Purity of Olive Oil Commercially Available in Poland

Ying Qian¹*, Anna Grygier¹, Arkadiusz Majewski², Dorota Walkowiak-Tomczak¹, Aleksander Siger¹, and Magdalena Rudzińska¹

¹ Poznań University of Life Sciences, Faculty of Food Science and Nutrition, Wojska Polskiego 28, 60-637 Poznań, POLAND
² Poznań University of Medical Sciences, Department of Computer Science and Statistics, Rokietnicka 7, 60-806 Poznań, POLAND

Abstract: The aim of this study was to examine olive oils purchased in Poland for their compliance with label declarations and EEC criteria. Statistical analysis was used to compare the olive oils in terms of their content and composition of essential constituents and color parameters. Fifty olive oils (extra virgin, bio-extra virgin, cold-pressed, refined, and pomace) from different countries (Spain, Italy, Greece, Portugal, Germany, France, Israel, and the European Union), were purchased commercially in Poland. The contents of triacylglycerols, sterols, and tocopherols, the fatty acid composition, and the color parameters were determined using chromatographic and spectrophotometric methods. Statistical methods were used to divide the olive oils into clusters. Our results show that the composition and color parameters of olive oils available commercially in Poland, excluding pomace olive oils, are similar. It can thus be concluded that, irrespective of the type of olive oil stated on the label, their quality is the same or very similar.

Key words: olive oil, triacylglycerols, fatty acids, tocopherols, phytoesteroles, color

1 Introduction

Olive oil is obtained from the fruits of the olive tree (Olea europaea). This oil has a long history, and olive trees can bear fruit for over a century. Olive trees are grown mainly in Mediterranean countries such as Greece, Spain, Italy, Tunisia, Turkey, Morocco, and Syria. Australia and California are also new sources of olive oil. Global annual production of olive oil is about three million tons. The consumption of olive oil is the highest in Spain and Italy, followed by North America. A rapid increase in the demand for olive oil is evident in countries such as India, China, and Japan, closely linked to increases in domestic production. The production and consumption of olive oil in Brazil is also expected to increase in the coming years. An olive oil may be described as virgin, pomace, or refined. Commission Regulation (EEC) No 2568/91 described the quality criteria for olive oil and olive pomace oils and distinguished eight types: extra virgin olive oil, virgin olive oil, lampante virgin olive oil, refined olive oil, olive oil, crude olive–pomace oil, refined olive–pomace oil, and olive–pomace oil. The differences between these oils are measured by organoleptic analysis, free acidity, peroxide value, free fatty acids, wax content, fatty acids, triacylglycerols, sterols, alcohols, 2-glycerol mono-palmitate, and absorbance in the ultraviolet. Additives to virgin olive oils or olive–pomace oils are not allowed. Only α-tocopherol can be added to refined olive, refined olive–pomace oils, olive, and olive–pomace oils.

Olive oil is characterized by a high level of oleic acid and antioxidant compounds. The Codex Alimentarius states that olive oil consists of 55%–83% oleic acid, followed by 7.5%–20% palmitic acid and 3.5%–21% linoleic acid. The antioxidative compounds in olive oils include phenolic compounds, chlorophylls, carotenoids, sterols, squalene, and α-tocopherol. The antioxidant properties of olive oils depend on agricultural techniques, harvest time, and climate conditions. The minimum total sterol content depends on the type of olive oil, and ranges from 1000 mg/kg in virgin and refined olive oil to 1800 mg/kg in pomace and refined pomace olive oil. Olive oils contain 0.15–61.96 mg/kg chlorophyll and 0.53–31.51 mg/kg carotenoids. These compounds are responsible for the green color of the oil. The maximal levels of phenol and tocopherols in olive oil are 1000 mg/kg and 600 mg/kg oil respectively.

Global olive oil production has increased from 105 million tons (2001–2006) to 169 million tons (2011–2016), an increase of 61%. It has been forecast that, in the coming years the demand for virgin olive oil will increase due to its growing acceptance for culinary purposes. This change is associated with the increasing awareness of the importance of healthy eating. The consumption of olive oil in Poland has been increasing for 12 years on account of
both greater awareness of the positive effects of olive oil on health and the increasing number of tourist trips being made to the Mediterranean Sea by Poles, who experience the regional cuisine and wish to recreate it at home. Olive oil now accounts for 0.2% of the energy supplied with food in the average Polish diet.

