

Article

Impact of Olive Variety and Cultivation Region on the Chemical Composition and Sensory Attributes of Turkish Olive Oils

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Abstract

Extra virgin olive oils obtained from the Ayvalık, Memecik, Gemlik, Çekişte, and Sarı Ulak Turkish cultivars were evaluated to determine their chemical composition, quality classification, authenticity indicators, and sensory characteristics. Standard quality parameters, including free fatty acidity, peroxide value, and ultraviolet absorbance (K232, K270), were analyzed in accordance with International Olive Council (IOC) regulations. The majority of the samples met the criteria for extra virgin olive oil. The oleic acid content varied by variety and region, with Ayvalık and Memecik showing notably high levels. Sterol profile analyses revealed distinctive chemical markers that indicate authenticity and quality. Sensory analysis results showed that regional differences had a significant impact on aroma, taste, and overall acceptability. Oils from Ayvalık and Memecik received high scores for positive sensory attributes such as fruitiness, bitterness, and pungency. The results show that the chemical and sensory qualities of olive oil are directly influenced by both genetic diversity and growing conditions, which underscores the importance of conserving local varieties and promoting regional production methods.

Keywords: extra virgin olive oil; fatty acids; standard quality parameters; sterol composition



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1. Introduction

The olive tree (*Olea europaea* L.) is an evergreen tree belonging to the family Oleaceae and is one of the most important fruit crops of the Mediterranean region. The environmental conditions affect the chemical composition of the oil, such as phenol, tocopherol and volatile compounds [1–3]. In regions where temperatures vary markedly between day and night, olives typically develop higher levels of phenolics, resulting in improved antioxidant activity and greater resistance to oxidation [1].

The chemical composition of soil, like pH, texture and organic matter, affects the olive oil quality [4,5]. Phenols give olive oil its flavor, aroma, and health benefits. Extra virgin olive oil (EVOO) is rich in polyphenols, which are natural antioxidants with medicinal properties. Their consumption helps reduce inflammation, protects the heart, exhibits antimicrobial activity, prevents cancer, and supports brain health.

Extra virgin olive oil (EVOO) is considered a high-value product due to its sensory attributes, health benefits, and distinctive chemical composition. EVOO contains two fractions: the saponifiable fraction, which constitutes 98% and contains acylglycerides (SFA, MUFA, and PUFA), and the unsaponifiable fraction, which includes a diverse range of chemicals such as volatile organic compounds, phenols, terpenes, and hydrocarbons. The present study identified 79 metabolites in virgin olive oils, including 13 fatty acids (FAs), 21 phenols, and 45 volatile organic compounds (VOCs). The phenolic content depends on several factors, including cultivar, ripening index, and extraction conditions. The phenolic compounds can be classified into: (i) oleuropein and ligstroside aglycones; (ii) oleocanthal and oleacein; and (iii) cultivars characterized as intermediate, balanced, or lacking association with a specific phenolic profile. This compound influences its stability during storage, including its organoleptic features [6].

The phenolic acids found in EVOO are grouped into four main classes, phenolic acids, phenolic alcohols, flavonoids and secoiridoids, of which the most representative were found to be caffeic acid, vanillic acid (phenolic acids), tyrosol, hydroxytyrosol (phenolic alcohols), luteolin-7-glucoside, rutin (flavonoids and derivatives), oleuropein and ligstroside (secoiridoids) [7].

Volatile organic compounds (VOCs) in extra virgin olive oil (EVOO) include a diverse range of aroma compounds responsible for its sensory profile. These compounds primarily originate from enzymatic reactions, particularly the lipoxygenase (LOX) pathway activated during olive crushing and malaxation. The VOC families include aldehydes, alcohols, esters, ketones, hydrocarbons, and terpenes, which collectively contribute to the fruity, green, bitter, and pungent notes characteristic of high-quality EVOO. Their composition is strongly influenced by factors such as cultivar, ripening stage, processing conditions, and storage [7].

Rocha et al. (2026) [1] reported that α -tocopherol was the primary vitamin found in all extra virgin olive oils (EVOOs) studied, accounting for 90% of the total vitamin E content. The study showed that the region affects the content of α -tocopherol, whereas the levels of hydroxytyrosol and tyrosol are influenced by geographical origin.

Olive varieties grown across Türkiye vary in morphological, physicochemical and biochemical traits, influencing oil quality [5]. The fragrance of olive oil is influenced by factors including the composition of the soil in which olives are cultivated, enzymatic activity, processing conditions, and the presence of volatile compounds such as aldehydes, esters, and alcohols. Olive oil, a plant-based fat valued in nutrition and food science, is well known for its beneficial health effects and practical uses [8]. Olive oil is high in monounsaturated fatty acids (MUFAs), phenolic compounds, tocopherols, and phytosterols. It has been linked to lowering oxidative stress, reducing inflammation, and decreasing the risk of cardiovascular diseases [9–12]. The chemical composition and quality parameters of olive oil are essential factors in establishing its physiological advantages and commercial significance [13,14].

Recently, diets rich in omega-3 fatty acids (from fish) and omega-9 MUFA (from olive oil) have been employed as nanopharmacological strategies due to their cardiovascular, anti-inflammatory, and metabolic health benefits for the treatment of depression. Olive oil supplementation has been shown to partially reduce stress-related neuroinflammatory markers and decrease kynurenine pathway metabolites in both the brain and gut [15].

Recently, olive oil has been incorporated into colloidal structures, such as emulsion gels, due to its unique composition and excellent stability during storage, enabling a wide range of potential applications in the food industry [16].

Olive oil is a key part of the Mediterranean diet and is valued for its healthy fats. The composition is predominantly MUFAs, with oleic acid (C18:1) typically representing

55–85% of the total fatty acid content. Saturated fatty acids (SFAs), including palmitic acid (C16:0) (7.0–20%) and stearic acid (C18:0) (0.5–5.0%), comprise approximately 0.5–20%. Polyunsaturated fatty acids (PUFAs), chiefly linoleic acid (C18:2) (2.5–21%) and α -linolenic acid (C18:3) ($\leq 1\%$), constitute about ≤ 1 –21%. This composition improves oxidative stability, nutrition, and health benefits like cardiovascular protection and anti-inflammation. Fatty acid profiles differ by olive variety, origin, and processing. Authenticating and assessing olive oil quality is essential for consumer safety and preventing fraud [17–20].

Uluata and Özçelik [21] investigated the biochemical composition and antioxidant activity of extra virgin olive oils produced from different olive cultivars grown in two coastal regions of Türkiye—the Aegean and the Mediterranean. The findings indicated that oleic acid was the main fatty acid, with its proportion varying from 46.7% to 71.6% across different cultivars. The main sterol found was β -Sitosterol, while triacylglycerols were the most prevalent lipid type in every sample [21].

Korkmaz (2023) reported that extra virgin olive oils obtained from five Turkish cultivars grown in the Aegean and Marmara regions showed clear cultivar-dependent differences in their chemical and sensory characteristics [22]. Recent studies [23] investigated on geographical and climatic influences on the fatty acid composition of olive oil. According to this study, the lipid profile affects the content of oleic (47–83%), palmitic (8–22%), and linoleic acids (1–23%), depending on the cultivar and growing region [23]. According this study, fatty acid biosynthesis in olives is a complex, tightly regulated pathway involving sequential elongation and desaturation steps. These processes are coordinated by multiple enzyme-encoding genes, including fatty acid synthases, elongases, desaturases, and carboxylases [23].

Türkiye possesses a diverse agro-ecological landscape conducive to olive cultivation, with numerous indigenous cultivars such as Ayvalık, Memecik, Gemlik, Çekişte, and Sarı Ulak grown across distinct climatic and edaphic zones. These regional and varietal differences exert significant influence on the physicochemical attributes, sensory profiles, and biochemical constituents of the resulting olive oils. Quality assessment of olive oil is governed by internationally recognized standards, including those set by the International Olive Council (IOC), which emphasize parameters such as free fatty acid content, peroxide value, UV absorbance indices (K232 and K270), fatty acid composition, and sterol profile [24].

This study examines the quality, sensory traits, fatty acids, and sterol profiles of olive oils from five cultivars in seven Turkish provinces (Ayvalık, İzmir, Aydın, Muğla, Ödemiş, Hatay, and Mersin). The objective is to elucidate the impact of genetic variation and geographical origin on the chemical structure and organoleptic properties of olive oil, thereby informing quality-oriented production strategies and enhancing the global competitiveness of local cultivars. The findings are expected to contribute to the optimization of quality control protocols and support value-added initiatives such as geographical indication labeling within the Turkish olive oil sector.

2. Results and Discussion

2.1. Chemical Properties of Olive Oil Samples

Table 1 shows the quality criteria and chemical properties of olive oil samples taken from different provinces of Türkiye. The olive oil samples' free fatty acid (FrA) content, peroxide value (PeV), K232 and K270 absorption coefficients, fatty acid ethyl ester (FAEE) content, and wax content are listed. The FrA values ranged from 0.17 to 0.57 (in terms of oleic acid %), with the lowest FrA value detected in Ayvalık olive oil from Ayvalık III and the highest in Gemlik olive oil from Hatay I. PeVs varied between 3.18 and 8.66 meqO₂/kg

oil, with the lowest value determined in Ödemiş I Çekişte olive oil and the highest in İzmir VI Memecik olive oil.

Table 1. Quality criteria and chemical characteristics of olive oils from different provinces. The values presented indicate the peak area of each compound (%). Results are expressed as average $\pm$ SD. The different letters indicate significant differences ($p < 0.05$) between the average results for each component separately based on Tukey's test.

