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Review

Quercetin content in olive oil and olive by-products as affected by cultivar, geographical origin, cultivation practices, and processing

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Abstract: Olive oil is rich in different classes of phenolic compounds, and their content is important for the quality assessment of virgin olive oil. Phenolic compounds contribute to the taste and aroma of olive oil and protect it from oxidation. The present review article aimed to collect and evaluate several research data concerning the effect of variety, geographical origin, cultivation practices, and processing on a less studied plant flavonol, namely quercetin, in olive oil and olive by-products. Collected data included measurements of quercetin content and total phenolic compounds in olive oil of Greek, Italian, Spanish, Turkish, Algerian, Tunisian, and Brazilian olive varieties. Olive varieties, geographical region, temperature, and malaxation processing affect the concentration of total phenolic content and, consequently, the quercetin content. In addition, differences in the reported quercetin content may partly stem from methodological variability. To enrich the article's data and evaluate the concentration of phenolic compounds in olive oil, olives and olive leaves were also studied. However, a gap was identified in the literature, as research studies are lacking on the specific effect of the factors mentioned above on the quercetin content of olive oil. For this reason, the collection of several findings on the effect of such factors on quercetin content was considered to be necessary.

Keywords: quercetin, olive oil, olive leaves, olive varieties, glucosides, phenolic content

1. Introduction

The olive tree (*Olea europaea* L.) is one of the most important perennial species in the Mediterranean basin. The Mediterranean form, *Olea europaea* subsp. *europaea*, includes both wild (*Olea europaea* subsp. *europaea* var. *sylvestris*) and cultivated (*Olea europaea* subsp. *europaea* var. *europaea*) varieties. *Olea europaea* is the main cultivated species from the monotypic family Oleaceae, which comprises approximately 30 genera and 600 species. The genus *Olea* includes approximately 30 species distributed across Europe, Asia, Oceania, and Africa [1].

Olive cultivation began in ancient times in the Mediterranean region, where the species holds considerable economic, ecological, and cultural significance [2]. The Mediterranean area is particularly rich in olive tree varieties, largely due to its favorable climate and long history of domestication [3,4]. Today, more than 2000 olive varieties have been identified, although some are no longer cultivated due to changes in agricultural practices [4]. Olive oil is considered a healthy fat due to its high content of monounsaturated lipids and the presence of phenolic compounds with various preventive bioactive health properties. In addition to its beneficial lipid composition, olive oil is an excellent source of phenolic substances [5].

The qualitative and quantitative composition of hydrophilic phenols in extra-virgin olive oil is influenced by both endogenous and exogenous factors: olive variety, climate, soil, harvest time, processing, and storage conditions [6]. Phenolic compounds are classified as flavonoids and non-flavonoids. Depending on their complexity, they can be further characterized as monomeric and polymeric compounds [7]. Flavonoids are related to the Latin word *flavus*, which means yellow, their natural color in nature. Flavonoids are a category of polyphenols, secondary metabolites that exist in plants, fruits, and vegetables, such as lettuce, spinach, green hot peppers, kale, red cabbage, cauliflower, blueberries, elderberries, cranberries, chokeberries, black currants, red apples, pears, white and red onions, tea, and nuts. An important category of flavonoids is flavones. Flavones or glucosides are found in abundance in edible plants and include tangeretin, apigenin, and luteolin. Many vegetables, fruits, and cereals are rich in flavonols, which are particularly widespread in green leaves. They are usually present as aglycone-based glucosides, such as rhamnetin, myricetin, kaempferol, and quercetin. Edible plants mainly contain flavonoids such as the 3-O-glycosides of quercetin, which include rutin, isoquercitrin, and quercitrin [8]. Quercetin is a flavonoid that has high natural antioxidant activity and many therapeutic properties against cancer, hypertension, rheumatoid arthritis, and type 2 diabetes [9–14]. Also, quercetin inhibits the activity of many Gram-positive and negative bacteria, fungi, and viruses [15–22]. Quercetin also prevents the activity of drug-resistant bacterial strains and decreases the resistance of fungi to medicine [16–29].

Considering the above, this study summarizes the effect of processing practices, such as malaxation, on the quercetin content of olive oil, along with how some crucial parameters (i.e., geographical region, agricultural practices, and environmental conditions) could significantly affect the total phenolic content, focusing mainly on the concentration of quercetin in olives, olive leaves, and olive oil.

This review article aimed to search for articles that had as their main subject the effect of olive cultivar, geographical origin, cultivation practices, and processing on quercetin content in olive oil. Olive and leaf data were used for supporting purposes.

2. Literature search strategy

In this review article, the databases of Google Scholar, PubMed, Scopus, and Phenol-Explorer were used to search for studies published within the last 15 years (2010–2025). Over 130 (n > 130) articles were screened and found to be related to the topic based on keywords related to quercetin content in olive oil, olives, and olive leaves; 106 articles were only considered as references in this review article. More specifically, keywords and sentences used during the literature search were "Quercetin", "Olive oil", Olive leaves", "Quercetin in olive oil", "Total phenolic content in olive oil", and "Malaxation of olive oil". Selection criteria considered the relevance of the findings to the research topic and the publication date of each study.

3. Olive oil bioactive compounds: Geographical, environmental, and genetic/cultivar impact

Olive oil is one of the most important foods and sources of fat in the Mediterranean diet. Its nutritional properties have been highlighted widely in previous research studies around the world [30,31]. Due to the use of olive oil, the Mediterranean diet presents a low risk of different diseases, such as chronic cardiovascular diseases and cancer. These benefits are related to the bioactive compounds contained in olive oil [30,32]. The main bioactive compounds found in olive oil are phenolic compounds, although it also contains valuable secoiridoid compounds [33]. Particularly, tyrosol, hydroxytyrosol, and oleuropein account for approximately 30% of the total phenolic compounds present in olives, providing pharmaceutical properties such as antioxidant, anticancer, and antibacterial activities [30,33]. However, many key factors can affect the phenolic composition and nutritional properties of olive oil, such as the location, altitude, fruit harvesting, cultivar, etc. The olive cultivar is the most important factor regarding the chemical and sensory profile of extra-virgin olive oil (EVOO). The cultivar primarily drives the ratio between polyunsaturated and monounsaturated fats, such as the proportion of linoleic acid to oleic acid [34]. Also, different olive cultivars contain enzymes that are responsible for several volatile compounds, which provide a distinct aroma. In addition, cultivars like Koroneiki typically produce a more robust and pungent flavor profile, whereas Galega and Arbequina yield sweeter and more buttery notes [34–36]. Geographical impact and environmental factors can also significantly affect the chemical composition of EVOO [37]. Higher altitudes correspond to cooler climates and greater abiotic stress, resulting in higher oleic acid content [34]. Soil composition parameters, such as mineral content and pH, are crucial factors for the sensory and chemical characteristics of EVOO [36]. Finally, post-harvest techniques used for oil extraction during processing in the mill, such as crushing, centrifugation, or filtration, significantly affect the phenolic composition and quality parameters of olive oil [38].

