Partition of Lipid Classes in Extra Virgin Olive Oil via Classic Liquid Chromatography and Subsequent Characterization Employing GC-FID and ESI-MS

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Olive oil is daily consumed due to its exceptional properties, such as pleasant organoleptic characteristics, oxidative stability, and chemical composition. Moreover, the edible oil has a high content of several compounds, for example, hydrocarbons, tocopherols, aliphatic alcohols, volatile phenolic compounds, pigments, lipids, among others. In order to properly separate, identify, and quantify all lipid species present in olive oil, adequate analytical methods are indispensable. Therefore, this study aimed to employ classic liquid chromatography to separate, identify and quantify the lipid classes in olive oil employing classic liquid chromatography (CLC), gas chromatography with flame ionization detector (GC-FID), and direct infusion by electrospray ionization mass spectrometry (ESI-MS). The results indicated a higher percentage of monounsaturated fatty acids (MUFA) in the non-polar lipid fraction than in the polar fraction, which in turn displayed higher content of saturated fatty acids (SFA) due to its greater affinity towards the stationary phase, while the unsaturated fatty acids (UFA) displayed stronger interactions with the mobile phase. These results concur with those obtained by ESI-MS, which proved possible the partition of polar and non-polar lipid fractions of olive oil by CLC, and that the major triacylglycerols (TAG) of olive oil were identified in the neutral lipid fraction.

Keywords: Fatty acids; triacylglycerols; classic liquid chromatography; gas chromatography; mass spectrometry.

1. Introduction

Olea Europaea, commonly referred as olive tree, is one of the oldest trees discovered, mainly cultivated for its fruits, from which olive oil is extracted. The edible oil is consumed on a daily basis owing to the sheer volume of articles that sustain its outstanding properties, provided by organoleptic characteristics, oxidative resistance, and chemical composition, which lead to olive oil being used as a potential treatment for diseases such as stomach ulcers and skin disorders.1-3

Due to its nutritional benefits and unique sensorial characteristics, olive oil (OO) is widely consumed worldwide. A statistical report by Espadas-Aldan et al. (2019) and IOC (2021), stated that OO consumption skyrocketed between 2000 and 2017, peaking at 2.76×10^6 tons, indicating a 5.2% growth in consumption compared to 2000. To supply this overwhelming demand for OO, the production rates of this vegetable oil also greatly increased4-5

A report by the International Olive Council (IOC) stated that between 2017 and 2018 the global production of OO increased 29.4%, peaking at 3.314×10^6 tons in 2018 4-5. OO is primarily cultivated in the Mediterranean bay, which is responsible for 95% of the world’s production of this vegetable oil. Furthermore, because of adequate climatic conditions, other regions, for example, North Africa, North America, South America, and Asia also invested in OO production. South America, specifically, has a few countries such as Argentina, Chile, and Uruguay who have been cultivating OO for several years. However, Brazil has only recently started investing in OO production, with only three states actively producing the vegetable oil: Minas Gerais, São Paulo, and Rio Grande do Sul. 6-7

Nevertheless, the investments of Brazil in Olive tree cultivation positively influenced national agriculture and agribusiness. According to the Instituto Brasileiro de Azeitonas, in 2018, the production of OO in Brazil increased 42.8% compared to 2017, reaching 150.000 L of OO, thus signaling a growing trend in the national production. 8-9
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OO has a complex chemical composition attributable to the several different compounds in the oil, for instance, hydrocarbons, tocopherols, aliphatic alcohols, volatile phenolic compounds, pigments, lipids, and others. Lipids, the major compounds of OO, are defined as a broad and complex group of organic compounds typically soluble in organic solvents and insoluble in water. Furthermore, lipids can be divided into non-polar lipids, such as triacylglycerols (TAGs), diacylglycerols (DAGs), monoacylglycerols (MAGs), sterols, wax, and fatty acids (FAs), and polar lipids, for instance, phospholipids and glycolipids.\(^{11-12}\)