Many varieties and brands of olive oils are commercially available in Poland. Polish consumers tend not to prefer high-quality extra virgin olive oils, on account of their pungent, bitter taste and dark color. Light and soft oils are better accepted. This may be the reason that low-quality olive oils are wrongly distributed in Poland with the label "Extra Virgin Olive Oil" (EVOO).

The aim of this work was to study olive oils purchased in Poland for their compliance with label declarations and EEC criteria. Statistical analysis was used to compare the olive oils on the basis of content and composition of essential constituents and color parameters.

2 Materials and Methods
2.1 Materials
Fifty different olive oils were purchased commercially in Poland. When purchasing the oils, no criterion other than availability on store shelves was taken into account. Most of the oils were produced in Spain (25), followed by Italy (12), Greece (4), Portugal (3), Germany (1), France (1), Israel (1), and the European Union (3). Most of the oils (45, including three described as "bio extra virgin", meaning "organic") were extra virgin olive oil. Two refined olive oils, two pomace olive oils, and one cold-pressed olive oil were also examined. The analysis was performed in September 2019, when all the oils were within their shelf lives. Two samples were taken from each oil for analysis. The types of oils and countries of origin are presented in Table 1.

Analytical-grade solvents were purchased from Sigma-Aldrich (Steinheim, Germany). Fatty acids methyl esters: saturated and unsaturated kites; phytosterols: β-sitosterol, campesterol, stigmasterol, Δ5-avenasterol, 5α-cholestanol (Internal Standard); tocopherols: α-, β- and γ-tocopherols, pyridine and BSTFA with 1% TMCS were obtained from Sigma-Aldrich (St. Louis, MO, USA). Standards of triacylglycerols: trioleoyl-glycerol (OOO); 1,2-oleoyl-3-sn-palmitoyl-glycerol (OOP); 1,2-palmitoyl-3-oleoyl-sn-glycerol (PPO); 1,2-palmitoyl-3-linoleoyl-sn-glycerol (PLL); 1,2-oleoyl-3-stearoyl-sn-glycerol (OOS); 1-palmitoyl-2-stearoyl-3-oleoyl-sn-glycerol (PSO); 1-palmitoyl-2-oleoyl-3-linoleoyl-sn-glycerol (POL); 1,2-oleoyl-3-linoleoyl-sn-glycerol (OLL); and trinonadecanoyl-glycerol (NNN, Internal Standard) were purchased from Larodan (Solna, Sweden). KOH in methanol was obtained from Chempur (Piekary Śląskie, Poland).

| Table 1 | Type and country of origin of tested oils. |
|---------|---------------------------------|
| Type of oil | Country of origin | Number of oils |
| extra virgin | Spain | 23 |
| extra virgin | Italy | 10 |
| extra virgin | Portugal | 3 |
| extra virgin | blend of olive oils | 3 |
| extra virgin | Greece | 2 |
| extra virgin | Israel | 1 |
| bio extra virgin | Germany | 1 |
| bio extra virgin | Italy | 1 |
| bio extra virgin | France | 1 |
| cold pressed | Greece | 1 |
| refined | Italy | 1 |
| refined | Spain | 1 |
| pomace | Spain | 1 |
| pomace | Greece | 1 |

2.2 Triacylglycerols
To determine TAG concentrations, a 0.2% solution of olive oil in dichloromethane with an internal standard (NNN-trinonyl-glycerol) were prepared. To separate the TAGs from the olive oil, a Trace 1300 gas chromatograph (Thermo Scientific, Waltham, MA, USA) equipped with an Rtx-65TG capillary column (30 m × 0.25 mm × 0.1 μm, Bellefonte, PA, USA) and a flame ionization detector were used. The carrier gas was hydrogen at a flow rate of 1.5 mL/min. The initial oven temperature was 250°C, increasing by 4°C/min to 360°C, where it remained for 2.5 min. The temperature of the injector and detector was 350°C. TAGs were identified by comparing retention times with standards. TAGs were determined in duplicate.