3.1. Processing: The case of malaxation

Temperature is one of the most critical parameters that influences the quality of olive oil. Low temperature extraction (below 27 °C), known as "cold pressing", is crucial for the maintenance of the natural characteristics of olive oil [39]. As the extraction temperature increases, it enhances enzymatic reactions such as oxidation and lipolysis, leading to a differentiated phenolic composition and volatile profile of olive oil [40]. At this point, we should state that some interactions of

endogenous enzymes, such as lipoxygenase (LOX) and hydroperoxide lyase, are desired. The LOX pathway acts directly on polyunsaturated fatty acids to synthesize C_6 and C_9 volatile compounds (alcohols and aldehydes), which significantly affect the fresh and fruity aromas of EVOO [41]. In contrast, hydrolytic enzymes like lipases can cleave triacylglycerols (TGAs) into glycerol and free fatty acids, resulting in the degradation of EVOO quality, and this process can be measured as free acidity [42]. Additionally, low temperatures during processing and storage (<20 ℃) prevent the action of endogenous enzymes, such as β-glucosidase, which catalyze the hydrolysis of phenolic glucosides and prematurely exhaust the phenolic profile [43]. In general, oxidative transformations occur at higher temperatures, as reported by Gómez-Alonso et al. [44]. Molecular oxygen attacks the double bond of unsaturated fatty acids, forming unstable peroxides. These hydroperoxides rapidly decompose into alcohols, aldehydes, and ketones, which drive sensory effects and rancidity [44,45]. Moreover, higher temperatures during the kneading and centrifugation stages of olive paste allow the small droplets of oil to merge with larger ones, reducing the paste viscosity and leading to the transfer of various substances from aqueous to oil phase [40,46]. Angeloni et al. [40] tested three malaxation temperatures (21 ℃, increased temperature from 21 to 27 ℃, and 27 ℃) and found that the higher temperature led to a significantly ($p < 0.05$) higher yield of phenolic composition. However, the impact of malaxation temperature on the concentration of quercetin in olive oil has not been studied extensively in the literature, thus opening a field for further research. Heat treatment significantly affects the bioavailability of flavonoids in food, with the effect depending on the intensity and duration of heating. Studies examining various foods rich in quercetin have shown that the application of heat leads to the degradation of this flavonoid [47]. Malaxation time of olive paste also influences the composition of phenolic compounds in olive oil [48]. Previous studies demonstrated a general pattern that a long malaxation time reduces the concentration of major phenolic compounds [48–50]. On the other hand, Inarejos-García et al. [51] explained that the decrease in phenolic concentration in the oil fraction results from the activity of oxidative and hydrolytic enzymes or from the long contact between the vegetation water and paste, which enhances the diffusion of phenolic compounds into the aqueous phase [52]. Because of the polar preference of phenolic compounds, only 2% of the total phenolic content of olive fruits is transferred into the final product, while the remaining 98% can be lost in olive mill wastewater [53]. This problem can be solved using new technologies, like horizontal centrifugation to manipulate the partition coefficient and enhance compound transfer, without encouraging oxidative or microbial degradation [54]. Generally, longer malaxation time degrades the nutritional and phenolic profile of olive oil (especially in oxygen-rich environments), but it can also provide a high yield when it is performed properly. Clodoveo [55] suggested that the optimal malaxation conditions depend on olive characteristics (i.e., variety) and temperature, but excessive paste processing (beyond 60 min) leads to a reduced yield. Similarly, the malaxation time of olive paste needs further investigation, regarding quercetin composition in olive oil, as there are no reports in the literature. Also, the impact of malaxation temperature and time of olive paste on the concentration of quercetin in olive oil has not been studied extensively in the literature, thus opening a field for further research regarding possible transformations (enzymatic/oxidative) and focusing specifically on quercetin and quercetin glycosides during processing at a mechanistic level.

3.2. Effect of ripening, harvesting, and transportation

The ripening stage of the olive fruit and the harvest period significantly influence the quality of olive oil. During ripening, a series of metabolic processes occur that affect fatty acid composition, total phenolic content, antioxidant capacity, and overall quality of the oil. An increase in the maturity index is associated with a reduction in phenolic compounds [56]. According to Özcan et al. [57], the harvest season has a significant impact on the phenolic content of olive oil. Furthermore, the time between harvesting and pressing plays a crucial role in determining oil quality. Prolonged storage of olives before processing can lead to quality deterioration. In addition, transportation conditions of both olives and olive oil are critical factors. If temperature is not properly controlled, quality degradation occurs. For instance, transporting extra-virgin olive oil during the summer can result in a decline in quality, potentially reducing it to a virgin olive oil grade due to elevated temperatures [58]. We should also not forget that oxygen exposure and water content can also affect the stability of individual phenolic compounds, and thus quercetin. However, this has not been extensively reported. Figure 1 presents a visual summary of the key factors that may affect quercetin content in olive oil.

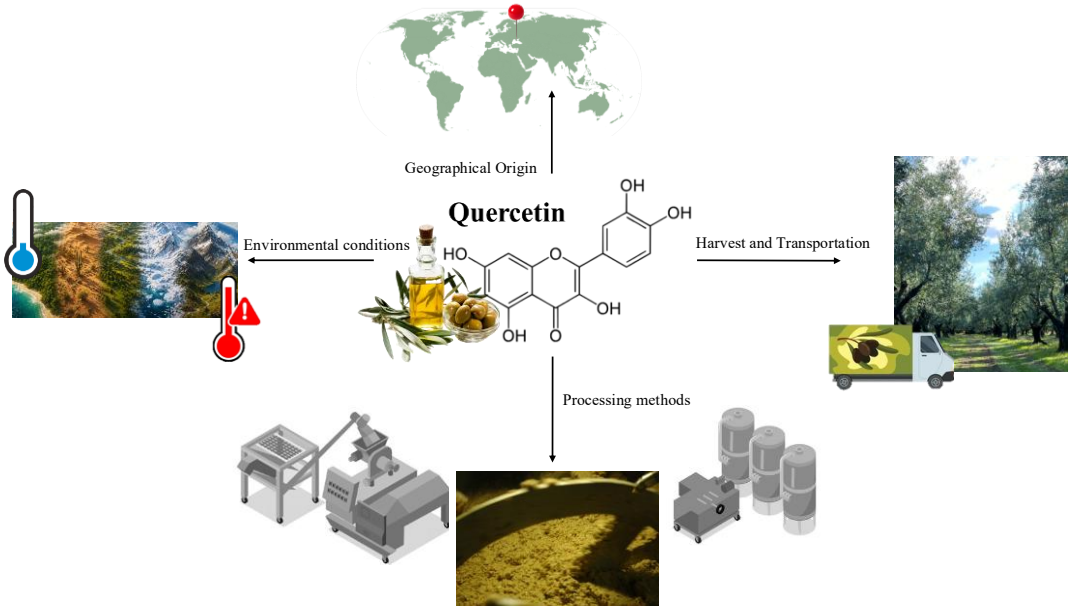

Figure 1. Key factors that may affect quercetin content in olive oil.

4. Quercetin

Quercetin is a widely occurring polyphenolic flavonoid. Beyond its classification as a flavonol, it also functions as a natural pigment that humans are unable to synthesize, being further recognized as a phytoestrogen. Structurally, quercetin contains three rings and five hydroxyl groups. It exhibits several health-promoting effects, including supporting cardiovascular function and lowering the risk of cancer development [47]. Quercetin is one of the most powerful scavengers of free radicals and exhibits anti-inflammatory, antidiabetic, anti-obesity, and anti-aging activities. It is a yellow, solid, hydrophobic compound with a bitter taste, soluble in glacial acetic acid and slightly soluble in alcohol [8]. Most flavonoids are bound to sugars in the form of O-glycosides, in which glycosylation

can occur at any hydroxyl group to yield a sugar moiety. The most common quercetin glycosides possess a sugar group at the 3 position. These structures are encountered more frequently than the aglycone, or parent compound [55]. The constitution of quercetin is either unbound or linked in the form of quercetin-3-O-glucoside (isoquercetin), quercetin-3-O-rutinoside (rutin), quercetin 4-O-glucoside, quercetin 3,4-O-diglucoside, quercetin-3-O-arabinoside (avicularin), quercetin 3-O-galactoside (hyperoside), or quercetin-3-O-rhamnoside (quercetrin). The affixing of the sugar in place of a hydroxyl group causes amplified bioavailability due to better dissolution. The antioxidant activity of quercetin glycosides is diminished compared to that of free quercetin, owing to the lower accessibility of quercetin glycosides to free radicals in the starting and dissemination phases of the sequence, contrasted with the separate form of quercetin [59]. Figure 2 represents the structures of quercetin glucosides as obtained individually from the PubMed database. Table 1 shows the quercetin glucosides as obtained from the Phenol-Explorer database.

Table 1. Quercetin compounds and their glucosides.