Sample	Variety	FrA (in Oleic Acid %)	PeV (meqO ₂ /kg yağ)	K ₂₃₂	K ₂₇₀	FAEE (mg/kg)	Waxes (mg/kg)
Ayvalık I	A	0.54 $\pm$ 0.01 ^{cd}	6.66 $\pm$ 0.16 ^b	1.76 $\pm$ 0.03 ^{cd}	0.11 $\pm$ 0.01 ^d	3.10 $\pm$ 0.02 ^c	22.90 $\pm$ 1.26 ^a
Ayvalık III	A	0.54 $\pm$ 0.01 ^{cd}	6.66 $\pm$ 0.16 ^b	1.76 $\pm$ 0.03 ^{cd}	0.11 $\pm$ 0.01 ^d	3.10 $\pm$ 0.02 ^c	22.90 $\pm$ 1.26 ^a
Ayvalık V	A	0.17 $\pm$ 0.02 ^{cd}	5.71 $\pm$ 0.21 ^b	1.75 $\pm$ 0.07 ^{cd}	0.14 $\pm$ 0.01 ^{cd}	2.50 $\pm$ 0.71 ^c	21.00 $\pm$ 2.12 ^a
Ayvalık II	G	0.36 $\pm$ 0.02 ^{bc}	3.90 $\pm$ 0.07 ^b	1.70 $\pm$ 0.07 ^{bc}	0.10 $\pm$ 0.01 ^c	1.12 $\pm$ 0.71 ^{bc}	33.77 $\pm$ 1.41 ^a
Ayvalık IV	G	0.37 $\pm$ 0.03 ^c	6.77 $\pm$ 0.21 ^b	1.65 $\pm$ 0.04 ^c	0.07 $\pm$ 0.00 ^c	2.50 $\pm$ 0.17 ^c	36.50 $\pm$ 0.3 ^a
İzmir I	G	0.47 $\pm$ 0.01 ^c	7.84 $\pm$ 0.01 ^b	1.76 $\pm$ 0.02 ^c	0.10 $\pm$ 0.01 ^c	11.08 $\pm$ 0.07 ^b	45.28 $\pm$ 0.21 ^a
İzmir II	G	0.46 $\pm$ 0.04 ^d	7.79 $\pm$ 0.14 ^b	1.80 $\pm$ 0.01 ^{cd}	0.10 $\pm$ 0.01 ^d	4.50 $\pm$ 0.71 ^c	23.50 $\pm$ 2.12 ^a
İzmir IV	G	0.22 $\pm$ 0.01 ^d	4.99 $\pm$ 0.01 ^b	1.78 $\pm$ 0.04 ^{cd}	0.11 $\pm$ 0.01 ^d	2.82 $\pm$ 0.23 ^c	15.35 $\pm$ 0.19 ^a
İzmir III	A	0.44 $\pm$ 0.01 ^d	5.19 $\pm$ 0.15 ^c	1.74 $\pm$ 0.07 ^{cd}	0.01 $\pm$ 0.01 ^d	14.88 $\pm$ 0.07 ^b	32.64 $\pm$ 0.71 ^a
İzmir V	A	0.41 $\pm$ 0.04 ^c	7.25 $\pm$ 0.14 ^b	1.89 $\pm$ 0.07 ^c	0.15 $\pm$ 0.01 ^c	5.13 $\pm$ 0.07 ^b	24.35 $\pm$ 0.35 ^a
İzmir VI	M	0.41 $\pm$ 0.07 ^c	5.51 $\pm$ 0.54 ^b	1.74 $\pm$ 0.07 ^c	0.11 $\pm$ 0.01 ^c	13.32 $\pm$ 0.14 ^a	15.36 $\pm$ 0.21 ^a
Aydın I	M	0.55 $\pm$ 0.04 ^d	8.66 $\pm$ 0.07 ^c	1.77 $\pm$ 0.07 ^d	0.13 $\pm$ 0.01 ^d	19.66 $\pm$ 0.35 ^b	30.43 $\pm$ 0.42 ^a
Aydın II	M	0.23 $\pm$ 0.04 ^{de}	7.21 $\pm$ 0.21 ^b	1.45 $\pm$ 0.07 ^{cd}	0.12 $\pm$ 0.01 ^e	2.50 $\pm$ 0.71 ^c	23.00 $\pm$ 2.83 ^a
Aydın IV	M	0.20 $\pm$ 0.01 ^d	6.59 $\pm$ 0.07 ^b	1.85 $\pm$ 0.07 ^c	0.14 $\pm$ 0.01 ^d	2.50 $\pm$ 0.71 ^c	24.00 $\pm$ 1.41 ^a
Aydın III	G	0.30 $\pm$ 0.02 ^c	7.70 $\pm$ 0.07 ^b	1.87 $\pm$ 0.07 ^c	0.14 $\pm$ 0.01 ^c	8.23 $\pm$ 0.71 ^b	31.78 $\pm$ 1.41 ^a
Ödemiş I	Ç	0.38 $\pm$ 0.03 ^d	7.09 $\pm$ 0.07 ^b	1.75 $\pm$ 0.07 ^c	0.13 $\pm$ 0.01 ^d	2.50 $\pm$ 0.03 ^c	31.00 $\pm$ 0.71 ^a
Ödemiş II	M	0.32 $\pm$ 0.02 ^c	3.18 $\pm$ 0.10 ^b	1.47 $\pm$ 0.03 ^{bc}	0.11 $\pm$ 0.01 ^c	3.06 $\pm$ 0.07 ^b	31.55 $\pm$ 0.74 ^a
Muğla I	M	0.45 $\pm$ 0.01 ^d	5.79 $\pm$ 0.07 ^c	1.76 $\pm$ 0.07 ^{cd}	0.12 $\pm$ 0.01 ^d	14.67 $\pm$ 0.07 ^b	39.97 $\pm$ 0.7 ^b
Muğla II	M	0.25 $\pm$ 0.04 ^d	5.77 $\pm$ 0.21 ^b	1.70 $\pm$ 0.01 ^c	0.10 $\pm$ 0.01 ^d	2.50 $\pm$ 0.04 ^c	23.00 $\pm$ 2.83 ^a
Muğla III	M	0.54 $\pm$ 0.06 ^{de}	7.54 $\pm$ 0.49 ^c	1.75 $\pm$ 0.07 ^d	0.12 $\pm$ 0.01 ^{de}	11.00 $\pm$ 0.71 ^b	29.00 $\pm$ 2.83 ^a
Mersin I	SU	0.31 $\pm$ 0.01 ^b	5.71 $\pm$ 0.14 ^{ab}	1.65 $\pm$ 0.07 ^b	0.11 $\pm$ 0.01 ^b	2.50 $\pm$ 0.02 ^b	21.00 $\pm$ 1.41 ^a
Hatay I	G	0.30 $\pm$ 0.07 ^c	5.16 $\pm$ 0.23 ^b	1.65 $\pm$ 0.07 ^{bc}	0.09 $\pm$ 0.001 ^c	3.00 $\pm$ 0.04 ^{bc}	32.20 $\pm$ 0.71 ^a

FrAs are the most important parameter for determining olive oil quality, as they contribute to the oil's freshness and purity. FrAs result from the hydrolysis of triglycerides, which releases fatty acids from the glycerol backbone. An increase in FrAs is caused by factors such as poor handling and improper storage of olive oil, both of which degrade its sensory and nutritional quality [25]. The specific absorbance values at UV, K232 and K270, indicate the oxidation level of olive oil, with K232 values ranging from 1.45 to 1.89 and K270 values ranging from 0.01 to 0.15.

The FAEE value is an important parameter for olive oil quality, with the lowest value determined in Ayvalık V for Ayvalık olive oil (1.12 mg/kg) and the highest in İzmir VI for Memecik olive oil (19.66 mg/kg). The wax value indicates the amount of waxy components in olive oil. Waxy substances are long-chain alcohol esters of fatty acids naturally found in olive oil. The wax value in olive oil is considered an indicator of quality, and a high amount of waxy substances negatively affects the quality of olive oil and is generally found in lower-quality oils [26]. The wax value also helps to determine whether other vegetable oils or waxy substances have been mixed into the olive oil. Some province olive oils may naturally have a higher waxy substance content, so it is beneficial to take province differences into account. While a maximum of 150 mg/kg is accepted for extra virgin olive oil and virgin olive oil, this value is accepted as a maximum of 300 mg/kg for lampante virgin olive oil (IOC, 2025) [27]. The wax value is an important chemical parameter used to assess the purity and processing quality of olive oil. Waxes are naturally present in olives, mainly in the skin, and small amounts are transferred into the oil during extraction. The wax content increases significantly when the oil is poorly processed, subjected to excessive

heating, or when low-quality materials such as olive pomace are used. The wax value serves as an indicator of oil quality and technological treatment [28].

Wax values ranged from 15.35 to 45.28 mg/kg and were found to be quite low, corresponding to high-quality olive oil levels. The lowest value was determined in Gemlik olive oil in İzmir II, and the highest in Gemlik olive oil in Ayvalık IV. When the FrAs, PeV, K232, K270, FAEE, and wax values of the olive oil samples were evaluated according to international (IOC, 2025) standards [29], they were found to fall within the extra virgin olive oil category.

Figure 1 shows a spider-web graph of the sensory characteristics of different olive oils by province. The fruitiness characteristic of olive oil expresses the fresh fruit aroma of the olive, with green and ripe fruit notes, and generally indicates that the olive oil is fresh, aromatic and of high quality if the fruitiness is >4.5. According to Serrano et al. (2021) [30], the chemical composition of extra virgin olive oil (EVOO) plays a significant role in determining both its oxidative stability and its sensory characteristics. Their study identified several associations between specific phenolic compounds and key sensory attributes of EVOO, particularly bitterness and pungency. Furthermore, certain volatile compounds were shown to contribute to the characteristic fruity sensory notes of high-quality olive oil [30].

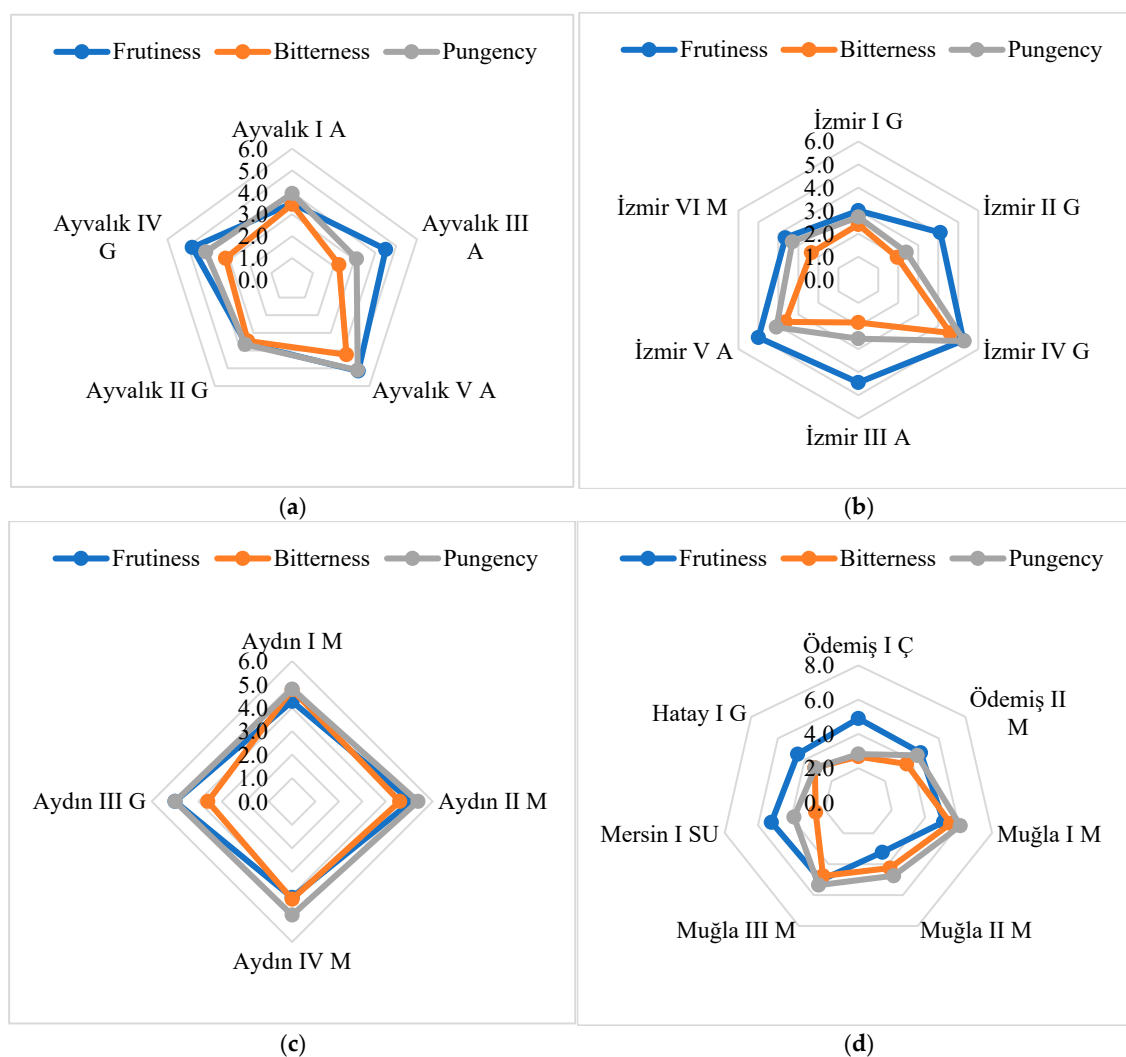


Figure 1. Sensory characteristics of olive oils from different provinces, presented as a spider-web (radar) graph.