2.3 Fatty acid composition
A Trace 1300 gas chromatograph equipped with an SP-2560 capillary column (100 m × 0.25 mm × 0.2 μm, Supelco, Darmstadt, Germany) and an FID detector was used to separate FAME. The carrier gas was hydrogen with a flow rate of 1.5 mL/min. The initial oven temperature was 160°C, increasing at 12°C/min to 220°C, where it was held for 20 min. The temperature of the detector was 240°C. Fatty acids were identified in comparison with retention time of standards. Fatty acids were determined in duplicate.

2.4 Tocopherols
Liquid chromatography was used to determine the tocopherol content in the oils. Each olive oil (200 mg) was dissolved in 10 mL of hexane and analyzed using HPLC liquid chromatography with a Waters HPLC System (Waters, Milford, MA) with the LiChrosorb Si 60 (250 × 4.6
Purity of Olive Oil

2.5 Phytosterols
A total of 0.05 g of each olive oil and 50 µg of internal standard (5α-cholestanol) were saponified using 1 M KOH in methanol. Extraction of the sterol fraction was performed using hexane:MTBE (1:1, v/v). The solvent was evaporated by nitrogen and the sample was dissolved in 100 µL of pyridine. It was then silylated by BSTFA with 1% TMCS. The phytosterols were analyzed using a Hewlett-Packard 6890 gas chromatograph in splitless mode with an FID detector. We used a DB-35MS capillary column (30 m × 0.25 mm × 0.25 µm, J&W Scientific, Folsom, CA, USA). The injector and detector were kept at 300°C; the oven temperature was initially 100°C for 5 min, increasing at 25°C/min to 250°C and then at 3°C/min to 290°C. The final temperature was held for 20 min. The carrier gas was hydrogen and the flow rate was 1.5 mL/min. Sterols were identified by comparing their retention times with those of standards. The sterols were determined in duplicate.

2.6 Color
Color was measured instrumentally in a CM-3600d spectrophotometer (Konica-Minolta, Tokyo, Japan) equipped with software (Color Data Software Spectra Magic). The spectrophotometer was calibrated with a white standard board following the instructions in the software. Measurements were carried out in transmitted light, with a D65 light source and an observation angle of 10°, in cuvettes in an optic layer of 1 cm in thickness. Color parameters were determined in the CIE XYZ system. The XYZ components are expressed by the trichromatic coordinates of Yxy, where the Y component corresponds to luminance (brightness) and the xy components to color chromaticity. The color determinations were made in duplicate.

3 Results and Discussion
The oils for the study were purchased randomly, though with the same distribution of producing countries as represented on the store shelves. The main producer of olive oils is Spain, followed by Italy, Greece, and Portugal and this is reflected in the origins of the olive oils on the shelves in Polish stores. Extra virgin olive oils are the most common type on the Polish market.

3.1 Statistics
Cluster analysis began by choosing one of the hierarchical methods, of which agglomeration techniques are most often used. The Ward method that we chose differs from other methods in that it uses the variance analysis approach to estimate the distance between clusters. This method aims to minimize the sum of squares of deviations within clusters. ESS (Error Sum of Squares), also known as the sum of squares error, measures the variation in clustering relative to the mean values. ESS is given by the formula:

\[ ESS = \sum_{i=1}^{n} (x_i - \bar{x})^2 \]

Where:
\[ x_i \] is the value of the variable that is the segmentation criterion for the \( i \)-th object.
\( k \) is the number of objects in focus.

Before starting the calculations, we verified the empirical data in terms of outliers and standardized variables using \( z_i = \frac{x_i - \mu}{\sigma} \), where \( \bar{x} \) is the average and \( SD \) is the standard deviation of the variable in the sample. The result is a dendrogram illustrating the hierarchical structure of the set of objects due to the decreasing similarity between them. For each olive oil, we prepared a tree graph and a plot of the binding distance versus binding steps. The Ward method allowed the selection of the correct number of clusters for k-means grouping. The k-means method uses a known number of clusters, allowing the assignment of individual cases to the appropriate cluster in tabular form.