Compounds	**Glucosides**
Avicularin	Quercetin-3-O-arabinoside
Hyperoside	Quercetin-3-O-galactoside
Iso-glucoside	Isorhamnetin-3-O-glucoside
Isorhamnetin	3'-O-methylquercetin
Isoquercetin	Quercetin-3-O-glucoside
Miquelianin	Quercetin-3-O-glucuronide
Q-diglucoside	Quercetin-3,4'-di-O-glucoside
Quercetrin	Quercetin-3-O-rhamnoside
Rutin	Quercetin rutinoside
Spiraeoside	Quercetin-4'-O-glucoside
Tamarixetin	4'-O-methylquercetin
Rutoside	Quercetin 3-O-rutinoside
Baimaside	Quercetin-3-O-sophoroside
Quercetin-3-O-xylosyl-rutinoside	Quercetin-3-O-xylosyl-rutinoside
Quercetin-3-O-glucosyl-xyloside	Quercetin-3-O-glucosyl-xyloside
Quercetin 3-O-glucosyl-rhamnosyl-glucoside	Quercetin 3-O-glucosyl-rhamnosyl-glucoside
Quercetin 3-O-neohesperidoside	Quercetin 3-O-neohesperidoside
Quercetin 3-O- malonylglucoside	Quercetin 3-O- malonylglucoside
Myricitrin	Myricitrin-3-O-glucoside
Tellimoside	Quercetin 3-O- (6”-O-galloyl)-β-D-glucoside
Quercetin 3-O-sambubioside	Quercetin 3-O-sambubioside
Quercetin 3-gentiobioside	Quercetin 3-gentiobioside
Quercetin 3-O-rhamnoside-7-O-glucoside	Quercetin 3-O-rhamnoside-7-O-glucoside
Quercetin 3'-O-sulfate	Quercetin 3'-O-sulfate
Quercetin 3,4',7-triglucoside	Quercetin 3,4',7-triglucoside
Quercetin 7-glucuronide	Quercetin 7-O-Beta-D-Glucuronide
Quercimeritrin	Quercetin-7-O-glucoside

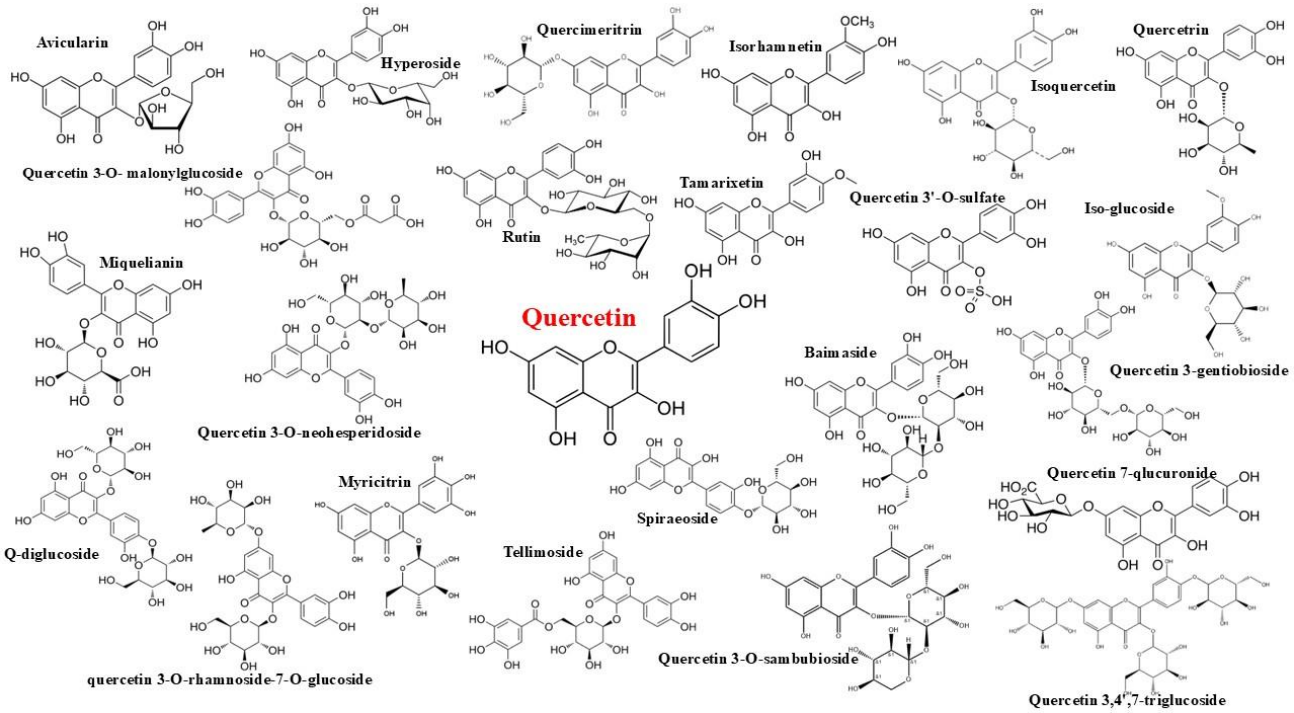

Figure 2. Structures of quercetin glucosides.

4.1. Quercetin and total phenolic content in olive oil

4.1.1 Total phenolic content in olive oil

The physicochemical properties and phenolic content of extra-virgin olive oil are influenced by environmental factors during cultivation, such as biotic and abiotic stresses, as well as the plant's genetic background and the agricultural practices applied [60]. Quercetin and total phenolic content differ among different regions. Sulastri et al. [61] found that the leaves of *Moringa oleifera* from a region with medium altitude (Sigi regency) had higher total phenolic and quercetin content than those from regions with low and high altitudes (Parigi and Palu cities). Andjelkovic et al. [62] reported that the total phenolic content of French olive oil samples was lower than that of Spanish samples. Ninfali et al. [63] found that the total phenolic content of extra-virgin olive oil from four different Italian regions, Marches, Apulia, Umbria, and Venetia, was 255, 329, 340, and 139 mg/kg, respectively. Bakhouche et al. [64] reported significant differences in the total phenolic content of extra-virgin olive oil from the Arbequina cultivar across various locations in Southern Catalonia with different soil characteristics. Sibel Uluata et al. [65] found that the total phenolic content of Arbequina from Aegean and Mediterranean was 454.68 and 50.86 mg of gallic acid/kg oil, respectively. Alves Cantareli et al. [66] reported differences in total phenolic content of olive cultivar Arbequina between nine Brazilian commercial brands in the states of Minas Gerais (MG), Paraná (PR), Santa Catarina (SC), and Rio Grande do Sul (RS) (Table 2). The production of the above olive oils complied with all the standards of the International Olive Council (IOC).

García et al. [67] reported differences in total polyphenol content between olive cultivars Picual, Arbequina, Hojiblanca, and Cornicabra. Differences in total phenolic content between olive cultivars

Arbequina, Arbequina I-18, Arbosana, and Koroneiki were also stated by Allalout et al. [68]. Škevin et al. [69] concluded that the phenol content depends significantly on the olive variety. Seydou et al. [70] found differences in total phenolic content between extra-virgin olive oil samples from different regions of Turkey (Table 3). Yildirim et al. [71] stated that the phenolic content of the oil of the Memecik variety was significantly higher compared to the oil of Ayvalık and Topakaşı varieties. Soufi et al. [72] studied the phenolic profile of olive oil from three Algerian cultivars (Azeradj, Bouchouk, and Chemlal) and found significant differences in phenolic content: 318.9 ± 0.07, 132.8 ± 0.9, and 221.3 ± 0.9 mg of gallic acid equivalent/kg, respectively. The total ortho-diphenol content was 31.1 ± 0.2, 13.2 ± 0.2, and 30.7 ± 0.4, respectively, and the total flavonoid content was 13.1 ± 0.1, 6.5 ± 0.7, and 13.6 ± 0.2, respectively.