The highest fruitiness intensity was determined in İzmir IV and Gemlik olive oil (5.3), Ayvalık V and Ayvalık olive oil (5.2), Mersin I and Sarı Ulak olive oil (5.2), Muğla I and Memecik olive oil (5.1), and Aydın II and Memecik olive oil (5.1). Low fruitiness levels of 3.0–3.5 intensity were detected in İzmir I and Gemlik olive oil (3.0), Ayvalık I and Ayvalık olive oil (3.5), and Muğla II and Memecik olive oil (3.2). In some provinces, fresher and stronger fruity characteristics prevail. The bitter pepper taste created by olive oil on the palate/tongue is referred to as bitterness. As bitterness is associated with phenolic compounds, it is considered a positive quality indicator. Oils rich in phenolic compounds, with healthy and protective properties, can generally be considered to have high bitterness (four and above). The highest bitterness intensity in the study was observed in Muğla I (5.5), Aydın I (4.8) and Muğla III (4.8) and Memecik olive oil samples. The lowest pungency intensity was detected in İzmir III and Ayvalık olive oil (1.9), İzmir II and Gemlik olive oil (2.0), and İzmir I and Gemlik olive oil (2.4). The level of pungency intensity is important in terms of health and durability, and olive oils with high pungency intensity are generally preferred. The burning sensation felt in the throat when consuming olive oil is referred to as pungency. Pungency is also related to phenolic compounds and is an indicator of quality and freshness. In this study, the highest pungency intensity was determined in Muğla I and Memecik olive oil (6.1), İzmir IV and Gemlik olive oil (5.3), and Muğla III and Memecik olive oil (5.4). The lowest pungency intensity was detected in İzmir II and Gemlik olive oil (2.4), Ödemiş I and Çekişte olive oil (2.8), and İzmir I and Gemlik olive oil (2.7). High pungency is also considered a positive characteristic in terms of quality and health. Overall, examples such as Muğla I, Muğla III, İzmir IV, and Aydın II have high fruitiness, bitterness, and pungency intensity; that is, they are sensorially rich, strong, and high-quality olive oils, while examples such as İzmir I, İzmir II, and Ödemiş I are lighter, with low bitterness and pungency intensity, representing more delicate, mild olive oils, while the Ayvalık province represents olive oils with medium levels of fruitiness, bitterness, and pungency.

2.2. Fatty Acid Composition of Olive Oil Cultivars

Table 2 shows the fatty acid composition (%) of different olive oils by province. The C18:1 (oleic acid) content in olive oil samples was found to vary between 67.52% and 75.96%. Ödemiş I (Çekişte) was found to have the highest oleic acid content at 75.96%, followed by Ayvalık III (Ayvalık—75.81%) and İzmir V (Ayvalık—73.54%). In general, the oleic acid content of Ayvalık and Gemlik olive oils was found to be between 70 and 75%, while that of Memecik and Sarı Ulak olive oils was found to vary between 68 and 72%. Cetinkaya et al. [19] reported a high level of oleic acid (71.73%) in Gemlik oil, and Avcı et al. (2018) reported oleic acid content in Kilis Yağlık Halhalı, Gemlik–Kilis, and Gemlik–Gemlik varieties [31]. The following results were reported: SFAs, including palmitic (C16:0; 7.5–20%) and stearic acids (C18:0; 0.5–3.5%); MUFAs, such as palmitoleic (C16:1; 0.3–3.5%) and oleic acids (C18:1; 56.0–85.0%); and PUFAs, including linoleic (C18:2; 3.5–20%) and linolenic acids (C18:3; 0–1.5%) [31].

Oleic acid is the essential fatty acid that determines the quality and health benefits of olive oil, and a high oleic acid content is a positive and desirable characteristic. According to Lu et al. (2024), oleic acid is the predominant fatty acid in Mediterranean oil and plays an important role in human health, particularly in protecting against cardiovascular disease, reducing the risk of oxidative stress and inflammation, regulating blood pressure, and lowering cholesterol levels [32].

Table 2. Fatty acid composition (%) of studied olive oils. Results are expressed as average $\pm$ SD. The different letters indicate significant differences ($p < 0.05$) between the average results for each component separately based on Tukey's test.

Sample	C14:0	C16:0	C16:1	C17:0	C17:1	C18:0	C18:1	C18:2	C18:3	C20:0	C20:1	C22:0	C24:0
Ayvalık I	0.02 $\pm$ 0.001 ^c	14.15 $\pm$ 0.06 _b	0.86 $\pm$ 0.07 ^c	0.15 $\pm$ 0.01 ^c	0.21 $\pm$ 0.02 ^c	2.66 $\pm$ 0.01 ^c	70.36 $\pm$ 0.01 _a	10.35 $\pm$ 0.11 _b	0.54 $\pm$ 0.01 _c	0.38 $\pm$ 0.04 ^c	0.23 $\pm$ 0.02 ^c	0.06 $\pm$ 0.005 _c	0.05 $\pm$ 0.005 _c
Ayvalık III	0.01 $\pm$ 0.001 ^c	12.47 $\pm$ 0.01 _b	1.02 $\pm$ 0.1 ^c	0.16 $\pm$ 0.01 ^c	0.27 $\pm$ 0.02 ^c	3.13 $\pm$ 0.01 ^c	75.81 $\pm$ 0.02 _a	5.67 $\pm$ 0.07 ^b	0.45 $\pm$ 0.02 _c	0.58 $\pm$ 0.05 ^c	0.26 $\pm$ 0.02 ^c	0.11 $\pm$ 0.01 ^c	0.06 $\pm$ 0.006 _c
Ayvalık V	0.02 $\pm$ 0.002 ^c	12.73 $\pm$ 0.07 _b	0.77 $\pm$ 0.06 ^c	0.17 $\pm$ 0.02 ^c	0.23 $\pm$ 0.01 ^c	2.88 $\pm$ 0.07 ^c	70.53 $\pm$ 0.07 _a	11.06 $\pm$ 0.04 _b	0.65 $\pm$ 0.05 _c	0.45 $\pm$ 0.04 ^c	0.29 $\pm$ 0.02 ^c	0.15 $\pm$ 0.01 ^c	0.09 $\pm$ 0.008 _c
Ayvalık II	0.01 $\pm$ 0.0011 _c	14.03 $\pm$ 0.04 _b	0.96 $\pm$ 0.08 ^c	0.14 $\pm$ 0.02 ^c	0.23 $\pm$ 0.03 ^c	2.31 $\pm$ 0.08 ^c	70.91 $\pm$ 0.21 _a	9.76 $\pm$ 0.02 ^b	0.46 $\pm$ 0.04 _c	0.67 $\pm$ 0.05 ^c	0.34 $\pm$ 0.03 ^c	0.14 $\pm$ 0.02 ^c	0.07 $\pm$ 0.006 _c
Ayvalık IV	0.01 $\pm$ 0.001 ^c	13.69 $\pm$ 0.04 _b	1.02 $\pm$ 0.10 ^c	0.16 $\pm$ 0.01 ^c	0.24 $\pm$ 0.03 ^c	3.08 $\pm$ 0.07 ^c	72.42 $\pm$ 0.14 _a	8.02 $\pm$ 0.07 ^b	0.61 $\pm$ 0.04 _c	0.40 $\pm$ 0.03 ^c	0.23 $\pm$ 0.03 ^c	0.10 $\pm$ 0.01 ^c	0.06 $\pm$ 0.006 _c
İzmir I	0.01 $\pm$ 0.001 ^c	13.73 $\pm$ 0.14 _b	0.99 $\pm$ 0.08 ^c	0.16 $\pm$ 0.02 ^c	0.22 $\pm$ 0.02 ^c	3.13 $\pm$ 0.16 ^c	69.23 $\pm$ 0.14 _a	11.04 $\pm$ 0.04 _b	0.45 $\pm$ 0.04 _c	0.60 $\pm$ 0.05 ^c	0.28 $\pm$ 0.02 ^c	0.12 $\pm$ 0.01 ^c	0.06 $\pm$ 0.005 _c
İzmir II	0.01 $\pm$ 0.001 ^c	14.63 $\pm$ 0.16 _b	0.83 $\pm$ 0.04 ^c	0.15 $\pm$ 0.02 ^c	0.18 $\pm$ 0.01 ^c	3.64 $\pm$ 0.02 ^c	67.52 $\pm$ 0.04 _a	11.64 $\pm$ 0.16 _b	0.61 $\pm$ 0.04 _c	0.47 $\pm$ 0.05 ^c	0.21 $\pm$ 0.02 ^c	0.11 $\pm$ 0.01 ^c	0.03 $\pm$ 0.003 _c
İzmir IV	0.01 $\pm$ 0.001 ^c	13.84 $\pm$ 0.07 _b	0.95 $\pm$ 0.05 ^c	0.15 $\pm$ 0.01 ^c	0.21 $\pm$ 0.02 ^c	2.68 $\pm$ 0.01 ^c	68.52 $\pm$ 0.09 _a	12.16 $\pm$ 0.02 _b	0.51 $\pm$ 0.07 _c	0.46 $\pm$ 0.04 ^c	0.30 $\pm$ 0.03 ^c	0.15 $\pm$ 0.01 ^c	0.08 $\pm$ 0.007 _c
İzmir III	0.01 $\pm$ 0.001 ^c	12.43 $\pm$ 0.21 _b	0.62 $\pm$ 0.04 ^c	0.13 $\pm$ 0.01 ^c	0.22 $\pm$ 0.02 ^c	3.06 $\pm$ 0.06 ^c	70.35 $\pm$ 0.35 _a	11.70 $\pm$ 0.21 _b	0.57 $\pm$ 0.14 _c	0.47 $\pm$ 0.03 ^c	0.31 $\pm$ 0.03 ^c	0.12 $\pm$ 0.01 ^c	0.04 $\pm$ 0.005 _c
İzmir V	0.01 $\pm$ 0.001 ^c	12.49 $\pm$ 0.07 _b	1.14 $\pm$ 0.10 ^c	0.14 $\pm$ 0.01 ^c	0.24 $\pm$ 0.02 ^c	2.82 $\pm$ 0.07 ^c	73.54 $\pm$ 0.14 _a	8.21 $\pm$ 0.14 ^b	0.67 $\pm$ 0.03 _c	0.40 $\pm$ 0.03 ^c	0.26 $\pm$ 0.02 ^c	0.08 $\pm$ 0.005 _c	0.02 $\pm$ 0.001 _c
İzmir VI	0.01 $\pm$ 0.001 ^c	12.40 $\pm$ 0.21 _b	0.89 $\pm$ 0.07 ^c	0.07 $\pm$ 0.005 _c	0.10 $\pm$ 0.01 ^c	2.73 $\pm$ 0.07 ^c	71.70 $\pm$ 0.21 _a	10.51 $\pm$ 0.14 _b	0.75 $\pm$ 0.06 _c	0.45 $\pm$ 0.03 ^c	0.28 $\pm$ 0.03 ^c	0.10 $\pm$ 0.01 ^c	0.02 $\pm$ 0.001 _c
Aydın I	0.01 $\pm$ 0.001 ^c	13.40 $\pm$ 0.16 _b	0.97 $\pm$ 0.09 ^c	0.04 $\pm$ 0.004 _c	0.08 $\pm$ 0.007 _c	2.23 $\pm$ 0.03 ^c	71.30 $\pm$ 0.21 _a	10.24 $\pm$ 0.05 _b	0.42 $\pm$ 0.03 _c	0.83 $\pm$ 0.05 ^c	0.31 $\pm$ 0.03 ^c	0.13 $\pm$ 0.01 ^c	0.06 $\pm$ 0.001 _c
Aydın II	0.02 $\pm$ 0.002 ^c	14.53 $\pm$ 0.14 _b	1.01 $\pm$ 0.10 ^c	0.05 $\pm$ 0.002 _c	0.07 $\pm$ 0.005 _c	2.56 $\pm$ 0.07 ^c	71.68 $\pm$ 0.07 _a	8.31 $\pm$ 0.14 ^b	0.45 $\pm$ 0.04 _c	0.83 $\pm$ 0.07 ^c	0.31 $\pm$ 0.03 ^c	0.14 $\pm$ 0.01 ^c	0.07 $\pm$ 0.008 _c
Aydın IV	0.02 $\pm$ 0.002 ^c	12.11 $\pm$ 0.07 _b	1.03 $\pm$ 0.11 ^c	0.05 $\pm$ 0.004 _c	0.07 $\pm$ 0.005 _c	2.64 $\pm$ 0.02 ^c	72.82 $\pm$ 0.02 _a	9.40 $\pm$ 0.04 ^b	0.96 $\pm$ 0.02 _c	0.44 $\pm$ 0.04 ^c	0.32 $\pm$ 0.03 ^c	0.10 $\pm$ 0.01 ^c	0.06 $\pm$ 0.006 _c
Aydın III	0.01 $\pm$ 0.001 ^c	13.14 $\pm$ 0.07 _b	0.97 $\pm$ 0.08 ^c	0.14 $\pm$ 0.01 ^c	0.22 $\pm$ 0.01 ^c	3.18 $\pm$ 0.06 ^c	73.20 $\pm$ 0.07 _a	7.70 $\pm$ 0.07 ^b	0.48 $\pm$ 0.03 _c	0.57 $\pm$ 0.05 ^c	0.24 $\pm$ 0.02 ^c	0.12 $\pm$ 0.01 ^c	0.06 $\pm$ 0.005 _c
Ödemiş I	0.01 $\pm$ 0.001 ^c	11.84 $\pm$ 0.15 _b	0.93 $\pm$ 0.08 ^c	0.19 $\pm$ 0.05 ^c	0.34 $\pm$ 0.04 ^c	2.72 $\pm$ 0.05 ^c	75.96 $\pm$ 0.02 _a	6.46 $\pm$ 0.08 ^b	0.76 $\pm$ 0.04 _c	0.40 $\pm$ 0.04 ^c	0.28 $\pm$ 0.02 ^c	0.09 $\pm$ 0.008 _c	0.05 $\pm$ 0.004 _c
Ödemiş II	0.02 $\pm$ 0.002 ^c	13.69 $\pm$ 0.07 _b	1.02 $\pm$ 0.10 ^c	0.09 $\pm$ 0.008 _c	0.13 $\pm$ 0.01 ^c	2.87 $\pm$ 0.14 ^c	71.64 $\pm$ 0.10 _a	8.85 $\pm$ 0.14 ^b	0.78 $\pm$ 0.07 _c	0.48 $\pm$ 0.05 ^c	0.28 $\pm$ 0.02 ^c	0.12 $\pm$ 0.01 ^c	0.04 $\pm$ 0.003 _c
Muğla I	0.02 $\pm$ 0.002 ^c	13.82 $\pm$ 0.21 _b	1.13 $\pm$ 0.11 ^c	0.05 $\pm$ 0.004 _c	0.08 $\pm$ 0.007 _c	2.41 $\pm$ 0.07 ^c	70.34 $\pm$ 0.14 _a	10.29 $\pm$ 0.14 _b	0.45 $\pm$ 0.02 _c	0.91 $\pm$ 0.08 ^c	0.33 $\pm$ 0.03 ^c	0.13 $\pm$ 0.01 ^c	0.07 $\pm$ 0.006 _c
Muğla II	0.01 $\pm$ 0.001 ^c	13.17 $\pm$ 0.21 _b	1.12 $\pm$ 0.12 ^c	0.09 $\pm$ 0.008 _c	0.14 $\pm$ 0.01 ^c	2.96 $\pm$ 0.07 ^c	71.63 $\pm$ 0.21 _a	9.21 $\pm$ 0.07 ^b	0.47 $\pm$ 0.01 _c	0.74 $\pm$ 0.06 ^c	0.28 $\pm$ 0.03 ^c	0.13 $\pm$ 0.01 ^c	0.06 $\pm$ 0.007 _c
Muğla III	0.02 $\pm$ 0.002 ^c	13.15 $\pm$ 0.06 _b	0.82 $\pm$ 0.08 ^c	0.04 $\pm$ 0.004 _c	0.07 $\pm$ 0.005 _c	2.22 $\pm$ 0.07 ^c	70.76 $\pm$ 0.21 _a	11.21 $\pm$ 0.21 _b	0.41 $\pm$ 0.01 _c	0.80 $\pm$ 0.07 ^c	0.32 $\pm$ 0.03 ^c	0.13 $\pm$ 0.01 ^c	0.07 $\pm$ 0.006 _c
Mersin I	0.01 $\pm$ 0.001 ^c	13.28 $\pm$ 0.21 _b	0.78 $\pm$ 0.06 ^c	0.26 $\pm$ 0.02 ^c	0.30 $\pm$ 0.04 ^c	3.14 $\pm$ 0.07 ^c	70.17 $\pm$ 0.21 _a	10.29 $\pm$ 0.21 _b	0.75 $\pm$ 0.06 _c	0.52 $\pm$ 0.04 ^c	0.31 $\pm$ 0.03 ^c	0.13 $\pm$ 0.01 ^c	0.08 $\pm$ 0.007 _c
Hatay I	0.01 $\pm$ 0.001 ^c	13.46 $\pm$ 0.21 _b	1.06 $\pm$ 0.01 ^c	0.14 $\pm$ 0.01 ^c	0.20 $\pm$ 0.02 ^c	3.71 $\pm$ 0.02 ^c	68.55 $\pm$ 0.05 _a	11.46 $\pm$ 0.12 _b	0.64 $\pm$ 0.02 _c	0.47 $\pm$ 0.05 ^c	0.24 $\pm$ 0.03 ^c	0.06 $\pm$ 0.005 _c	0.04 $\pm$ 0.005 _c