Having assigned individual olive oils to their clusters, we looked to see which oils were similar in their features and which differed significantly using analysis of variance (ANOVA). We checked whether the samples followed the normal distribution; statistically significant differences were determined, and then the Tukey HSD post hoc test was used to determine the homogeneous groups and their significant differences.
using the variables that characterize them; one important part of cluster analysis is thus to appropriately select the variables used to generate the clusters. Grouping combines objects that are close together but far from others, creating a different focus. The distance function is defined for pairs of objects and takes nonnegative real number values. Its form depends on whether the variables are quantitative, ordinal, or qualitative in nature.

Figure 1 presents a tree graph illustrating the clusters obtained for the total TAG contents of the oils. Figure 2 illustrates the increase in binding length in the subsequent steps of the cluster analysis of TAG levels in olive oils. Based on the vertical line in Fig. 2, we can conclude that cutting off the graph at a standardized distance of 9.56 would allow us to identify as many as four clusters in Fig. 1. The clusters are distant at this point, and this is the best location for a cut-off. Significant differences between clusters were shown (Table 3, \( p < 0.05 \)). There are 14 oils in cluster 1, nine in cluster 2, fifteen in cluster 3, and twelve in cluster 4. The average TAG content of the oils in clusters 1 and 2, and in clusters 3 and 4 clusters are similar (Table 4). Most Greek olive oils (75\%) are in cluster 1. All the olive oils in cluster 2 were refined, while 67\% of the oils describing themselves as “bio extra” fell into cluster 1. A total of 54\% of the olive oils belong to clusters 3 and 4, which have highest levels of TAGs. The average amount of PPL and OOP by the Tukey HSD test is the most homogeneous variable tested. Significant differences between clusters occur in terms of the average amount of LLO in oils, while the clusters differ most in terms of OOO (Fig. 3).

Göktebağ et al. found that TAG composition was the most useful parameter to distinguish between varieties and their

| Variable | Minimum | Maximum | Median | Average | Standard Deviation |
|----------|---------|---------|--------|---------|-------------------|
| PPO      | 18.21   | 95.76   | 61.71  | 57.58   | 18.21             |
| PPL      | 3.88    | 61.80   | 12.69  | 15.75   | 9.39              |
| PSO      | 5.37    | 32.6    | 15.72  | 15.15   | 4.28              |
| OOP      | 168.99  | 289.09  | 239.42 | 241.29  | 23.11             |
| POL      | 29.74   | 218.74  | 83.27  | 89.88   | 34.09             |
| OOS      | 12.04   | 76.99   | 49.94  | 47.89   | 15.28             |
| OOO      | 168.80  | 512.18  | 358.91 | 358.58  | 68.64             |
| OOL      | 44.44   | 165.43  | 109.55 | 104.01  | 27.99             |
| LLO      | 0.00    | 30.31   | 10.70  | 10.02   | 8.90              |
| Total    | 690.99  | 999.92  | 959.80 | 940.15  | 64.09             |

1,2-palmitoyl-3-oleoyl-sn-glycerol (PPO); 1,2-palmitoyl-3-linoleoyl-sn-glycerol (PPL); 1-palmitoyl-2-stearoyl-3-oleoyl-sn-glycerol (PSO); 1,2-oleoyl-3-sn-palmitoyl-glycerol (OOP); 1-palmitoyl-2-oleoyl-3-linoleoyl-sn-glycerol (POL); 1,2-oleoyl-3-stearoyl-sn-glycerol (OOS); trioleoyl-glycerol (OOO); 1,2-oleoyl-3-linoleoyl-sn-glycerol (OOL); 1,2-linoleoyl-3-oleoyl-sn-glycerol (LLO)
Purity of Olive Oil

Table 3 Summary of homogeneous groups and significant differences based on Tukey’s HSD post hoc test.

| Cluster | Mean   | Group 1 | Group 2 | Group 3 | Cluster | Mean   | Group 1 | Group 2 | Group 3 |
|---------|--------|---------|---------|---------|---------|--------|---------|---------|---------|
| c2      | 885.4240 |        |         |         | c1      | 0.023619 | 0.913908 | 0.042568 |
| c1      | 935.9555 | ****   |         |         | c2      | 0.023619 | 0.003792 | 0.000145 |
| c3      | 945.6999 | ****   | ****    |         | c3      | 0.913908 | 0.003792 | 0.162733 |
| c4      | 978.9329 | ****   |         |         | c4      | 0.042568 | 0.000145 | 0.162733 |