Franco et al. [73] reported that the content of total phenolic compounds of seven virgin olive oil varieties from Extremadura of South-West Spain was between 130 and 1203 mg/kg. Samples were collected in different maturation stages (green, spotted, and ripe), and the harvest time was between November and January. Ballus et al. [74] stated that the total phenol content of the virgin vegetable oil of cultivars Coratina, Arbosana, and Grappolo was significantly higher compared to that of Arbequina, Koroneiki, Manzanilla, Frantoio, and MGS Mariense. Medina et al. [75] reported that there were differences in total phenolic content between olive cultivars El Viso and Los Tomillos from Tenerife, Antequera, Baena, La Rambla, and Úbeda from Andalusia. These different olive cultivars have been grown in different environmental conditions and during different harvest seasons (September, October, and November). In a previous study, it was reported that the total phenolic content of Arbequina olive leaves was higher compared to that of Sikitita and Picual olive leaves [76].

Table 2. Total phenolic content of nine Brazilian monovarietal olive oil samples of cultivar Arbequina from the states of Minas Gerais, Paraná, Santa Catarina, and Rio Grande do Sul [55].

Production areas	Geographical coordinates		Total phenolic content in olive oil (mg GAE/L)
Rio Grande do Sul	30°00′45″ S	52°55′11″ W	328.68 ± 2.81
Rio Grande do Sul	30°00′45″ S	52°55′11″ W	337.63 ± 1.49
Rio Grande do Sul	00°30′59″ S	53°29′12″ W	424.91 ± 0.92
Rio Grande do Sul	31°23′44″S	52°41′11″ W	299.74 ± 2.88
Rio Grande do Sul	31°19′43″S	54°06′26″ W	348.49 ± 2.23
Minas Gerais	22°17′46″ S	45°23′05″ W	189.17 ± 1.66
Minas Gerais	21°55′46″ S	44°36′07″ W	166.62 ± 3.61
Paraná	04°14′40″ S	50°14′36″ W	168.72 ± 1.87
Santa Catarina	27°40′45″ S	49°00′27″ W	138.05 ± 1.22

Table 3. Total phenolic content of extra-virgin olive oil (EVOO) samples from different regions of Turkey [60].

Olive oil	Total phenolic content in EVOO (mg GAE/g)
Ayvalık	39.60 ± 1.10
Izmir sofralık	180.12 ± 1.04
Tavşan yüreği	33.13 ± 5.88
Kilis yağlık	157.76 ± 1.3

4.1.2. Quercetin content in olive oil

Oğraş [77] evaluated quercetin content in olive oils derived from different geographic regions and varieties. In the Mediterranean region, the highest quercetin content was recorded in the variety Hasebi (1.24 ± 0.10 mg/kg), followed by Sri Ulak (1.23 ± 0.21 mg/kg). The varieties Gemlik (1.03 ± 0.09 mg/kg) and Saurani (0.95 ± 0.03 mg/kg) exhibited intermediate values, while Ayvalik showed the lowest content (0.91 ± 0.06 mg/kg). In the Aegean region, the variety Uslu (1.24 ± 0.22 mg/kg) presented the highest quercetin content. The varieties Domat and Gemlik displayed comparable concentrations (0.98 ± 0.05 and 0.98 ± 0.07 mg/kg), whereas Memecik exhibited the lowest value (0.97 ± 0.19 mg/kg). In Southeastern Anatolia, the highest concentration was found in Ayvalik (1.25 ± 0.20 mg/kg), followed by Halhali (1.20 ± 0.05 mg/kg), Kilis Yaglik (1.09 ± 0.11 mg/kg), and Nizip Yaglik (0.99 ± 0.18 mg/kg). The lowest quercetin content in this region was measured in Karamani (0.91 ± 0.11 mg/kg). In the Marmara region, the highest concentration was in Celebi (0.96 ± 0.05 mg/kg). The varieties Ayvalik, Domat, and Memecik showed intermediate content (0.95 ± 0.03, 0.92 ± 0.04, and 0.92 ± 0.06 mg/kg), respectively. The lowest content was shown in Gemlik (0.84 ± 0.06). In the Black Sea region, quercetin content values were highest in Sati (1.27 ± 0.25 mg/kg), followed by Gorvele (1.21 ± 0.04 mg/kg). Kizil Sati exhibited moderate content (0.95 ± 0.03 mg/kg), while Butko and Otur recorded the lowest content values (0.90 ± 0.16 and 0.90 ± 0.10 mg/kg, respectively) (Table 4 and Figure 3).

In another study, Xiang et al. [78] examined the quercetin content across several olive oil cultivars. The Manzanilla variety exhibited the highest concentration (0.89 ± 0.01 mg/kg), followed by Koroneiki (0.71 ± 0.05 mg/kg) and Coratina (0.49 ± 0.01 mg/kg), while the Barnea variety had the lowest (0.49 ± 0.01 mg/kg) (Table 5). It is important to note that the differences in quercetin content of olive oil discussed above may also originate from methodological variability (i.e., inter-laboratory variability), given that research laboratories throughout the world use liquid-chromatography methods that differ based on extraction solvents, programs/conditions of analysis, and, primarily, different equipment (older or newer) for the determination of quercetin in olive oil, olive products, or olive materials.

Table 4. Quercetin content in olive oil from the Mediterranean, Aegean, Black Sea, and Marmara regions.

Geographical region	Variety	Quercetin in olive oil (mg/kg)
Mediterranean	Gemlik	1.03 ± 0.09
	Ayvalik	0.91 ± 0.06
	Saurani	0.95 ± 0.03
	Hasebi	1.24 ± 0.10
	Sri Ulak	1.23 ± 0.21
Aegean	Memecik	0.97 ± 0.19
	Domat	0.98 ± 0.05
	Uslu	1.24 ± 0.22
	Gemlik	0.98 ± 0.07
	Erkence	1.2 ± 0.53
Southeastern Anatolia	Nizip Yaglik	0.99 ± 0.18
	Ayvalik	1.25 ± 0.20
	Kilis Yaglik	1.09 ± 0.11
	Halhali	1.2 ± 0.05
	Karamani	0.91 ± 0.11
Marmara	Gemlik	0.84 ± 0.06
	Ayvalik	0.95 ± 0.03
	Celebi	0.96 ± 0.05
	Domat	0.92 ± 0.04
	Memecik	0.92 ± 0.06
Black Sea	Butko	0.90 ± 0.16
	Otur	0.90 ± 0.10
	Gorvele	1.21 ± 0.04
	Sati	1.27 ± 0.25
	Kizil Sati	0.95 ± 0.03

Table 5. Quercetin and rutin content in olive oil of different varieties.

Varieties	Quercetin in olive oil (mg/kg)	Rutin in olive oil (mg/kg)
Barnea	0.42 ± 0.01	18.84 ± 0.13
Coratina	0.49 ± 0.01	16.97 ± 0.14
Koroneiki	0.71 ± 0.05	21.74 ± 0.23
Manzanilla	0.89 ± 0.01	11.21 ± 0.17

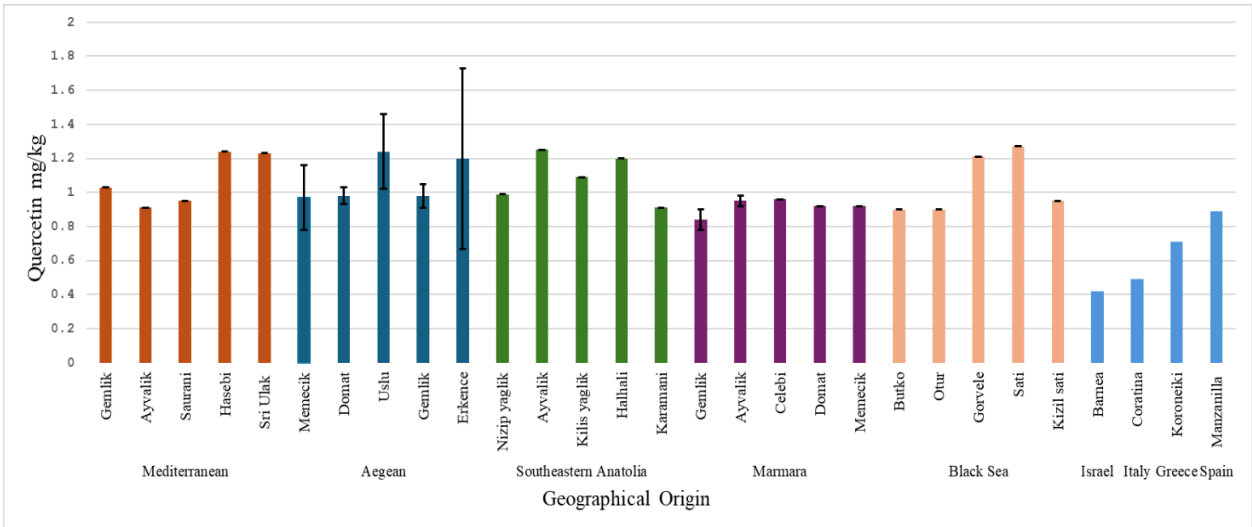

Figure 3. Quercetin content (mg/kg) of olive oil from different olive cultivars [66,67].