Note: Myristic (C14:0), palmitic (C16:0), palmitoleic (C16:1), margaric (C17:0), margoleic (C17:1), stearic (C18:0), oleic (C18:1), linoleic (C18:2), linolenic (C18:3), arachidic (C20:0), gadoleic (C20:1), behenic (C22:0), lignoceric (C24:0). Values indicated with letters a and b were significantly different from each other at $p \leq 0.05$ levels.

According to [23], the biosynthesis of oleic acid (C18:1), the major monounsaturated fatty acid in olive oil, occurs in the plastid stroma. In this pathway, stearoyl-ACP $\Delta 9$ -desaturase catalyzes the desaturation of stearoyl-ACP, the final product of the fatty acid elongation cycle. In contrast, linoleic acid (C18:2) is synthesized in the endoplasmic reticulum, where oleate desaturase catalyzes the desaturation of oleic acid to produce this polyunsaturated fatty acid.

C16:0 (palmitic acid) is a saturated fatty acid, and lower levels indicate that the olive oil is preferable in terms of health. The C16:0 (palmitic acid) content was found to vary between 11.8 and 14.6%, with the lowest palmitic acid value detected in the Ödemiş I (Çekişte) sample. C18:2 (linoleic acid) is a polyunsaturated fatty acid and, although important as an omega-6 fatty acid, its very high content reduces the quality of olive oil and decreases the oil's resistance to oxidation. International (IOC, 2025) [27] standards specify that it should be between 2.5 and 21.0%. Linoleic acid levels were determined to be between 5.7 and 12.1%. The highest linoleic acid value, 12.16%, was found in the İzmir IV (Gemlik) sample. C18:3 (linolenic acid) is generally found in small amounts in olive oil and varies according to variety, province, climate and ripening period. According to the IOC (2025) standard [27], its ratio in olive oil should be below 1%, and, in the study, it was determined to be in the range of 0.41–0.96%. The highest values were determined in the Aydın IV (Memecik) sample. Linolenic acid was generally lower in the Memecik samples from Aydın and Muğla and was found at medium levels in the Ayvalık and Gemlik varieties. A low C18:3 ratio contributes to the oxidative stability of the oil, as linolenic acid is highly unsaturated and therefore one of the most oxidation-sensitive fatty acids. Therefore, varieties with low C18:3 ratios, such as Memecik, are advantageous in terms of shelf life. Ayvalık III (Ayvalık) can be said to be more advantageous in terms of quality and health due to its highest C18:1 ratio and relatively low C16:0 ratio. The fatty acid composition of all samples was found to be below the limits specified in the IOC (2025) standard [29].

The fatty acid profile aligns with the findings of Revelou et al. (2021) [33], who reported similar compositions across several Greek olive cultivars, such as Koroneiki, Megaritiki, Amfissis, and Manaki. The reported average fatty acid composition included 12.72% palmitic, 71.51% oleic, and 10.10% linoleic acid. Saturated fatty acids (SFAs) averaged 15.82%, MUFAs averaged 72.69%, and PUFAs averaged 11.45%, with MUFA/PUFA and C18:1/C18:2 ratios at 6.94 and 7.98, respectively. The MUFA/PUFA ratio indicates oil stability and resistance to rancidity. A higher C18:1/C18:2 ratio means greater chemical stability, less oxidation sensitivity, longer shelf life, and a high oleic acid content beneficial for cardiovascular health.

2.3. Nutritional Quality Indices

The nutritional quality indices of the olive oil samples are shown in Table 3.

SFAs in all samples ranged between 15.3 and 19%, with the highest value observed in İzmir II and the lowest in Aydın IV (15.42%). MUFA is the predominant fatty acid, ranging from 68.7% to 77.5%. PUFA content is found at low concentrations, between 6.12% and 12.67%. Olive oil has lower TI and AI values due to its high content of MUFAs. For a healthy diet, it is recommended that the AI be below one and the TI below 0.5; all samples meet these criteria. A high AI promotes atherogenesis (the formation of fatty deposits in arteries). A lower AI is recommended for a healthy diet because it indicates a lower SFA content, which tends to promote plaque formation in blood vessels. The TI is below 0.5 in all samples, indicating healthy lipid profiles in olive oil that support cardiovascular health. High quantities of MUFAs and PUFAs positively influence the nutritional quality indices and are beneficial for consumers [34]. The hypocholesterolemic/hypercholesterolemic

(h/H) index measures the balance of fatty acids that affect cholesterol levels. The h/H values are characteristic of a high-oleic olive oil, where MUFA dominates. The highest value (Ödemiş I) suggests superior dietary quality. Health-promoting index (HPI) values ranged between 5.5 and 7.1, indicating a consistently positive contribution to cardiovascular health. The samples Ödemiş I and Aydın IV showed the highest HPI values. DFAs are the sum of stearic acid (C18:0) and UFA, and the obtained values are high for all samples, reflecting the nutritional quality of the oil. NVI values were higher in all samples, indicating high nutritional potential. The polyene index (PI), which ranged from 0.37 to 0.76, was associated with high PUFA content but is sensitive to oxidative damage [35–37].

Table 3. Nutritional quality indices of olive oils from different provinces.