Table 4 Percentage of fatty acids in olive oils.

| Fatty Acid | Minimum | Maximum | Median | Average | Standard Deviation |
|------------|---------|---------|--------|---------|--------------------|
| C16:0      | 3.87    | 12.43   | 7.73   | 7.83    | 1.83               |
| C16:1      | 0.17    | 1.15    | 0.36   | 0.39    | 0.19               |
| C18:0      | 0.37    | 1.57    | 0.98   | 0.97    | 0.22               |
| C18:1      | 73.72   | 92.93   | 86.65  | 85.86   | 3.64               |
| C18:2      | 1.37    | 11.56   | 4.24   | 4.67    | 2.18               |
| C18:3      | 0.14    | 0.39    | 0.25   | 0.25    | 0.05               |

Fig. 3 Average concentrations of individual TAGs by cluster.

Table 5 presents the minimum, maximum, median, average, and standard deviations of fatty acids composition in the olive oils. The average percentage of individual fatty acids in the tested oils was typical of olive oils. The main fatty acid was oleic acid C18:1, which made up about 86%. According to Codex Alimentarius, there are no differences in the fatty acid percentages of different types of oils, other than for trans-fatty acids, which we did not detect here. The research of Wabaidur et al. and Martínez et al. also failed to detect trans-fatty acids.

The olive oils fell into six clusters, with clusters 1 through 6 containing 12, 8, 3, 14, 7, and 6 oils, respectively. All Greek olive oils were in cluster 3, and 67% of so-called "bio extra" virgin oils were in cluster 1. García & López attempted to predicted fatty acid levels for oils from Spain, Portugal, and Italy. The largest variation in fatty acids occurred between Spanish and Italian oils, while the smallest difference was between Portuguese and Italian. This research did not detect similarities in cluster membership between Spanish, Italian, and Portuguese oils: each olive oil from Portugal belonged to a different cluster, while half of the Italian samples belonged to cluster 1, and 48% of Spanish samples belonged to cluster 4. Martínez et al. studied fatty acid contents of olive oils from five regions of Spain, finding that the results for one particular region differed significantly from those of the others. The four regions also showed some differences in fatty acid percentages.

The main tocopherol homolog in olive oil is α-tocopherol. The determination of α-tocopherol levels in olive oil can be useful to detecting adulteration. Tocopherol content of olive oil depends on the type of olive and to a lesser extent on its ripeness and the climate. In the research of Baiano et al., tocopherols varied with were found, but were not affected by geographical origin. Table 6 shows the minimum and maximum values, medians, averages, and standard deviations of the tocopherol homolog levels we
found in the olive oils. Tocopherol levels ranged from 13.58 to 42.75 mg per 100 g, with an average of 22.58 mg per 100 g, including 21.41 mg per 100 g \(\alpha\)-tocopherol. After the ANOVA test, oils were divided into two homogeneous groups by \(\gamma\)-tocopherol content; while \(\alpha\)-tocopherol and \(\beta\)-tocopherol led to a division into three homogeneous groups. This means there was greater variety of \(\alpha\)-tocopherol and \(\beta\)-tocopherol content in the oils. Overall, all the oils fell into one of five clusters, of which the largest, cluster 3, contained 18 oils. Of the Spanish olive oils, 37.5\% and 42\% fell into clusters 2 and 3, respectively. Comparing the tocopherol levels in the Spanish oils with the results of Beltrán et al.\cite{14}—from 16.3 mg per 100 g to 510 mg per 100 g—the oils purchased in Poland had a lower range of tocopherol values, from 14.56 mg per 100 g to 31.90 mg per 100 g. The total tocopherols in the Portuguese oils are within the range given by Matos et al.\cite{17}, who characterized Portuguese olive oils. Half of the oils from Greece were in cluster 5. Tocopherol content of the Greek oils ranged from 18.48 mg to 42.66 mg per 100 g—higher than found by Psomiadou et al.\cite{18}, who found values of 9.8 mg to 37.0 mg per 100 g. In total, 67\% of the “bio extra” virgin olive oils were in cluster 5. All the pomace oils were in cluster 1, where tocopherol values were highest; this cluster contained only three oils. Cluster 4 contained eight oils, which had the lowest tocopherol levels. Both clusters 1 and 4 are statistically significantly different from the others clusters. All refined and “bio extra” virgin oils were in the uniform clusters 2, 3, and 5. The average \(\gamma\)-tocopherol content relates two homogeneous groups. More statistically significant differences were found for the average \(\alpha\)- and \(\beta\)-tocopherol contents, with three homogeneous groups (Fig. 4).