4.2. Quercetin and total phenolic content in olive fruit varieties

4.2.1. Quercetin content in olive fruit varieties

Fruits and specifically olives from the same variety but from different geographical origins also present differences in their phenolic characteristics [79]. For this reason, quercetin content exhibits differences among various olive cultivars. Esti et al. [80] reported that quercetin content in olive cultivars Gentile de Colletorto, Leccino, Gentile de Larino, and Coratina was 0.36, 0.37, 0.21, and 0.14 mg/g, respectively. The harvest time was in November. Ghreishi Rad et al. [60] also reported that quercetin content in olive cultivars Manzanilla, Koroneiki, and Arbequina was 1.50, 5.26, and 10.20 mg/g, respectively. Ghasemi et al. [81] stated that the quercetin content fluctuated from 1.45% to 1.51% (w/w) in olive cultivars Conservolea, Arbequina, Roghani, Amphissis, Yellow, Amigdalolia, Marry, Leccino, Shenge, Gordal, Fishomi, and Beleidi. In olive cultivars Manzanilla, Mishen, Coratina, Kalamon, and Sevillence, the quercetin content was 1.84%–4.07% (w/w).

Vinha et al. [82] reported differences in quercetin 3-O-rhamnoside content among several olive cultivars (Table 6). Banco et al. [83] reported significant differences in quercetin content and total phenolic content among 18 olive varieties cultivated at two growing seasons (2013/2014 and 2014/2015) in the Mendoza province of Argentina (33°06′S, 68°29′W) (Table 7). Soufi et al. [84] reported that the quercetin-3-rutinoside content in Algerian olive cultivars Azeradj, Abelout, Aberkane, Atefah, and Bouchouk was 1857.16 ± 79.72, 227.63 ± 22.41, 410.73 ± 0.41, 461.94 ± 61.96, and 454.27 ± 61.52 mg/kg of dried weight, respectively. The samples were harvested at the ripe stage in December. Djemaa-Landri et al. [85] found significant differences in total phenolic content of olive oil between six Algerian olive cultivars (Table 8).

Table 6. Quercetin 3-O-rhamnoside content of various olive cultivars [82].

Olive cultivars	Geographical origin	Quercetin 3-O-rhamnoside content (mg/kg of olives)
Bical	Macedo de Cavaleiros	17.0 ± 0.57
	Mogadouro	44.4 ± 0.49
Bical de Castelo	Castelo Branco	16.1 ± 0.88
Branco	Fundao	20.5 ± 0.33
Borreira	Mogadouro	119 ± 12.5
Borrenta	Valpacos	122.8 ± 1.63
	Mirandela	100.9 ± 4.45
Cobrancosa	Valpacos	162 ± 4.25
	Mirandela	55.6 ± 0.80
	Fundao	46.3 ± 1.51
	Mogadouro	31.9 ± 1.40
Cordovesa	Macedo de Cavaleiros	54.0 ± 1.58
Cordovil de Castelo	Fundao	65.0 ± 0.71
Branco	Castelo Branco	37.6 ± 0.06
Cornicabra	Figueira de Castelo Rodrigo	95.2 ± 8.70
Galega	Castelo Branco	189 ± 5.04
	Fundao	9.6 ± 0.37
Lentisca	Valpacos	56.9 ± 0.26
Madural	Mirandela	54.6 ± 0.55
	Valpacos	17.4 ± 7.53
Madural Fina	Mogadouro	125 ± 6.82
Madural Negra	Mogadouro	69.7 ± 2.11
Negrinha do Freixo	Figueira de Castelo Rodrigo	64.6 ± 3.70
Picual	Mirandela	43.1 ± 20.43
Roupuda	Mogadouro	193 ± 1.05
Santulhana	Mogadouro	64.9 ± 0.81
Verdeal	Macedo de Cavaleiros	Traces
Transmontana	Mirandela	25.9 ± 0.72
	Valpacos	138 ± 9.97

Table 7. Quercetin and total phenolic content of various olive varieties [84].

Varieties	Quercetin (mg caffeic acid equivalent/kg of olives)*	Total phenolic content (mg/kg of olives)*
Arauco	12.67	413.63
Blanqueta	10.04	324.77
Canino	15.66	440.64
Criolla Salvarredi	13.03	371.16
Cucci	6.17	105.45
Dritta	7.56	241.52
Dulzal	3.82	250.22
Empeltre	19.62	217.03
Farga	9.21	268.93
Frantoio	9.67	227.34
Genovesa	4.76	236.74
Jabaluno	10.97	231.58
Morchiaio	Nd	285.92
Nebbio	Nd	416.06
Nevadillo Blanco	5.82	345.92
Piangente	11.75	304.96
Selección	31.72	190.81
Villalonga	7.79	357.14

Note: *Standard deviation values were not provided by the authors.

Table 8. Total phenolic content of olive oil of the varieties Ayemel, Achemlale, Azeradj, Agraraz, Atefah, and Azeboudj [86].

Varieties of olive stones	Total phenolic content (mg gallic acid equivalent/g of olive stone)
Ayemel	5.14 ± 0.16
Achemlale	7.23 ± 0.08
Azeradj	5.35 ± 0.05
Agraraz	5.63 ± 0.08
Atefah	6.04 ± 0.15
Azeboudj	6.34 ± 0.02

4.2.2. Total phenolic content in olive fruits

Mansouri et al. [86] stated that the total phenol content in Koroneiki, Abrosana, and Arbequina cultivars was 5.66, 454.8, and 286.51 mg/kg, respectively. In another study, Mansouri et al. [87] declared that olive cultivar Koroneiki had the highest total phenol content, when compared with Abrosana and Arbequina. Khaliq et al. [88] found that in Koroneiki, Abrosana, and Arbequina cultivars, the total phenol content was 426.92, 165.32, and 136.5 mg/Kg, respectively. In a previous study, the Manzanilla olive cultivar had the highest total polyphenol content (22.81 mg GAE/g) compared to Arbosana, Arbequina, Frantoio, and Koroneiki [89]. On the other hand, Antunes et al. [90]