Despite the wide range of lipids in OO, TAGs are the major components of edible oil and represent 99% of the whole oil composition.\(^{13}\) TAGs molecules consist of three FAs residues, the main lipid class in living beings, attached to a glycerol backbone. In Extra virgin olive oil (EVOO), the major FAs are oleic acid (18:0, 55-83%), followed by linoleic (18:2n-6, 3.5-2.1%), and stearic acids (18:0 0.5%-5%), respectively.\(^{14}\) However, the major compounds of OO,10 are defined as a broad and complex group of organic compounds typically soluble in organic solvents and insoluble in water. Furthermore, lipids need to undergo a derivatization step before instrumental analysis to increase their volatility and thermal stability.\(^{21}\) Mass spectrometry (MS) is a major separation and characterization technique, extensively used to analyze a broad spectrum of molecules as a result of the technique’s ability to detect, characterize and separate molecules based on their mass and charge (\(m/z\)).\(^{22}\) Besides, the technique speed, sensitivity, and selectivity are crucial for the characterization of vegetable oils.\(^{15,28-30}\) Hence, this study aimed to partition, identify, and quantify the lipid classes in EVOO using CLC, GC-FID, and ESI-MS, respectively.

2. Material and Methods

2.1. Reagents and materials

Methanol, acetone, n-heptane, potassium hydroxide, and chloroform were purchased from Synth (São Paulo, Brazil). Analytical standard methyl tricosanoate (23:0me), and ammonium formate (97%) were acquired from Sigma-Aldrich (Darmstadt, Germany). GC-FID analysis was performed using analytical grade reagents. HPLC-grade solvents were used for ESI-MS analysis.

2.2. Samples

EVOO was purchased from the local market in Maringá-PR, Brazil. The oil was stored in its original package, under refrigeration (6 to 10 °C), sheltered from light until analysis.

2.3. Separation of lipid classes in EVOO by classic liquid chromatography

Aliquots of EVOO (2g) were divided into non-polar and polar lipid fractions using CLC, following the procedure proposed by Johnston et al. (1983).\(^{20}\) The column utilized for separation has 30 cm in length and an internal diameter of 2 cm. Silica gel (70-230 mesh, Merck), rinsed with methanol followed by chloroform, was used as stationary phase.

The mixture of solvent and adsorbent was placed on a magnetic stirrer for 1 hour for each new solvent added. After stirring, a vacuum pumped rotary evaporator was utilized
to evaporate solvents in the mixture. Then, the adsorbent was placed in a desiccator until completely dried. Lastly, a slurry prepared with 60 g of adsorbent and a small volume of chloroform, was carefully poured into the column until 16 cm of the column was filled.

Elution of the lipid fractions was performed as follows:
1) Fraction 01: Non-polar lipids were eluted using 200 mL of a 20% acetone/chloroform solution.
2) Fraction 02: Polar lipids were eluted with 200 mL of methanol.

The lipid content of each eluted fraction was determined gravimetrically. Solvents were evaporated using a rotary evaporator. A small volume of chloroform was utilized to transfer the lipid fractions to a previously weighted flat-bottomed flask. The percentage of each lipid fraction was calculated based on the volume of lipid poured into the column.

2.4. Esterification/ Transesterification methodology

Fatty acid esterification and transesterification reactions were performed according to ISO 5509 methodology. First, 0.1 g of lipids and 2 mL of n-heptane were added to a previously weighted test tube. The mixture was stirred for 1 min in a magnetic stirrer. Then, 2 mL of esterification solution KOH/MeOH was added, and stirring maintained for 2 min. Lastly, 0.5 mL methyl tricosanoate (23:0me) was added to the test tube, and the mixture was centrifuged to assist phase separation. After phase separation was completed, the upper phase was collected and injected into a gas chromatograph equipped with a flame ionization detector.

2.5. Fatty acid composition by GC-FID

Chromatographic analysis was performed in a Shimadzu gas chromatograph equipped with a flame ionization detector (FID), split/splitless injector, and a fused silica capillary column GC-2010 Plus (Select FAME, 100.0 m long, 0.25 mm internal diameter, and 0.25 μm thin film of cyanopropyl as stationary phase). Fatty acid methyl esters (FAMEs) were analyzed in triplicate using the following conditions, Table 1.