The sterol contents ranged from 1076 to 4276 mg/kg. The Codex Alimentarius\cite{4} describes olive oil quality categories with minimum sterol values for each. Virgin, refined, and olive oil cannot have less than 1000 mg/kg; refined

---

**Table 5** Tocopherol levels in olive oils (mg/100 g).

|        | minimum | maximum | median | average | standard deviation |
|--------|---------|---------|--------|---------|--------------------|
| \(\alpha\)-T | 13.25   | 41.45   | 20.70  | 21.41   | 4.54               |
| \(\beta\)-T | 0.12    | 0.39    | 0.20   | 0.20    | 0.05               |
| \(\gamma\)-T | 0.13    | 1.88    | 0.96   | 0.96    | 0.38               |
| total   | 13.58   | 42.75   | 22.00  | 22.58   | 4.59               |

\(\alpha\)-T: alpha-tocopherol; \(\beta\)-T: beta-tocopherol; \(\gamma\)-T: gamma-tocopherol.

**Table 6** Sterol levels in olive oils (mg/kg).

| Sterol               | minimum | maximum | median | average | standard deviation |
|----------------------|---------|---------|--------|---------|--------------------|
| campesterol          | 30.76   | 125.81  | 50.59  | 53.93   | 17.88              |
| campestanol          | 3.94    | 41.82   | 16.57  | 17.85   | 6.72               |
| stigmasterol         | 1.68    | 64.64   | 12.76  | 14.96   | 10.13              |
| \(\beta\)-sitosterol | 667.54  | 3079.96 | 1081.68| 1176.84 | 379.31             |
| sitostanol           | 8.43    | 752.24  | 22.11  | 32.57   | 74.00              |
| \(\Delta\)5-avenasterol | 47.94  | 315.36  | 93.64  | 112.59  | 85.33              |
| stigmasta-5,24-dienol| 15.13   | 231.00  | 85.73  | 89.67   | 38.73              |
| gramisterol+\(\alpha\)-amyrin | 0.00  | 129.68  | 66.25  | 68.57   | 20.84              |
| cycloartenol         | 95.74   | 1262.04 | 275.67 | 345.63  | 200.40             |
| 24-methylenecycloartanol | 31.42  | 226.53  | 78.30  | 86.4    | 36.89              |
| total sterols        | 1075.72 | 4276.48 | 1867.64| 2022.93 | 567.53             |

---

![Fig. 4](image-url) Average concentrations of individual tocopherols by cluster (\(\alpha\)-T: alpha-tocopherol; \(\beta\)-T: beta-tocopherol; \(\gamma\)-T: gamma-tocopherol).
pomace olive oil should have at least 1800 mg/kg, while olive–pomace oil must have 1600 mg/kg sterols. All the oils we test met the above standard. Only one olive oil was had very low levels of sterols, below 1300 mg/kg, thus falling into category 5 of Kyçyk et al.\textsuperscript{10}. Fifteen olive oils were had very high sterol levels of over 2200 mg/kg, which is those authors’ category 1. Table 7 shows the minimum and maximum values, medians, averages, and standard deviations of sterol values. The main sterol was $\beta$-sitosterol, whose concentration ranged from 667.54 mg/kg to 3079.96 mg/kg. The amount of $\beta$-sitosterol in olive oil depends on the year of cultivation, while the amount of campesterol and stigmasterol varies with fruit ripeness\textsuperscript{20}. Genetic component also affects the total sterol content\textsuperscript{10}.

