscopy confirmed the presence of functional groups characteristic of phenolic compounds, fatty acids and triglycerides, highlighting the chemical richness of OP and the extracted oil. These results underline the potential of these by-products as a source of natural antioxidants and quality oil for food, cosmetic and pharmaceutical applications.

OP is a promising resource for sustainable use in various industries. Future research should focus on innovative extraction methods to optimize the recovery of bioactive compounds and enhance their integration into high-value products.

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Data availability All data generated or analyzed during this study are included in this published article.

Declarations

Conflict of interest The authors declare that there is no conflict of interest regarding the publication of this study.

Competing interest The authors declare that they have no competing interests.

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