stated that olive cultivars Manzanilla and Arbequina had the lowest total polyphenol content compared to Arbosana, Frantoio, and Koroneiki. According to Tous et al. [91], the Arbequina cultivar is categorized as having a low polyphenol content. Cavalheiro et al. [92] reported that the olive cultivar Arbosana had the highest phenolic compound content, compared to Ascolano, Negrinha do Freixó, Koroneiki, and Grappolo. Also, researchers found that the phenolic compound content of the olive cultivar Koroneiki was the lowest. This observation was in contrast with the observation by Antunes et al. [90], who found that the Koroneiki olive cultivar had the highest phenolic compound content. According to Otero et al. [93], the content and synthesis of phenolic compounds depend on the cultivar, the position of the tree, the type of soil and the minerals present, the geographic location, and the effect of sunlight, among other factors. Zagmutt et al. [94] noted that the total phenolic content of the olive variety Barnea was significantly higher than that of varieties Arbequina and Frantoio. Palmeri et al. [95] found that the total polyphenol content of leaves from the olive cultivars Nocellara Etnea, Nocellara Messinese, Biancolilla, and Nocellara Siracusana, during the time period January–February, was 26.4 ± 2.6, 24.0 ± 1.5, 16.3 ± 0.5, and 16.5 ± 0.2 mg of gallic acid equivalent/g dry leaf, respectively. The cultivars above are cultivated in the southeast of Sicily, Italy (37°04’09 N, 15°25’58 E). Dabbou et al. [96] reported that the total phenolic content in Chétoui cv. (grown in Zaghouan), Koroneiki, and Chétoui cv. (grown in Béja) were 446, 403, and 398 mg/kg, respectively. de Fernandez et al. [97] reported that the total phenolic content of olive cultivars Arauco, Farga, Arbequina, and Empeltre was 514.15, 278.58, 170.93, and 206.52 μg caffeic acid/g of olive oil, respectively. Manai-Djebali et al. [98] stated that Tunisian olive cultivar Betsijina had the highest total phenol content compared to the other Tunisian cultivars Hor Kesra, Sredki, Chladmi, and Aloui. Franco et al. [73] found that the content of total phenol compounds of seven virgin olive oil varieties from Extremadura of southwest Spain was between 130 and 1203 mg/kg. Ballus et al. [74] stated that the total phenol content of the virgin vegetable oil of cultivars Coratina, Arbosana, and Grappolo was significantly higher compared to that of Arbequina, Koroneiki, Manzanilla, Frantoio, and MGS Mariense. Medina et al. [75] reported that there were differences in total phenol content between olive cultivars El Viso and Los Tomillos from Tenerife, Antequera, Baena, La Rambla, and Úbeda from Andalusia. In a study conducted on olive varieties from Tunisia (Chemlali) during their maturation period, quercetin 3-arabino-glycoside prevailed throughout the entire aging process, while rutin increased slowly until the 10th day. However, its concentration decreased at the end of storage. The concentration of quercetin remained low, with only minor modifications. The above results can be explained by the fact that the fruit *Olea europaea* L. accumulates only glycosylated derivatives, as they are less toxic than aglycones. This leads to the conclusion that the flavonol content may vary depending on the stage of ripening [99].

4.3. *Quercetin and total phenolic content in olive leaves*

Olive leaves have been used in traditional medicine and pharmacy due to their phenolic and antioxidant compounds [100]. Deng et al. [101] reported differences in total flavonoid content of young leaves between olive cultivars Arbosana, Arbequina, and Picholine. The total flavonoid content of these olive cultivars was 55.50, 63.47, and 76.98 mg RE/g, respectively. Wang et al. [102] reported that the total phenolic content in young leaves of olive cultivars Frantioio and Arbosana was 125.00 and 135.10 mg/g per dry mass (DM), respectively, compared to olive cultivars Salonenque, Arbequina, Koroneiki, and Jiufeng, which had total phenolic content ranging between 141.60 and

151.04 mg/g DM. Uslu and Özcan [103] reported the effect of irrigation on the total phenolic content in olive leaves of four varieties (Table 9).

Table 9. Effect of irrigation on total phenolic content in olive leaves of the varieties Ayvalık, Çöpaşı, Gemlik, and Yağlık at five moments of harvest [103].

Varieties	Harvest 1	Harvest 2	Harvest 3	Harvest 4	Harvest 5	Harvest 6
Ayvalık	1718.75 ± 7.01	1838.75 ± 5.53	1745.00 ± 6.97	1792.50 ± 4.25	1786.25 ± 8.88	1945.00 ± 5.28
Çöpaşı	1662.50 ± 7.39	1538.75 ± 7.99	1418.75 ± 9.24	1902.50 ± 7.87	1503.75 ± 6.73	1786.25 ± 4.96
Gemlik	1845.00 ± 6.93	1807.50 ± 6.64	1485.00 ± 6.91	1873.75 ± 5.33	1761.25 ± 6.20	1903.75 ± 5.56
Yağlık	1835.00 ± 6.97	1745.00 ± 4.42	1705.00 ± 5.68	1752.50 ± 4.44	1685.00 ± 5.54	1771.23 ± 4.14

Ben Salah et al. [104] found significant differences in total phenolic content between eight olive cultivars (Table 10). Khelouf et al. [105] found significant differences in polyphenols and quercetin content of olive leaf extracts from eight olive varieties (Table 11). The extraction of polyphenols was performed by using the solvents ethanol, ethyl acetate, and hexane. According to Kiritsakis et al. [106], an analysis of Greek olive leaf varieties showed that the Kalamon variety had the highest quercetin concentration, with 1.74 ± 0.08 mg/g, followed by the Koroneiki (1.07 ± 0.06 mg/g), while the Megaritiki variety exhibited the lowest content (0.71 ± 0.04 mg/g) (Table 12).

Table 10. Total phenolic content of the olive varieties Gerboua, Chetoui, Limouni Chemlali, Sevillane, Lucques, Rosicola, and Meski [104].

Varieties	**Total phenolic content (mg GAE/g of olives)**
Gerboua	142.21 ± 3.53
Chetoui	102.32 ± 1.18
Limouni	144.19 ± 10.27
Chemlali	99.71 ± 11.45
Sevillane	73.05 ± 15.52
Lucques	106.80 ± 9.24
Rosicola	91.90 ± 11.04
Meski	110.03 ± 20.04

Table 11. Polyphenol content and quercetin content of olive leaf extracts of the olive varieties Sigoise, Rougette, Sofiana, Verdal, Chemlali, Octoubri, Gerboui, and Sayali [104].

	Polyphenol content (mg gallic acid equivalent/g of dry extract)			**Quercetin (mg/100 g of dry matter)**
Varieties	Ethanol	Ethyl Acetate	Hexane	
Sofiana	135.74 ± 1.41	93.03 ± 6.09	18.53 ± 1.41	12.98 ± 0.06
Rougette	160.53 ± 1.17	130.29 ± 2.77	46.09 ± 5.65	26.68 ± 0.13
Verdal	121.33 ± 2.11	160.15 ± 4.64	18.48 ± 0.49	15.15 ± 0.08
Octoubri	142.46 ± 2.45	118.49 ± 0.99	17.12 ± 0.77	27.89 ± 0.14
Gerboui	141.90 ± 1.71	118.87 ± 2.45	20.96 ± 2.53	15.87 ± 0.08
Sigoise	161.54 ± 0.99	133.66 ± 0.90	21.19 ± 0.32	28.85 ± 0.14
Chemlali	123.17 ± 2.15	106.79 ± 2.49	20.26 ± 1.06	94.48 ± 0.47
Sayali	106.32 ± 0.32	94.06 ± 1.55	23.30 ± 0.21	7.45 ± 0.04

Table 12. Quercetin concentration in olive leaves according to olive variety and total phenolic content (methanol/water extract).