The sterol concentration of the olive oils could be described with four clusters. Cluster 3 was the largest, with 35 oils, including 79% of Spanish oils, 67% of Italian oils, and 67% of Portuguese olive oils was in that cluster. Cluster 1 contained 50% of the Greek oils. All the pomace olive oils were in cluster 4, which was characterized by the greatest sterol concentrations, and contained only three oils. Cluster 3 contained 76% of the extra virgin olive oils and 67% of the "bio extra" virgin olive oils. The olive oils in clusters 1 and 2 are similar in terms of sterols. Cluster 3 was characterized by lower levels of sterols. Campesterol, campestanol, sitosterol, and stigmastera-5,24-dienol form three homogeneous groups from all clusters in terms of the average sterol content of the olive oils (Fig. 5). The remaining sterols form two homogeneous clusters.

Two types of compound affect the color of olive oil: chlorophylls and carotenoids. Table 7 shows the minimum and maximum values, medians, averages, and standard deviations of the color parameters. The average X, Y, Z parameters are respectively 60.31, 63.14, and 6.94. Moyano et al. found the average of these parameters to be higher, at respectively 63.48, 67.58, and 13.97. X, Y, and Z increase with the ripening of the olives, and the extracted oils are darker\textsuperscript{20}. The X, Y, Z parameters group the olive oils into 6 clusters. Greek olive oils fall 50% into cluster 1 and 50% into cluster 2. In the case of extra virgin olive oils, 26% belong to cluster 1 and again 26% belong to cluster 2. All olive oils in clusters 4 and 6 were extra virgin olive oil.

The oil clusters were analyzed, taking into account the total TAGs, sterols, and tocopherols. The Tukey test gives the homogeneity of the total tocopherols in all clusters. There are no differences between tocopherol contents of the oils, which excludes this parameter for oil differentiation. The situation is different in the case of TAGs and sterols, the average totals of which fall into three homogeneous groups. The TAG analysis shows significant differences between clusters 4 and 1, 4 and 5, 4 and 2, 3 and 2, and 3 and 4. The sterol analysis showed significant differences between clusters 5 and 1, 2 and 1, 2 and 5, 4 and 1, 4 and 2, 3 and 1, 3 and 5, and 3 and 4. The resulting aggregation groups and homogeneous groups do not correspond to the types of oil approved by Commission Regulation (EEC) No 2568/91\textsuperscript{11}.

In summary, cluster 1 of tocopherols and cluster 4 of sterols consist of the same three olive oils (nr 1, 15 and 40). These oils contain the highest levels of sterols and tocopherols, and have the lightest and greenest colors. Two of these oils are pomace olive oils, and another was labeled as EVOO. This last is likely also a pomace olive oil, but has been mislabeled named by the supplier. Adulteration of oils with other vegetable oils was not detected, but we cannot exclude the possibility that some lower quality olive oils were added. Additionally, we did not find any differences between the olive oils labelled cold-pressed, bio extra virgin, extra virgin, and refined olive oils.

### 4 Conclusion

Our results showed that the composition and color parameters of olive oils available commercially in Poland, excluding pomace olive oils, are similar. It can thus be concluded that, irrespective of the type of olive oil stated on the label, their quality is the same or very similar.