<table>
<thead>
<tr>
<th>Rate (°C min⁻¹)</th>
<th>Temperature (°C)</th>
<th>Hold Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>165.0</td>
<td>7.00</td>
</tr>
<tr>
<td>4.00</td>
<td>185.0</td>
<td>3.00</td>
</tr>
<tr>
<td>6.00</td>
<td>235.0</td>
<td>2.67</td>
</tr>
</tbody>
</table>

Gas flows of 1.2 mL min⁻¹ and 30 mL min⁻¹ were utilized for carrier (H₂) and make-up (N₂) gases, respectively. In the detector, gas flows of 30.0 mL min⁻¹ and 300.0 mL min⁻¹ of H₂ and synthetic air, respectively, were employed to feed the detector’s flame. 1.0 μL of samples were injected into the gas chromatograph using a 40:1 split ratio. FAMEs were identified by comparing the retention times of the sample’s constituents with those of the Sigma FAMEs analytical standard. All samples were analyzed in triplicate.

2.6. TAG profile by direct infusion ESI-MS

TAGs with ammonium adducts (+ 18,03 m/z) in EVOO’s lipid fractions were detected by triple quadrupole mass spectrometer Xevo TQD™ (Waters, Massachusetts, United States) equipped with a Waters Zspray™ (Milford, Massachusetts, United States) electrospray ionization source.

The analysis was carried out as described by Silveira et al. (2017). 15 0.05 mL of oil was diluted in 0.95 mL of chloroform, then an aliquot of 0.005 mL of this solution was collected and mixed with 1.0 mL of a methanol: chloroform (90:10) solution. Lastly, 0.02 mL of an 0.1 mol L⁻¹ ammonium formate solution was added to the final solution to form adduct ions consequently favoring ionization via [TAG + NH₄⁺]⁺ and enhancing the analysis reproducibility. The final solution was infused into the mass spectrometer with a 10.0 mL min⁻¹ flow. Data were automatically processed by MassLynx™ 4.1 software.

The following conditions were employed for TAG analysis: capillary voltage of 3 kV, cone voltage of 20 V, desolvation temperature of 200 °C, and mass/charge range of 100-1200 m/z. Different TAG species were analyzed.

2.7. TAG identification

The major TAGs detected by ESI-MS for each sample were identified using LAMES platform combined with the Lipid maps® data bank. The platform utilizes an algorithm that predicts the distribution of the FA moieties in the triacylglycerol structure and estimates the content of the specific TAG based on the FA composition of samples.32

2.8. Statistical Analysis

FA composition of samples was determined in triplicate and results were expressed as mean ± standard deviation. GC-FID data were submitted to variance analysis (ANOVA) and compared by Tukey’s test (p < 0.05), using Assistat 7.6 software. 33

3. Results and Discussion

3.1 Fatty acid composition of the lipid fractions

Partition of the lipid fractions of EVOO by CLC utilized a chloroform: acetone (8:2) solution and purified methanol to separate non-polar and polar lipids, respectively. To elute non-polar lipids, 200 mL of the chloroform: acetone (8:2) solution was eluted and collected in four 50 mL fractions.
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The fatty acids detected in OO are majorly responsible for the organoleptic and biological properties of the oil, as well as its numerous health benefits. For instance, the World Health Organization (WHO) recommends the consumption of OO for a diet rich in MUFAs since they are preferable over SFAs due to their capability of regulating cholesterol levels in the blood. Furthermore, oleic acid, the major FA of OO, has several health benefits such as helping control the secretory activity of both pancreas and liver, and decreasing the risk of developing gastric-duodenal ulcers and cardiovascular diseases. However, OO also has a substantial content of palmitic acid, which despite its nutritional benefits must be consumed with caution as SFA-rich diets are severely condemned for being attributed to the lipotoxicity of numeral organs and increasing the risk of developing diabetes and cardiovascular diseases. Nonetheless, the Food and Drug Administration (FDA) recommends consuming two spoons of OO daily.

MUFAs were the major compounds in all non-polar lipid classes analyzed, however, none of the FNs showed significant differences in their FA composition in comparison to other neutral fractions analyzed, which indicates that the chloroform: acetone (8:2) solution utilized may not be efficient to concentrate a specific FA. On the other hand, the purified methanol used as mobile phase to elute Fraction 02 demonstrated efficiency in concentrating predominantly SFA throughout collected FPs, while the higher percentages for MUFAs and PUFAs were obtained in the first polar lipid fraction.