Region	SFA	MUFA	PUFA	UFA	TI	AI	h/H	HPI	NVI	PI	DFA
Ayvalık I	17.46	71.65	10.89	82.54	0.35	0.17	10.79	5.8	85.4	0.62	85.20
Ayvalık III	16.52	77.36	6.12	83.48	0.34	0.15	12.76	6.7	77.4	0.37	86.61
Ayvalık V	16.48	71.82	11.71	83.53	0.32	0.15	12.08	6.5	96.0	0.71	86.41
Ayvalık II	17.36	72.44	10.22	82.66	0.34	0.17	10.94	5.9	76.3	0.59	84.97
Ayvalık IV	17.49	73.90	8.63	82.53	0.36	0.17	11.31	6.0	74.4	0.49	85.61
İzmir I	17.80	70.72	11.49	82.21	0.35	0.17	11.02	6.0	73.1	0.65	85.34
İzmir II	19.03	68.74	12.25	80.99	0.38	0.18	10.14	5.5	85.7	0.64	84.63
İzmir IV	17.36	69.98	12.67	82.65	0.34	0.17	10.91	6.0	74.9	0.73	85.33
İzmir III	16.25	71.50	12.27	83.77	0.31	0.15	12.39	6.7	118.4	0.76	86.83
İzmir V	15.95	75.18	8.88	84.06	0.32	0.15	12.61	6.7	67.0	0.56	86.88
İzmir VI	15.78	72.97	11.26	84.23	0.30	0.15	12.56	6.8	83.6	0.71	86.96
Aydın I	16.70	72.66	10.66	83.32	0.33	0.16	11.53	6.2	75.8	0.64	85.55
Aydın II	18.19	73.06	8.76	81.82	0.37	0.18	10.55	5.6	73.5	0.48	84.38
Aydın IV	15.42	74.23	10.36	84.59	0.30	0.14	12.98	6.9	73.6	0.67	87.23
Aydın III	17.21	74.63	8.18	82.81	0.35	0.16	11.86	6.3	78.7	0.48	85.99
Ödemiş I	15.30	77.51	7.22	84.73	0.30	0.14	13.56	7.1	84.6	0.47	87.45
Ödemiş II	17.30	73.07	9.63	82.70	0.34	0.17	11.26	6.0	73.0	0.56	85.57
Muğla I	17.40	71.87	10.74	82.61	0.34	0.17	11.05	5.9	64.7	0.62	85.02
Muğla II	17.15	73.17	9.68	82.85	0.34	0.16	11.72	6.3	66.6	0.56	85.81
Muğla III	16.42	71.96	11.62	83.58	0.32	0.16	11.72	6.3	89.0	0.71	85.80
Mersin I	17.41	71.56	11.04	82.60	0.34	0.16	11.49	6.2	94.0	0.63	85.74
Hatay I	17.88	70.05	12.10	82.15	0.35	0.16	11.19	6.1	68.2	0.68	85.86

Note: MUFA—monounsaturated fatty acid; PUFA—polyunsaturated fatty acid; SFA—saturated fatty acid; AI—atherogenic index; TI—thrombogenic index; HPI—health-promoting index; h/H—hypocholesterolemic/hypercholesterolemic index; NVI—nutritive value index; PI—peroxide index; and DFA—desired fatty acid.

2.4. Sterol Compositions

Table 4 shows the sterol composition (%) of different olive oils by province. Sterols are natural compounds found in vegetable oils and have a cholesterol-like structure. As shown in Table 4, β -sitosterol constitutes the vast majority of total sterols (around 80–90%) and is the healthiest and most common plant sterol. Campesterol and stigmasterol are present in lower amounts (around 1–3%) but are important sterols. They play an important role in cholesterol metabolism. Other sterols (colesterol, sitostanol, D5-avenesterol, etc.) are found in smaller amounts but enrich the sterol profile. Total sterol levels have been determined to vary between approximately 94 and 96%. High sterol content increases the quality and health benefits of olive oil, and it has been determined that sterol levels are quite high and β -sitosterol content is rich in provinces such as Ayvalık III (Ayvalık) and İzmir I (Gemlik). Erythrodiol + uvaol are triterpene alcohols in olive oil and have been determined to vary between 0.87 and 3.44%. The lowest value was determined in the İzmir V (Ayvalık) sample, and the highest in the Mersin I (Sarı Ulak) sample. The erythrodiol + uvaol values in the samples were found to be below the $\leq 4.5\%$ limit specified in the IOC (2025) standard. While the sterol profile and total sterol content were generally high and balanced in the Ayvalık, İzmir, Aydın and Muğla provinces, the erythrodiol + uvaol ratio was found to be

slightly higher in southern provinces such as Hatay and Mersin. The delta-7-stigmastenol ratio of the samples ranged from 0.22% to 0.77%. According to the IOC (2025) standard, the delta-7-stigmastenol ratio in natural olive oil should not exceed 0.5%. Of the 22 olive oil samples studied, only the İzmir III (Ayvalık, 0.77%) and Hatay I (Gemlik, 0.51%) samples were found to exceed the limit value. Delta-7-stigmastenol is naturally present in very low amounts in olive oil, while it is found at higher levels in seed oils (e.g., sunflower and safflower). The exceeding of the limit in the samples suggests natural variation due to factors such as cultivation conditions and ripening period.

2.5. Evaluation of Principal Component Analysis (PCA) Results

2.5.1. Quality and Purity Parameters

In the PCA conducted using quality and purity parameters, the first principal component (PC1) explained 41.5% of the total variance, while the second principal component (PC2) accounted for 33.3%, resulting in a cumulative explained variance of 74.8% (Figure 2). The relatively high total variance captured by the first two components indicates a robust multivariate model. PC1 was primarily influenced by oxidation-related variables, particularly the peroxide value (PeV) and the specific UV absorbance indices K232 and K270. These parameters showed strong loadings along the positive direction of PC1, suggesting that this axis reflects the oxidative status of the oils. PC2, in contrast, was mainly associated with free fatty acid (FrA), fatty acid ethyl ester (FAEE), and wax content (WAXS). High loadings of these variables indicate that PC2 reflects parameters related to hydrolytic degradation and processing quality, including refining or post-harvest handling effects. In the score plot, certain samples exhibited distinctive positioning. Samples such as İzmir IV (Gemlik) and Ödemiş I (Çekişte) showed higher values along PC2, indicating relatively elevated levels of FrA, FAEE, and WAXS. Conversely, Ayvalık II (Gemlik) and İzmir VI (Memecik) were positioned toward the positive side of PC1, suggesting a stronger influence of oxidation-related parameters (PeV, K232, and K270). Other samples displayed mixed behavior. For example, Ayvalık I (Ayvalık), Ayvalık IV (Gemlik), and Mersin I (Sarı Ulak) were characterized by relatively higher PC2 values and lower PC1 values, indicating a greater contribution of processing-related variables than oxidation markers. In contrast, Aydın III (Gemlik), Hatay I (Gemlik), and İzmir II (Gemlik) were located in the positive PC1 and negative PC2 quadrant, reflecting higher oxidative indicators but comparatively lower hydrolytic or processing-related parameters. Although clear clustering strictly based on geographical origin or variety was not observed, the distribution pattern highlights the differential influence of oxidative stability and processing-related quality parameters among samples. The dominance of oxidation variables on PC1 suggests that oils located on the positive side of this axis may have experienced higher oxidative stress, potentially influenced by storage conditions, fruit maturity, or initial raw material quality. Similarly, the association of PC2 with FrA, FAEE, and WAXS underscores the importance of processing conditions and post-harvest handling in shaping overall oil quality.

Table 4. Sterol composition (%) of olive oils from different provinces.