**Table 7** Values X, Y, Z color parameters in olive oils.

|   | minimum | maximum | median | average | standard deviation |
|---|---------|---------|--------|---------|-------------------|
| X | 51.00   | 75.37   | 59.64  | 60.31   | 3.98              |
| Y | 51.02   | 81.18   | 62.03  | 63.14   | 5.65              |
| Z | 0.76    | 56.38   | 3.43   | 6.94    | 10.07             |
References
1) Commission Regulation (EEC) No 2568/91 On the characteristics of olive oil and olive-residue oil and on the relevant methods of analysis.
2) Harwood, J.; Aparicio, R. Handbook of olive oil. Analysis and properties. An Aspen Publications, Gaithersburg, Maryland, USA (2000).
3) Koseoğlu, O.; Sevim, D.; Kadiroğlu, P. Quality characteristics and antioxidiant properties of Turkish monovarietal olive oils regarding stages of oil ripening. Food Chem. 212, 628-634 (2016).
4) Codex Alimentarius. Codex Standard for Olive Oils and Olive Pomace Oils, Codex Stan 33-1981. Food and Agriculture Organization of the United Nations. World Health Organization (2013).
5) Moyano, M.J.; Meléndez-Martínez, A.J.; Alba, J.; Herreria, F.J. A comprehensive study on the color of virgin olive oils and its relationship with their chlorophylls and carotenoid indices (I): CIEXYZ non-uniform color space. Food Res. Int. 41, 505-512 (2008).
6) Wroniak, M.; Maszewsk, M. Olive oil in mediterranean diet. Żywność. Nauka. Technologia. Jakość 78, 26-36 (2011).
7) Rosiak, E. The global market for vegetable oils. Problems of World Agriculture 32, 73-181 (2017).
8) Górska-Warsewicz, H.; Rejman, K.; Laskowski, W.; Czeczotko, M. Butter, margarine, vegetable oils, and olive oil in the average polish diet. Nutrients 11, 2935 (2019).
9) Mun, E.Y.; von Eye, A.; Bates, M.E.; Vaschillo, E.G. Finding groups using model-based cluster analysis: heterogeneous emotional self-regulatory processes and heavy alcohol use risk. Dev. Psychol. 44, 481-495 (2008).
10) Gökçebağ, M.; Durman, H.; Ozdemir, D. Classification of Turkish monocultivar (Ayvalık and Memecik cv.) virgin olive oils from north and south zones of Aegean region based on their triacylglycerol profiles. J. Am. Oil Chem. Soc. 90, 1661-1671 (2013).
11) Wabaidur, S.M.; AlAnnumari, A.; Aqel, A.; AL-Tamrah, S.A.; Alothman, Z.A.; Ahmed, A.Y.B.H. Determination of free fatty acids in olive oils by UPHLC–MS. J. Chromatogr. B 1031, 109-115 (2016).
12) Martínez, M.; Fuentes, M.; Franco, N.; Sánchez, J.; de Miguel, C. Fatty acid profiles of virgin olive oils from the five olive-growing zones of Extremadura (Spain). J. Am. Oil Chem. Soc. 91, 1921-1929 (2014).
13) García, M.V.A.; López, R.A. Characterization of European virgin olive oils using fatty acids. Grasas y Aceites 44, 18-19 (1993).
14) Beltrán, G.; Jiménez, A.; Río, C.; Sánchez, S.; Martínez, L. et al. Variability of vitamin E in virgin olive oil by agonomical and genetic factors. J. Food Comp. Anal. 23, 633-639 (2010).
15) Baiano, A.; Terracane, C.; Viggiani, I.; Del Nobile, M.A. Effects of cultivars and location on quality, phenolic content and antioxidiant activity of extra-virgin olive oils. J. Am. Oil Chem. Soc. 90, 103-111 (2013).
16) Cunha, S.C.; Amaral, J.S.; Fernandes, J.O.; Oliveira, M.B.P.P. Quantification of tocopherols and tocotrienols in Portuguese olive oils using HPLC with three different detection systems. J. Agric. Food Chem. 54, 3351-3356 (2006).
17) Matos, L.C.; Cunha, S.C.; Amaral, J.S.; Pereira, J.A.; Andrade, P.B. et al. Chemometric characterization of three varietal olive oils (Cvs. Cobrançosa, Madural and Verdeal Transmontana) extracted from olives with different maturation indices. Food Chem. 102, 406-414 (2007).
18) Psomiadou, E.; Tsámidou, M.; Boskou, D. α-Tocopherol content of Greek virgin olive oils. J. Agric. Food Chem. 48, 1770-1775 (2000).
19) Kyyk, O.; Aguilera, M.P.; Gaforio, J.; Jiménez, A.; Beltrán, G. Sterol composition of virgin olive oil of forty-three olive cultivars from the World Collection Olive Germplasm Bank of Cordoba. J. Sci. Food Agric. 96, 4143-4150 (2016).
20) Anastasopoulos, E.; Kalogeropoulos, N.; Kaliara, A.C.; Kountouri, A.; Andrikopoulos, N.K. The influence of ripening and crop year on quality indices, polyphenols, terpenic acids, squalene, fatty acid profile, and sterols in virgin olive oil (Koroneiki cv.) produced by organic versus non-organic cultivation method. Int. J. Food Sci. Tech. 46, 170-178 (2011).
CC BY 4.0 (Attribution 4.0 International). This license allows users to share and adapt an article, even commercially, as long as appropriate credit is given. That is, this license lets others copy, distribute, remix, and build upon the Article, even commercially, provided the original source and Authors are credited.