Varieties	**Quercetin (mg/g of olive leaves)**	**Total phenolic content (mg/g of olive leaves)**
Kalamon	1.74 ± 0.08	60.93
Koroneiki	1.07 ± 0.06	55.79
Megaritiki	0.71 ± 0.04	61.96

5. Conclusions and future research directions

The quercetin content in olive oil is influenced by various environmental factors, such as temperature and climate, but also by factors such as the method of processing and storage. Over the last twenty years, there have been very few studies on the measurement of quercetin in olive oil. Although olive oil is rich in flavonols, the content of quercetin is very low. The above-mentioned studies showed that the highest concentration of quercetin was in the olive oil of the Sati variety, from the Black Sea region (1.27 ± 0.25 mg/kg), and the lowest content was in the Greek variety Koroneiki (0.71 ± 0.05 mg/kg). Most studies in the recent literature focused on either total phenolic content or specific phenolic compounds, which are abundant in olive oil, leaving quercetin content relatively understudied. The quercetin content can be related not only to the production and storage of olive oil but also to its geographical origin. Furthermore, it is important to study how the malaxation of the olive and the temperature of the extraction process can affect the concentration of quercetin in the final product. Finally, an increased quercetin content in olive oil can improve its health benefits. Therefore, the quercetin content has critical implications for the nutritional labeling or health claims of olive oil. Quercetin quantification could be effectively achieved with an improvement in processing and extraction practices, as well as standardized analytical protocols related to the analysis of quercetin in olive oil and breeding programs that target olive varieties rich in quercetin. The lack of data on the quercetin content of olive oil produced in different countries highlights the need for further collaborative studies. Future research should also focus on the

development of analytical protocols for the identification and quantification of quercetin in olive oil, as well as on investigations specifically dedicated to this compound. In particular, a comprehensive study of olive oils originating from different geographical regions should be undertaken to thoroughly evaluate quercetin content and to elucidate, among others, the influence of geographical origin on its distribution, as products of a specific geographical origin and composition may have a higher price in the domestic and global markets.

Author contributions

Eirini Intzirtzi: Literature review, writing original draft, visualization, investigation, methodology, formal analysis. Andreas Panou: Literature review, writing original draft, investigation, formal analysis. Dimitrios G. Lazaridis: Literature review, writing original draft, investigation, formal analysis. Ioannis K. Karabagias: Writing original draft, conceptualization, data curation, resources, methodology, validation, project administration, proofreading, supervision. All authors have read and agreed to the published version of the manuscript

Use of Generative-AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

The authors declare no conflict of interest in this paper.

References

1. Chiappetta A, Muzzalupo I (2012) Botanical description, In: *The olive cultivation, table olive and olive oil industry in Italy*. http://doi.org/10.5772/51836
2. Arenas-Castro S, Gonçalves JF, Moreno M, et al. (2020) Projected climate changes are expected to decrease the suitability and production of olive varieties in southern Spain. *Sci Total Environ* 709: 136161.https://doi.org/10.1016/j.scitotenv.2019.136161
3. Sofo A, Manfreda S, Fiorentino M, et al. (2008) The olive tree: A paradigm for drought tolerance in Mediterranean climates. *Hydrol Earth Syst Sci* 12: 293–301 https://doi.org/10.5194/hess-12-293-2008
4. Fleyfel LM, Leitner NKV, Deborde M, et al. (2022) Olive oil liquid wastes–Characteristics and treatments: A literature review. *Process Saf Environ* 168: 1031–1048. https://doi.org/10.1016/j.psep.2022.10.035
5. Diamantakos P, Ioannidis K, Papanikolaou C, et al. (2021) A new definition of the term 'high-phenolic olive oil' based on large scale statistical data of Greek olive oils analyzed by qNMR. *Molecules* 26: 1115. https://doi.org/10.3390/molecules26041115

6. Bajoub A, Pacchiarotta T, Hurtado-Fernández E, et al. (2016) Comparing two metabolic profiling approaches (liquid chromatography and gas chromatography coupled to mass spectrometry) for extra-virgin olive oil phenolic compounds analysis: A botanical classification perspective. *J Chromatogr A* 1428: 267–279. https://doi.org/10.1016/j.chroma.2015.10.059
7. Yahia EM (2019) *Postharvest physiology and biochemistry of fruits and vegetables*, Duxford: Woodhead Publishing. https://doi.org/10.1016/B978-0-12-813278-4.00012-9
8. Vollmannová A, Bojňanská T, Musilová J, et al. (2024) Quercetin as one of the most abundant represented biological valuable plant components with remarkable chemoprotective effects—A review. *Heliyon* 10: e33342. https://doi.org/10.1016/j.heliyon.2024.e33342
9. Nile SH, Nile AS, Keum YS, et al. (2017) Utilization of quercetin and quercetin glycosides from onion (*Allium cepa* L.) solid waste as an antioxidant, urease and xanthine oxidase inhibitors. *Food Chem* 235: 119–126. https://doi.org/10.1016/j.foodchem.2017.05.043
10. Zeng Y, Song J, Zhang M, et al. (2020) Comparison of in vitro and in vivo antioxidant activities of six flavonoids with similar structures. *Antioxidants* 9: 732. https://doi.org/10.3390/antiox9080732
11. Joshi NS, Aggarwal P, Hirpara VK, et al. (2011) Novel quercetin derivatives as anti-cancer agents. Patent.
12. Hussain SA, Ahmed ZA, Mahwi TO, et al. (2012) Quercetin dampens postprandial hyperglycemia in type 2 diabetic patients challenged with carbohydrates load. *Int J Diabetes Res* 1: 32–35. https://doi.org/10.5923/j.diabetes.20120103.01
13. Edwards RL, Lyon T, Litwin SE, et al. (2007) Quercetin reduces blood pressure in hypertensive subjects. *J Nutr* 137: 2405–2411. https://doi.org/10.1093/jn/137.11.2405
14. Javadi F, Ahmadzadeh A, Eghtesadi S, et al. (2017) The effect of quercetin on inflammatory factors and clinical symptoms in women with rheumatoid arthritis: A double-blind, randomized controlled trial. *J Am Coll Nutr* 36: 9–15. https://doi.org/10.1080/07315724.2016.1140093
15. Osonga FJ, Akgul A, Miller RM, et al. (2019) Antimicrobial activity of a new class of phosphorylated and modified flavonoids. *ACS Omega* 4: 12865–12871. https://doi.org/10.1021/acsomega.9b00077
16. Li K, Xing S, Wang M, et al. (2012) Anticomplement and antimicrobial activities of flavonoids from Entada phaseoloides. *Nat Prod Commun* 7: 1934578X1200700. https://doi.org/10.1177/1934578X1200700715
17. Rocha MFG, Sales JA, da Rocha MG, et al. (2019) Antifungal effects of the flavonoids kaempferol and quercetin: A possible alternative for the control of fungal biofilms. *Biofouling* 35: 320–328. https://doi.org/10.1080/08927014.2019.1604948
18. Shishodia SK, Tiwari S, Hoda S, et al. (2020) SEM and qRT-PCR revealed quercetin inhibits morphogenesis of *Aspergillus flavus* conidia via modulating calcineurin-Crz1 signalling pathway. *Mycology* 11: 118–125. https://doi.org/10.1080/21501203.2020.1711826
19. Milanezi FG, Meireles LM, de Christo Scherer MM, et al. (2019) Antioxidant, antimicrobial and cytotoxic activities of gold nanoparticles capped with quercetin. *Saudi Pharm J* 27: 968–974. https://doi.org/10.1016/j.jsps.2019.07.005
20. Colunga Biancatelli RML, Berrill M, Catravas JD, et al. (2020) Quercetin and vitamin C: An experimental, synergistic therapy for the prevention and treatment of SARS-CoV-2 related disease (COVID-19). *Front Immunol* 11: 1451. https://doi.org/10.3389/fimmu.2020.01451