Region	Cholesterol	24-Metilen Cholesterol	Campesterol	Campestenol	Stigmasterol	Chlerosterol	B-Sitasterol	Sitostanol	D5-Avenesterol	D5,24-Stigmastanienol	Delta-7-stigmastenol	D7-Avenesterol	Toplam B-Sitosterol	Toplam Sterol	Erythrodiol + UVAOL
Ayvalık I	0.04 ± 0.003 j	0.06 ± 0.005 efgh	3.23 ± 0.42 abcde	0.08 ± 0.007 fgh	0.38 ± 0.03 hij	0.77 ± 0.07 fg	80.92 ± 0.11 a	0.54 ± 0.06 a	10.81 ± 0.04 ab	1.47 ± 0.12 bc	0.43 ± 0.05 bcdef	1.12 ± 0.10 defg	94.61 ± 0.04 a	2073 ± 7.07 [±] fgh	0.95 ± 0.08 defg
Ayvalık III	0.21 ± 0.02 bc	0.15 ± 0.01 abc	1.93 ± 0.26 i	0.13 ± 0.01 cde	0.59 ± 0.05 fgh	1.19 ± 0.02 ab	80.72 ± 0.02 a	1.19 ± 0.10 a	11.74 ± 0.07 ab	1.13 ± 0.013 de	0.24 ± 0.02 jk	0.92 ± 0.08 fghi	95.87 ± 0.07 a	1186 ± 7.07 [±] a	1.79 ± 0.15 efgh
Ayvalık V	0.09 ± 0.008 ghi	0.09 ± 0.009 de	3.76 ± 0.23 a	0.12 ± 0.01 def	0.27 ± 0.02 [±] jk	0.74 ± 0.06 fg	80.58 ± 0.07	0.42 ± 0.05 a	10.85 ± 0.14 ab	1.66 ± 0.02 ab	0.32 ± 0.4 fghijk	1.10 ± 0.10 defg	94.29 ± 0.14 a	2432 ± 7.07 [±] abc	1.56 ± 0.14 efghij
Ayvalık II	0.09 ± 0.001 ghi	0.14 ± 0.01 bc	3.40 ± 0.41 abc	0.04 ± 0.005 ij	0.40 ± 0.03 hij	0.86 ± 0.08 cdefg	84.30 ± 0.17 a	0.36 ± 0.05 a	7.78 ± 0.06 cd	1.51 ± 0.02 bc	0.26 ± 0.03 ijk	0.75 ± 0.08 hijk	94.88 ± 0.0 a 6	2040 ± 4.24 [±] fgh	1.45 ± 0.17 defg
Ayvalık IV	0.10 ± 0.01 fg	0.07 ± 0.006 defg	2.17 ± 0.21 ghi	0.21 ± 0.02 a	0.66 ± 0.05 defg	0.79 ± 0.08 efg	79.53 ± 0.14 a	1.33 ± 0.10 a	12.73 ± 0.04 a	0.96 ± 0.08 def	0.46 ± 0.05 bcde	1.31 ± 0.12 de	95.35 ± 0.04 a	1364 ± 4.95 [±] bcde	1.77 ± 0.21 ghij
İzmir I	0.13 ± 0.01 ef	0.13 ± 0.01 c	2.41 ± 0.24 efghi	0.05 ± 0.005 hij	0.35 ± 0.02 ij	0.93 ± 0.09 bcdef	79.16 ± 0.04 a	0.54 ± 0.04 a	12.30 ± 0.01 a	1.75 ± 0.14 ab	0.48 ± 0.05 hijk	1.74 ± 0.18 b	94.58 ± 0.01 a	1870 ± 1.41 [±] fgh	1.22 ± 0.10 hij
İzmir II	0.09 ± 0.009 ghi	0.05 ± 0.006 gh	3.18 ± 0.28 abcdef	0.17 ± 0.01 bc	0.80 ± 0.07 bcdef	1.02 ± 0.1 abcdef	88.00 ± 0.14 a	0.97 ± 0.08 a	4.43 ± 0.05 efgh	0.52 ± 0.05 ij	0.26 ± 0.02 bcdefg	0.34 ± 0.04 im	95.05 ± 0.05 a	1205 ± 5.66 [±] ab	1.01 ± 0.13 efghi
İzmir IV	0.04 ± 0.003 j	0.08 ± 0.007 def	2.81 ± 0.29 abcd	0.23 ± 0.02 a	0.36 ± 0.04 ij	0.57 ± 0.04 g	79.38 ± 0.14 a	0.73 ± 0.07 a	11.50 ± 0.07 ab	1.93 ± 0.23 a	0.42 ± 0.04 a	1.64 ± 0.15 bc	94.29 ± 0.07 a	2290 ± 2.83 [±] ab	1.52 ± 0.16 a
İzmir III	0.08 ± 0.007 ghij	0.05 ± 0.004 fgh	2.09 ± 0.21 abcdef	0.08 ± 0.008 fgh	0.26 ± 0.03 jk	0.83 ± 0.07 defg	81.54 ± 0.02 a	0.62 ± 0.05 a	10.62 ± 0.07 ab	1.20 ± 0.13 cd	0.77 ± 0.08 bcdefgh	2.11 ± 0.2 a	94.81 ± 0.07 a	2107 ± 6.36 [±] gh	3.09 ± 0.3 j
İzmir V	0.07 ± 0.006 ghij	0.08 ± 0.007 def	2.32 ± 0.26 ab	0.21 ± 0.02 ab	0.83 ± 0.07 bcde	0.85 ± 0.07 defg	81.32 ± 0.28 a	0.64 ± 0.05 a	11.32 ± 0.08 cd	0.85 ± 0.07 efgh	0.39 ± 0.04 ghijk	1.00 ± 0.15 efgh	95.27 ± 0.08 a	1011 ± 8.49 [±] fgh	0.87 ± 0.07 efgh
İzmir VI	0.08 ± 0.001 ghij	0.07 ± 0.006 defg	3.00 ± 0.32 ghi	0.10 ± 0.01 cde	0.66 ± 0.05 defg	0.73 ± 0.06 fg	85.75 ± 0.14 a	0.67 ± 0.05 a	7.39 ± 0.02 gh	0.58 ± 0.05 ghi	0.30 ± 0.03 defghij	0.61 ± 0.06 ijklm	95.70 ± 0.02 a	1368 ± 4.24 [±] fgh	1.54 ± 0.14 efg
Aydın I	0.21 ± 0.02 bc	0.13 ± 0.01 bc	3.37 ± 0.29 abcdef	0.14 ± 0.01 def	1.00 ± 0.10 ab	1.16 ± 0.14 ab	89.31 ± 0.03 a	0.23 ± 0.02 a	3.45 ± 0.07 h	0.51 ± 0.04 ij	0.36 ± 0.03 bcd	0.34 ± 0.03 lm	94.63 ± 0.07 a	1250 ± 6.36 [±] fgh	1.72 ± 0.16 bc
Aydın II	0.18 ± 0.01 cd	0.06 ± 0.006 efgh	3.15 ± 0.26 defghi	0.12 ± 0.01 a	1.10 ± 0.11 a	1.26 ± 0.13 a	89.82 ± 0.07 a	0.46 ± 0.04 a	2.47 ± 0.14 gh	0.63 ± 0.06 ghi	0.48 ± 0.04 k	0.32 ± 0.03 m	94.69 ± 0.14 a	1234 ± 7.07 [±] bcd	2.40 ± 0.20 fghij
Aydın IV	0.06 ± 0.004 hij	0.07 ± 0.007 defg	3.65 ± 0.28 abcd	0.21 ± 0.02 cde	0.64 ± 0.05 efg	1.07 ± 0.10 abcde	89.35 ± 0.04 a	0.77 ± 0.07 a	3.47 ± 0.06 ab	0.25 ± 0.02 j	0.22 ± 0.02 bcdefg	0.34 ± 0.04 lm	94.71 ± 0.06 a	1940 ± 4.95 [±] fgh	1.26 ± 0.12 bcd
Aydın III	0.26 ± 0.03 a	0.13 ± 0.01 bc	2.22 ± 0.24 cdefghi	0.13 ± 0.01 def	0.78 ± 0.08 cdef	1.02 ± 0.10 abcdef	80.93 ± 0.06 a	0.94 ± 0.09 a	11.11 ± 0.14 de	0.86 ± 0.06 efg	0.42 ± 0.04 efghijk	1.34 ± 0.12 cd	94.69 ± 0.14 a	1131 ± 4.24 [±] cdef	2.34 ± 0.2 def
Ödemiş I	0.14 ± 0.01 e	0.08 ± 0.008 de	3.10 ± 0.30 abcd	0.12 ± 0.01 c	0.88 ± 0.09 bcd	1.07 ± 0.13 abcde	85.80 ± 0.02 a	0.77 ± 0.06 a	6.33 ± 0.08 cd	0.72 ± 0.07 fghi	0.34 ± 0.03 bcdef	0.56 ± 0.05 jklm	94.70 ± 0.08 a	1603 ± 2.12 [±] fgh	1.80 ± 0.2 cde
Ödemiş II	0.07 ± 0.006 ghij	0.09 ± 0.009 d	2.52 ± 0.24 cdefhi	0.16 ± 0.02 fghi	0.84 ± 0.08 bcde	0.94 ± 0.08 bcdef	84.94 ± 0.01 a	0.96 ± 0.09 a	7.69 ± 0.20 fgh	0.69 ± 0.07 fghi	0.44 ± 0.04 cdefhi	0.65 ± 0.06 ijkl	95.39 ± 0.20 a	1338 ± 3.54 [±] efg	1.85 ± 0.2 efghij
Muğla I	0.16 ± 0.01 de	0.17 ± 0.01 a	3.36 ± 0.34 abcd	0.08 ± 0.007 fghi	1.11 ± 0.12 a	1.15 ± 0.05 abc	88.76 ± 0.05 a	0.28 ± 0.02 a	3.63 ± 0.35 bc	0.57 ± 0.04 ghi	0.38 ± 0.04 bc	0.47 ± 0.05 klm	94.52 ± 0.35 a	1445 ± 14.14 [±] fgh	1.38 ± 0.13 bc
Muğla II	0.16 ± 0.01 de	0.16 ± 0.01 d	2.56 ± 0.2 abcd	0.08 ± 0.006 def	0.98 ± 0.08 abc	1.11 ± 0.16 abcd	83.38 ± 0.21 a				0.49 ± 0.04 defghij	0.46 ± 0.04 a	9.12 ± 0.04 de	0.67 ± 0.05 [±] fghi	2.4 ± 0.2 [±] efg
Muğla III	0.23 ± 0.02 ab	0.14 ± 0.02 a	3.34 ± 0.3 cdefhij	0.12 ± 0.02 cd	1.18 ± 0.12 a	1.09 ± 0.14 abcd	88.73 ± 0.08 a	0.23 ± 0.02 a	3.85 ± 0.02 efgh	0.55 ± 0.05 hij	0.36 ± 0.03 bcdef	0.36 ± 0.03 im	94.31 ± 0.02 a	919 ± 9.19 [±] fgh	1.67 ± 0.2 efg

Table 4. Cont.

Region	Cholesterol	24-Metilen Cholesterol	Campesterol	Campestenol	Stigmasterol	Chlerosterol	B-Sitasterol	Sitostanol	D5-Avenesterol	D5,24-Stigmastanienol	Delta-7-stigmastenol	D7-Avenesterol	Toplam B-Sitosterol	Toplam Sterol	Erythrodiol + UVAOL
Mersin I	0.07 ± 0.006 _{ghij}	0.04 ± 0.005 _{ab}	3.36 ± 0.3 _j	0.16 ± 0.02 _j	0.55 ± 0.05 _{ghi}	0.98 ± 0.08 _{abcdef}	86.83 ± 0.21 _a	0.53 ± 0.05 _a	5.41 ± 0.04 _{defg}	0.62 ± 0.06 _{ghi}	0.44 ± 0.04 _{bcdef}	0.82 ± 0.08 _{ghij}	94.56 ± 0.04	1229 ± 2.83 _{fgh}	3.44 ± 0.3 ^a
Hatay I	0.14 ± 0.01 _e	0.05 ± 0.005 _{fgh}	2.67 ± 0.3 _j	0.03 ± 0.004 _{hij}	1.14 ± 0.12 ^a	1.23 ± 0.13 _a	86.46 ± 0.04 _a	0.34 ± 0.03 _a	6.17 ± 0.04 _{def}	0.47 ± 0.05 _{ij}	0.51 ± 0.05 ^b	0.72 ± 0.07 _{hij}	94.76 ± 0.04	1550 ± 6.36 _{def}	2.44 ± 0.4 ^b

Note: Values indicated with letters ^{abcdefghijklm} were significantly different from each other at $p \leq 0.05$ levels.

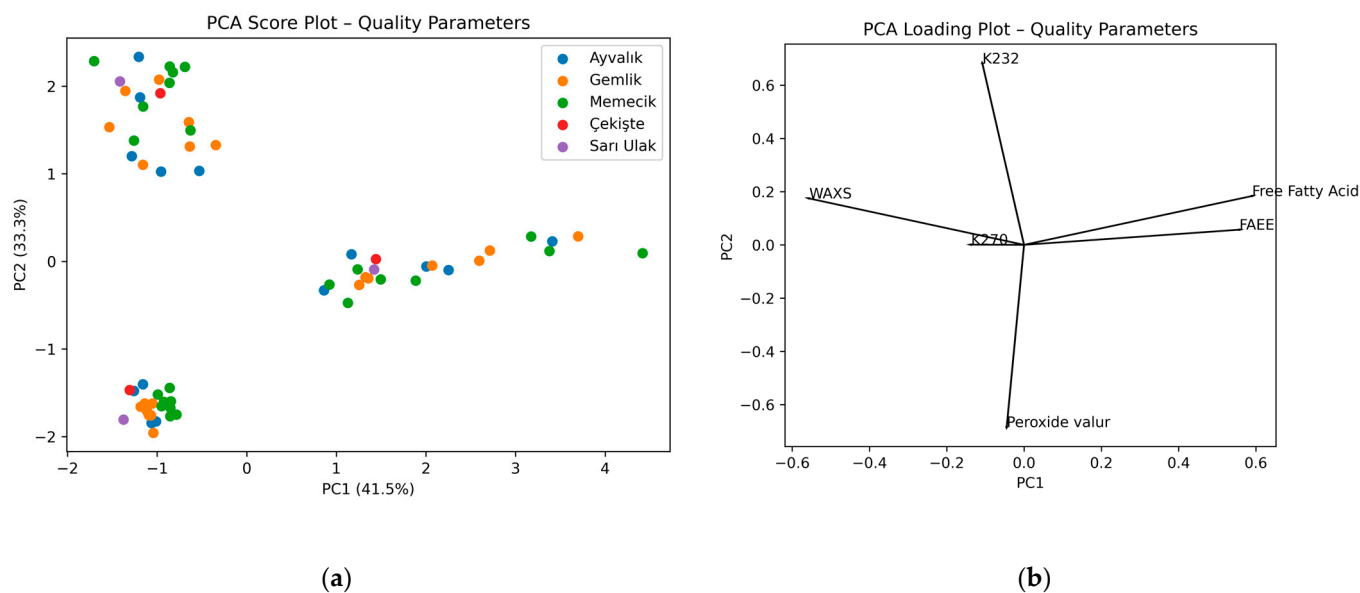


Figure 2. PCA (a) score plot and (b) loading plot based on quality and purity characteristics of olive oil samples.

2.5.2. Fatty Acid Composition

In the PCA applied to fatty acid composition data, the first principal component (PC1) explained 32.3% of the total variance, while the second principal component (PC2) accounted for 19.4%, as shown in Figure 3. Together, the first two components explained 51.7% of the overall variability, indicating moderate multivariate differentiation among samples. The loading plot indicates that PC1 captures the primary contrast between profiles rich in oleic acid (C18:1) and linolenic acid (C18:3) versus profiles characterized by higher proportions of palmitic acid (C16:0), linoleic acid (C18:2), and long-chain saturated fatty acids (C20:0–C24:0). Thus, PC1 reflects the balance between monounsaturated-rich oils and those relatively enriched in saturated and polyunsaturated fatty acids. In the score plot, Muğla I (Memecik) and Muğla III (Memecik), together with Aydın I (Memecik) and Aydın II (Memecik), were positioned toward the positive direction of PC1, indicating a composition relatively higher in palmitic, linoleic, and long-chain saturated fatty acids and comparatively lower in oleic acid. In contrast, Ödemiş I (Çekişte), İzmir V (Ayvalık), and part of Ayvalık III (Ayvalık) were located on the negative side of PC1, corresponding to oils richer in oleic acid and displaying a more typical high-MUFA olive oil profile. Hatay I (Gemlik), Mersin I (Sarı Ulak), and İzmir II (Gemlik) were located in the negative PC1 and positive PC2 quadrant, where contributions from stearic acid (C18:0), margaric acid (C17:0), and margoleic acid (C17:1) were more influential. This positioning suggests secondary differentiation related to specific minor saturated and monounsaturated fatty acids. Several samples, including Ayvalık I (Ayvalık), Ayvalık II (Gemlik), Ayvalık IV (Gemlik), İzmir I (Gemlik), and İzmir IV (Gemlik), were positioned close to the origin of the plot, indicating fatty acid compositions close to the overall mean profile and limited multivariate distinctiveness. While the first two components explain slightly more than half of the total variance and allow partial differentiation at the variety level, overlaps between groups remain evident. This suggests that, in addition to genetic factors, environmental conditions, harvest year, ripening stage, and microclimatic influences also contribute substantially to the observed variability in fatty acid composition.