3.2. Triacylglycerol composition

Although EVOO is composed predominantly of TAGs and FAs, the edible oil has numerous minor polar compounds, for instance, partial glycerides, hydrocarbons, tocopherols, pigments, sterols, alcohols, triterpenic acids, volatile compounds, phenolic compounds, and phospholipids.

Aiming to identify the lipid profile of each lipid fraction of EVOO, ESI-MS was applied since the technique is capable of providing results swiftly for a broad spectrum of polar molecules without requiring a sample preparation step before analysis, such as esterification/transesterification reactions. Additionally, ESI-MS allows quick characterization of samples via fingerprinting. TAGs of EVOO were identified and the main triacylglycerol was OOO, followed by POO, OOL, and SOO, where O, P, L, and S refer to oleic, palmitic, linoleic, and stearic acids, respectively. Figure 2 illustrates the spectra of the four non-polar lipid fractions collected in the region of 100-1050 m/z.

For EVOO, the region of DAG and TAG predominance was 600-800 m/z and 800-1050 m/z, respectively. The most
intense ion peak in EVOO was 902 m/z (OOO) which concurs with the results found by Silveira et al. (2017) where the same TAG exhibited the highest intensity.

Figure 3 demonstrates the mass spectra in the region of 100-1100 m/z for the polar lipid fractions of EVOO. As shown in figure 3, as the volume of eluent permeating the column increased the intensity of MAGs, DAGs, and TAGs decreased.

Table 2 exhibits the estimated percentage for the major TAGs detected in each eluted polar and non-polar lipid fraction.

As shown by table 2, twenty-five TAGs were identified in the non-polar lipid fraction whereas twenty-seven TAGs were identified in the polar lipid fraction, except for FP1 which, in contrast to the other eluted polar lipid fractions, did not present TAGs MOP (822 m/z) and MOO (848 m/z). Curiously, a TAG profile exceptionally similar to the non-polar lipid fractions was observed for FP1 despite the changes to the eluent’s strength. The similarity among the profiles of the non-polar fractions and FP1 was triggered by altering the eluent’s polarity, which subsequently affected the differential migration of the constituents of olive oil owing to new interactions with the eluent and stationary phase. From table 2, the major triacylglycerols detected in the neutral lipid fraction of olive oil were OOO (902 m/z) and POO (876 m/z). These results concur with those by Silveira et al. (2017), Simas et al. (2010). Besides POO (876 m/z) and OOO (902 m/z), the polar lipid fraction was also predominantly composed of SOO (904 m/z) and POP (850 m/z). Furthermore, the estimated concentration for TAGs in each lipid fraction substantiates the FA composition quantified for the respective samples, as demonstrated...
by Table 2. OOO intensity in the non-polar lipid fraction was substantially higher than that found for the same triacylglycerol in the polar lipid fraction, which indicates that the eluent employed to elute the neutral lipid fraction, a solution of chloroform: acetone (8:2), offered a better separation and higher intensities due to its greater selectivity compared to purified methanol. Moreover, as the non-polar lipid fractions were collected POO intensity increased and OOO decreased.

Also, the neutral lipid fraction displayed greater intensities for the major TAGs of olive oil in comparison with the polar lipid fraction because of the eluent’s polarity, the interaction between the stationary phase and analytes, and the effect of altering the eluent’s strength on its selectivity, since the results indicate that free FAs were eluted first, followed by flavonoids, steroids, phenolic acids, and hydrocarbons.42

### 4. Conclusion

Data provided by GC-FID and ESI-MS analysis demonstrated that classic liquid chromatography can be applied as a sample preparation technique to partition the lipid classes in EVOO. Furthermore, the fatty acid analysis indicated a greater content of MUFAs in the neutral lipid fraction in comparison with the polar lipid fraction which was richer in SFAs. These results were concurred by ESI-MS analysis.
data since the major TAGs of EVOO were detected with greater intensities in the non-polar lipid fraction of the oil.

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Conflict of interest

No potential conflict of interest was reported by the authors.

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