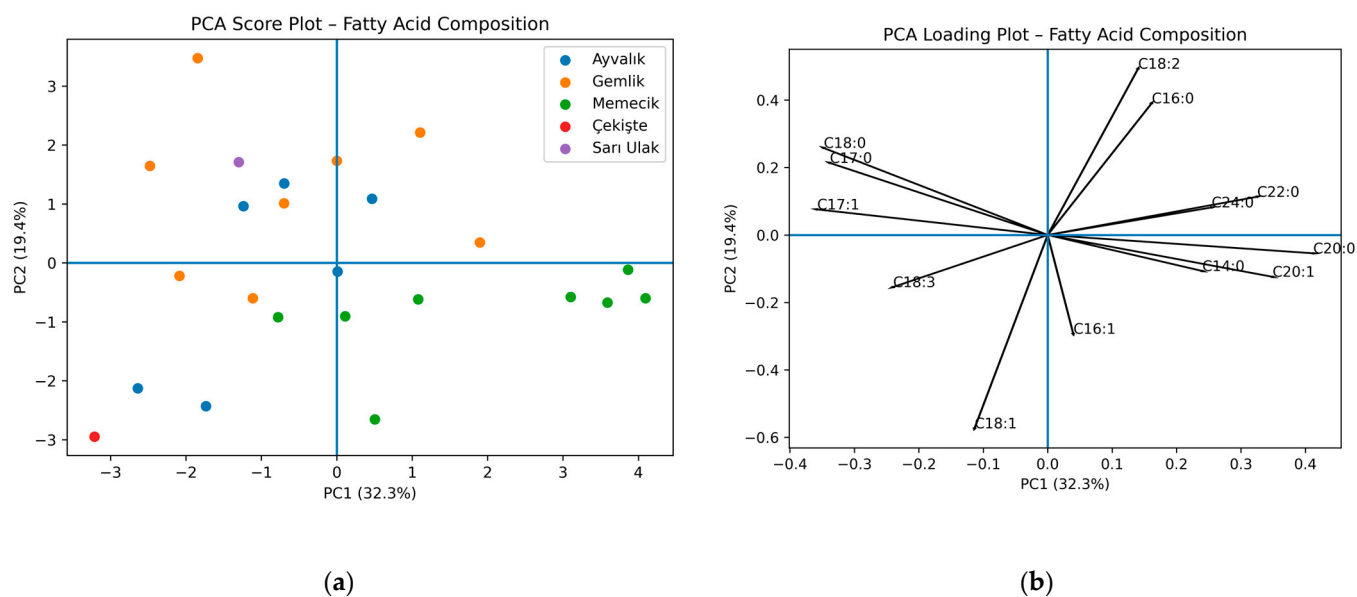


Figure 3. PCA (a) score and (b) loading vectors based on fatty acid composition of olive oil samples.

2.5.3. Sterol Composition

In the PCA applied to sterol composition, PC1 and PC2 explained 37.7% and 18.1% of the total variance, respectively (Figure 4), accounting for 55.8% of the overall variability. PC1 primarily separated samples enriched in D5-avenesterol, D7-avenesterol, D5,24-stigmastanienol and total sterols from those dominated by β -sitosterol and campesterol. Samples such as Ayvalık and several İzmir oils were positioned on the positive side of PC1, indicating relatively higher contributions of avenasterol-related compounds, whereas Aydın and Muğla samples were generally located in the negative PC1 region, reflecting a β -sitosterol- and campesterol-dominant profile. PC2 represented secondary variation mainly associated with total sterols and stanol-related compounds. While partial differentiation among varieties was observed, overlap between groups indicates that, beyond genetic factors, environmental conditions and production practices also contribute to sterol variability.

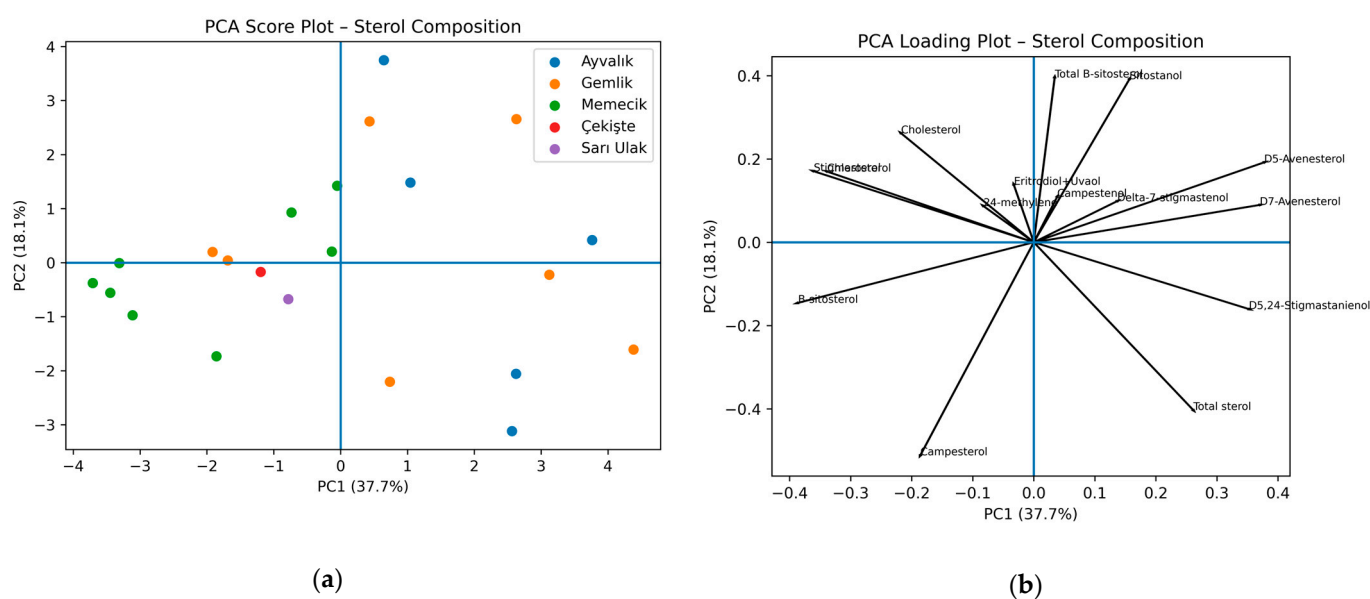


Figure 4. PCA (a) score and (b) loading vectors based on sterol composition analysis of olive oil samples.

In the PCA applied to the sensory attributes (fruitiness, bitterness, and pungency), the first principal component (PC1) explained 72.3% of the total variance, while the second principal component (PC2) accounted for 25.8%, together representing 98.1% of the overall variability (Figure 5). This very high cumulative variance indicates an excellent representation of the sensory data within a two-dimensional model. PC1 was strongly and positively associated with bitterness and pungency, defining an axis that can be interpreted as phenolic intensity. Oils positioned on the positive side of PC1 exhibited higher bitterness and pungency scores, typically reflecting a higher concentration of phenolic compounds and a more robust sensory profile. Conversely, samples located on the negative side of PC1 were characterized by milder sensory perception. PC2 mainly described the balance between fruitiness and the bitterness–pungency pair. Positive PC2 values were associated with higher fruitiness relative to bitterness and pungency, whereas negative PC2 values corresponded to oils in which fruitiness was less dominant. Thus, PC2 differentiates fruit-forward profiles from those driven primarily by phenolic sharpness. In the score plot, several Memecik samples, particularly from Muğla and Aydın, were positioned toward the positive PC1 region, indicating higher sensory intensity and stronger bitterness–pungency expression. In contrast, some Gemlik and Ayvalık samples were distributed toward the negative PC1 region, reflecting softer and more balanced profiles. Samples located near the origin exhibited intermediate sensory characteristics without a dominant attribute.

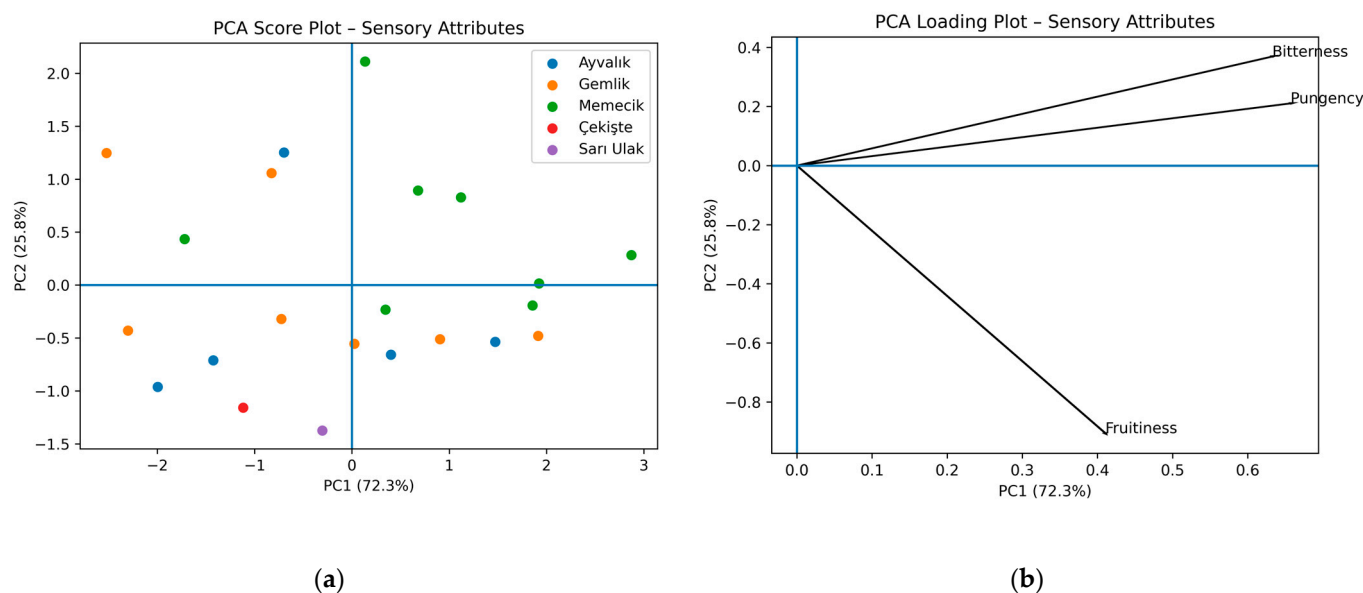


Figure 5. PCA (a) score and (b) loading vectors based on sensory analysis of olive oil samples.

While partial differentiation by variety is observable, the dispersion of samples suggests that, beyond genetic background, harvest timing, degree of ripeness, climatic conditions, and processing parameters also play a significant role in shaping the final sensory profile. In conclusion, PCA reveals a meaningful differentiation between samples based on sensory characteristics, with the PC1 axis representing phenolic intensity and sensory intensity. These findings can be used in product marketing strategies (e.g., robust, fruity–intense, fruity–mild) and in determining province’s quality differences.

3. Materials and Methods

3.1. Olive Oil Samples

Extra virgin olive oil from the Ayvalık (A), Memecik (M), Gemlik (G), Çekişte (Ç) and Sarı Ulak (SU) cultivars were collected from representative olive-growing regions in

Türkiye, namely Ayvalık (I, II, III, IV, V), İzmir (I, II, III, IV, V), Aydın (I, II, III, IV), Muğla (III), Ödemiş (I, II), Hatay (I) and Mersin (I) (Table 1).

3.1.1. Plant Material and Orchard Characteristics

The selected orchards represent the typical cultivation practices of each region. Trees were 20–40 years old, planted at 7×7 m to 8×8 m spacing, and managed under standard regional practices including pruning, pest and disease control, and fertilization based on soil analysis. Soils ranged from sandy loam to clay loam, with pH values between 6.5 and 8.2 and moderate organic matter content. Nutrient levels were adequate for olive cultivation. Orchards were either rain-fed or drip-irrigated during summer as needed. Altitude ranged from 10 to 250 m above sea level. All regions have a typical Mediterranean climate, with average annual temperatures of 15–20 °C and rainfall between 550 and 1000 mm.

3.1.2. Experimental Design and Replication

For each cultivar $\times$ region combination, fruits were collected from at least five randomly selected trees per orchard. All analyses were performed in triplicate.

3.1.3. Harvest Conditions and Sample Handling

Olives were mechanically harvested during the 2019–2020 harvest season at a comparable ripening stage. The maturity index, determined according to the International Olive Council method based on skin and pulp color (green–pink), ranged from 2.5 to 3.5. Approximately 200 kg of olives were collected for oil production. Fruits were transported in ventilated plastic crates and processed within 24 h using a two-phase centrifugal extraction system.

3.2. Chemicals, Analytical Instrumentation, and Analytical Methods

3.2.1. Reagent, Standard Solutions, and Certified Reference Materials (CRMs)

Chemicals and reagents of analytical grade or higher purity were used for analyses. *n*-Hexane, diethyl ether, *n*-heptane, potassium hydroxide, ethanol, and ethyl ether were obtained from Merck (Darmstadt, Germany). The internal standards, methyl heptadecanoate and *n*-eicosane or lauryl arachidate, FAEES (C4–C24), wax esters (C40–C46 esters), fatty acid methyl ester standard mixture (FAME 189-19), and α -cholestanol were obtained from Sigma Aldrich (Merck KGaA, Darmstadt, Germany).

3.2.2. Determination of Quality Parameters of Olive Oil Samples

The free acidity (FrA) [38] peroxide value (PeV) [39] and specific UV spectrophotometric indices (K232 and K270) [40] of EVOOs were evaluated by the analytical methods described by the IOC. Sensory evaluation was conducted by a ten-member expert panel recognized by the IOC and was ISO/IEC 17025 accredited [41], following IOC method COI/T.20/Doc. No 15/Rev. 10 [42]. Each panelist evaluated 15 mL of oil in separate booths at 10:00 a.m., maintaining a temperature of 28 ± 2 °C. Oils were assessed for positive attributes (fruity, bitter, and pungent) and negative defects (fusty, musty, winey, acid, frostbitten, rancid, etc.) with olfactory descriptors recorded. Scores were plotted on 10 cm profile papers and median values calculated using dedicated software.

3.3. Extraction of Oil from Olives Samples and Analysis of Its Compositions

3.3.1. Extraction of Oil

The olive oils were obtained using a two-phase centrifugal extraction system from fruit samples. After mechanical harvesting, the olives were brought to the factory, where they underwent leaf removal and washing before being crushed. The paste was kneaded

for 30 min under controlled conditions at $\leq 27^{\circ}\text{C}$, then separated into olive oil and aqueous pomace in a two-phase horizontal decanter centrifuge. The olive oil was further clarified by vertical centrifugation to remove residual moisture and solid particles. The obtained oils were stored in dark-colored glass bottles at 4°C until analysis.

3.3.2. Determination of Fatty Acid Ethyl Esters (FAEEs) by Gas Chromatography

Waxes (C40–C46 esters) and FAEEs (C16–C18) were determined according to the IOC method COI/T.20/Doc. No 28/Rev. 4 [43] by capillary gas chromatography (Agilent 6850, Santa Clara, CA, USA) equipped with an on-column injector and a fused silica capillary column. Olive oil samples (≈ 500 mg) were spiked with appropriate internal standards (methyl heptadecanoate for FAEEs and n-eicosane or lauryl arachidate for waxes), fractionated on hydrated silica gel, and eluted with n-hexane/diethyl ether. The collected fractions were evaporated, re-dissolved in n-heptane, and $1\ \mu\text{L}$ was injected into GC. The oven was programmed from 80°C to 140°C at $20^{\circ}\text{C}/\text{min}$, then to 340°C at $5^{\circ}\text{C}/\text{min}$ (20 min hold), with the injector and detector temperatures at 350°C . Quantification was performed by internal standard calibration, and results were expressed as mg/kg of fat for the sum of C42–C46 waxes (C40–C46 in non-virgin oils) and C16–C18 ethyl esters.

3.3.3. Determination of Fatty Acid Methyl Ester (FAME) Content Using GC-FID

The content of fatty acid methyl esters (FAMES) in virgin olive oil was determined using a gas chromatograph equipped with a flame ionization detector (GC-FID) (6850N, Agilent Technologies, Santa Clara, CA, USA) and a DB-23 capillary column ($60\text{ m} \times 0.25\text{ mm} \times 0.25\ \mu\text{m}$) (Agilent Technologies, Santa Clara, CA, USA) [44]. Helium (6.0 purity) served as the carrier gas, the split ratio was set to 1:100, and the injected volume was $0.2\ \mu\text{L}$. The temperature program for the GC oven comprised one stage: 170 to 210°C at a rate of $2^{\circ}\text{C min}^{-1}$ for 10 min. Both the injector and detector temperatures were maintained at 250°C to ensure complete vaporization of the sample and optimal detection sensitivity. The retention times of the sample FAMES were compared with those of a FAME standard mixture. Results were processed by using ChemStation software C.01.10 (Agilent OpelLab CDS, Santa Clara, CA, USA) and expressed as a relative percentage of total fatty acids, considering each peak identified.

3.3.4. Determination of Waxes Analysis

Waxes (C40–C46 esters) were determined according to IOC method COI/T.20/Doc. No 28/Rev.4 [43] by gas chromatography (Agilent 6850, Santa Clara, CA, USA) with an on-column injector and an HP-1 capillary column ($25\text{ m} \times 0.32\text{ mm i.d.}, 0.1\ \mu\text{m film}$). Olive oil (≈ 500 mg) was spiked with n-eicosane (0.1% in n-heptane, internal standard), dissolved in n-heptane, and $1\ \mu\text{L}$ was injected using helium ($1.2\text{ mL}/\text{min}$) as the carrier gas. The oven was programmed from 80°C (1 min) to 260°C at $15^{\circ}\text{C}/\text{min}$, then to 340°C at $5^{\circ}\text{C}/\text{min}$ (20 min hold), with the injector and detector temperatures at 350°C . Waxes were quantified by comparison with the internal standard.

3.3.5. Sterol Composition

Sterols and diols were determined following IOC method COI/T.20/Doc. No 26 (IOC, 2020) [45] using a GC-FID (Hewlett-Packard 6890, Santa Clara, CA, USA) with an HP-5 capillary column ($30\text{ m} \times 0.32\text{ mm}, 0.25\ \mu\text{m}$). Samples were saponified with 2 N ethanolic KOH after the addition of α -cholestanol (internal standard), and the unsaponifiable fraction was extracted with ethyl ether. The injection was $1\ \mu\text{L}$ (split 1:50) of helium carrier gas at 0.7 – $0.8\text{ mL}/\text{min}$, with injector/oven/detector temperatures of $280/260/290^{\circ}\text{C}$. Sterols were quantified relative to α -cholestanol and expressed as the % of total sterols.

3.3.6. Nutritional Quality Indices and Calculation Formulas

Quality indices were calculated based on FAME content according to Senila et al. [46]. The following indices were analyzed: atherogenic index (AI), thrombogenic index (TI), hypocholesterolemic/hypercholesterolemic ratio (h/H), health-promoting index (HPI), nutritive value index (NVI), polyene index (PI) and desirable fatty acids (DFAs). Equations (1)–(7) used for quality indices calculation are presented in Table 5.

Table 5. Nutritional quality indices and calculation formulas.

Parameter	Calculation Formulas	
TI ^a	$\frac{(C14:0+C16:0+C18:0)}{[(0.5 \times \sum UFA) + (0.5 \times \sum PUFA_{n-6}) + (3 \times \sum PUFA_{n-6}) + (\sum PUFA_{n-3} / \sum PUFA_{n-6})]}$	(1)
AI ^b	$\frac{[C12:0 + (4 \times C14:0) + C16:0]}{\sum UFA}$	(2)
h/H ^c	$\frac{(cis-C18:1 + \sum MUFA + \sum PUFA)}{(C12:0 + C14:0 + C16:0)}$	(3)
HPI ^d	$\frac{\sum UFA}{[C12:0 + (4 \times C14:0) + C16:0]}$	(4)
NVI ^e	$\frac{(C18:0 + C18:1)}{C16:1}$	(5)
PI ^f	$\frac{\sum PUFA}{\sum SFA}$	(6)
DFAs ^g	$C18:0 + \sum UFA$	(7)

^a Thrombogenic index; ^b atherogenic index; ^c hypocholesterolemic/hypercholesterolemic ratio; ^d health-promoting index; ^e nutritive value index; ^f polyene index; ^g desirable fatty acids.

3.4. Statistical Analyses

The EVOO samples were subjected to unsupervised chemometric techniques, specifically Paired Comparison App (Two-Way Analysis of Variance (ANOVA)) by using Origin software (version 2020b, OriginLab, Northampton, MA, USA). The correlation analyses were performed with Tukey's test ($p = 0.05$) using the Paired Comparison App (Two-Way ANOVA) by Origin software (version 2020b, OriginLab, Northampton, MA, USA). The different letters indicate statistically significant differences at a level of $p < 0.05$. Hierarchical clustering and multivariate analysis were applied to identify patterns of variation and groupings among the cultivars based on their chemical profiles by using Minitab Statistical software version 15; multivariate analysis (Minitab, LLC, State College, PA, USA) was also carried out.

4. Conclusions

This study conducted a comprehensive evaluation of olive oils derived from five Turkish cultivars—Ayvalık, Memecik, Gemlik, Çekişte, and Sarı Ulak—collected from various provinces, including Ayvalık, İzmir, Aydın, Muğla, Ödemiş, Hatay, and Mersin. The results demonstrated that the majority of samples met the criteria for extra virgin olive oil as defined by the International Olive Council (IOC), based on parameters such as free fatty acid content, peroxide value, and UV absorbance indices. Notably, the Ayvalık and Memecik varieties exhibited superior oleic acid concentrations and favorable sensory profiles, distinguishing them as premium-quality oils. Sterol composition analyses revealed province- and cultivar-specific chemical markers, supporting the potential for geographical indication labeling and authenticity verification. Sensory evaluations further confirmed that regional factors significantly influence aroma, taste, and overall consumer acceptability. Overall, the findings underscore the critical role of genetic diversity and agro-environmental conditions in shaping the chemical and sensory quality of olive oil. The study highlights the importance of preserving indigenous cultivars, promoting region-specific production strategies, and developing quality-driven marketing approaches.

These insights contribute to the scientific foundation for enhancing the competitiveness and sustainability of Türkiye's olive oil industry.

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