21. Cushnie TPT, Lamb AJ (2005) Antimicrobial activity of flavonoids. *Int J Antimicrob Ag* 26: 343–356. https://doi.org/10.1016/j.ijantimicag.2005.09.002
22. dos Santos AE, Kuster RM, Yamamoto KA, et al. (2014) Quercetin and quercetin 3-O-glycosides from *Bauhinia longifolia* (Bong.) Steud. show anti-Mayaro virus activity. *Parasites Vectors* 7: 130. https://doi.org/10.1186/1756-3305-7-130
23. Montone AMI, Papaianni M, Malvano F, et al. (2021) Lactoferrin, quercetin, and hydroxyapatite act synergistically against *Pseudomonas fluorescens*. *Intl J Mol Sci* 22: 9247–9247. https://doi.org/10.3390/ijms22179247
24. Yin J, Peng X, Lin J, et al. (2021) Quercetin ameliorates *Aspergillus fumigatus* keratitis by inhibiting fungal growth, toll-like receptors and inflammatory cytokines. *Int Immunopharmacol* 93: 107435. https://doi.org/10.1016/j.intimp.2021.107435
25. Amin MU, Khurram M, Khattak B, et al. (2015) Antibiotic additive and synergistic action of rutin, morin and quercetin against methicillin resistant *Staphylococcus aureus*. *BMC Complem Altern M* 15: 59. https://doi.org/10.1186/s12906-015-0580-0
26. da Costa Júnior, de Oliveira Santos JV, de Almeida Campos LA, et al. (2018) Antibacterial and antibiofilm activities of quercetin against clinical isolates of *Staphyloccocus aureus* and *Staphylococcus saprophyticus* with resistance profile. *IJAEB* 3: 1948–1958. https://doi.org/10.22161/ijeab/3.5.50
27. Gao M, Wang H, Zhu L (2016) Quercetin assists fluconazole to inhibit biofilm formations of fluconazole-resistant *Candida Albicans* in *in vitro* and *in vivo* antifungal managements of vulvovaginal candidiasis. *Cell Physiol Biochem* 40: 727–742. https://doi.org/10.1159/000453134
28. Singh BN, Upreti DK, Singh BR, et al. (2015) Quercetin sensitizes fluconazole-resistant candida albicans to induce apoptotic cell death by modulating quorum sensing. *Antimicrob Agents Chemother* 59: 2153–2168. https://doi.org/10.1128/aac.03599-14
29. Oliveira VM, Carraro E, Auler ME, et al. (2015) Quercetin and rutin as potential agents antifungal against *Cryptococcus* spp. *Braz J Biol* 76: 1029–1034. https://doi.org/10.1590/1519-6984.07415
30. Schmidt L, Prestes OD, Paula Rossini Augusti, et al. (2023) Phenolic compounds and contaminants in olive oil and pomace – A narrative review of their biological and toxic effects. 53: 102626. https://doi.org/10.1016/j.fbio.2023.102626
31. Servili M, Sordini B, Esposto S, et al. (2013) Biological activities of phenolic compounds of extra virgin olive oil. *Antioxidants* 3: 1–23. https://doi.org/10.3390/antiox3010001
32. Pang KL, Lumintang JN, Chin KY (2021) Thyroid-modulating activities of olive and its polyphenols: A systematic review. *Nutrients* 13: 529. https://doi.org/10.3390/nu13020529
33. Tzekaki EE, Papaspyropoulos A, Tsolaki M, et al. (2021) Restoration of BMI1 levels after the administration of early harvest extra virgin olive oil as a therapeutic strategy against Alzheimer's disease. *Exp Gerontol* 144: 111178. https://doi.org/10.1016/j.exger.2020.111178
34. Rey-Giménez R, Sánchez-Gimeno AC (2023) Effect of cultivar and environment on chemical composition and geographical traceability of Spanish olive oils. *J Am Oil Chem Soc* 101: 371–382. https://doi.org/10.1002/aocs.12774
35. Navas-López JF, Cano J, de la Rosa R, et al. (2020) Genotype by environment interaction for oil quality components in olive tree. *Eur J Agron* 119: 126115. https://doi.org/10.1016/j.eja.2020.126115

36. Rocha P, Lamas S, Casal S, et al. (2026) Can the region of production affect the quality and composition of olive oil? Comparative study on two olive cultivars. *Appl Food Res* 6: 101689. https://doi.org/10.1016/j.afres.2026.101689
37. Rodrigues N, Peres F, Casal S, et al. (2023) Geographical discrimination of olive oils from Cv. 'Galega Vulgar'. *Food Chem* 398: 133945. https://doi.org/10.1016/j.foodchem.2022.133945
38. Khdair AI, Ayoub S, Abu-Rumman G (2015) Effect of pressing techniques on olive oil quality. *Am J Food Technol* 10: 176–183. https://doi.org/10.3923/ajft.2015.176.183
39. Boselli E, Di Lecce G, Strabbioli R, et al. (2009) Are virgin olive oils obtained below 27 ℃ better than those produced at higher temperatures? *LWT-Food Sci Technol* 42: 748–757. https://doi.org/10.1016/j.lwt.2008.09.018
40. Angeloni G, Spadi A, Corti F, et al. (2024) Balancing efficiency and quality: Effects of gradual temperature increase on extra virgin olive oil extraction. *AgriEngineering* 6: 3553–3562. https://doi.org/10.3390/agriengineering6040202
41. Sun X, Wang Y, Li H, et al. (2021) Changes in the volatile profile, fatty acid composition and oxidative stability of flaxseed oil during heating at different temperatures. *LWT* 151: 112137. https://doi.org/10.1016/j.lwt.2021.112137
42. Flores M, Avendaño V, Bravo J, et al. (2021) Edible oil parameters during deterioration processes. *Int J Food Sci* 2021: 7105170. https://doi.org/10.1155/2021/7105170
43. De Santis D, Ferri S, Milana G, et al. (2024) Stability of monovarietal Sicilian olive oils under different storage condition: Chemical composition, sensory characteristics, and consumer preference. *Heliyon* 10: e29833. https://doi.org/10.1016/j.heliyon.2024.e29833
44. Gómez-Alonso S, Salvador MD, G. Fregapane (2004) Evolution of the oxidation process in olive oil triacylglycerol under accelerated storage conditions (40–60℃). *J Am Oil Chem Soc* 81: 177–184. https://doi.org/10.1007/s11746-004-0878-7
45. De Leonardis A, Angelico R, Macciola V, et al. (2013) Effects of polyphenol enzymatic-oxidation on the oxidative stability of virgin olive oil. *Food Res Int* 54: 2001–2007. https://doi.org/10.1016/j.foodres.2013.04.034
46. Nissim Y, Shloberg M, Biton I, et al. (2020) High temperature environment reduces olive oil yield and quality. *PLOS ONE* 15: e0231956. https://doi.org/10.1371/journal.pone.0231956
47. Kumar R, Vijayalakshmi S, Nadanasabapathi S (2017) Health benefits of quercetin. *Def Life Sci J* 2: 142–151. https://doi.org/10.14429/dlsj.2.11359
48. Miho H, Moral J, López-González MA, et al. (2020) The phenolic profile of virgin olive oil is influenced by malaxation conditions and determines the oxidative stability. *Food Chem* 314: 126183. https://doi.org/10.1016/j.foodchem.2020.126183
49. Angerosa F, Basti C (2001) Olive oil volatile compounds from the lipoxygenase pathway in relation to fruit ripeness. *Ital J Food Sci* 13: 421–428.
50. Jiménez B, Sánchez-Ortiz A, Rivas A (2014) Influence of the malaxation time and olive ripening stage on oil quality and phenolic compounds of virgin olive oils. *Int J Food Sci Technol* 49: 2521–2527. https://doi.org/10.1111/ijfs.12592
51. Inarejos-García AM, Gómez-Rico A, Salvador MD, et al. (2008) Influence of malaxation conditions on virgin olive oil yield, overall quality and composition. *Eur Food Res Technol* 228: 671–677. https://doi.org/10.1007/s00217-008-0977-9

52. Marx ÍMG, Priego-Capote F (2025) Importance of malaxation conditions to virgin olive oil polar phenolic compounds content. *Food Chem* 480: 143884. https://doi.org/10.1016/j.foodchem.2025.143884
53. Attard K, Oztop MH, Lia F (2022) The effect of hydrolysis on the antioxidant activity of olive mill waste. *Appl Sci* 12: 12187. https://doi.org/10.3390/app122312187
54. De Ceglie C, Abbattista R, Losito I, et al. (2020) Influence of horizontal centrifugation processes on the content of phenolic secoiridoids and their oxidized derivatives in commercial olive oils: An insight by liquid chromatography–High-resolution mass spectrometry and chemometrics. *J Agric Food Chem* 68: 3171–3183. https://doi.org/10.1021/acs.jafc.0c00455
55. Clodoveo ML (2012) Malaxation: Influence on virgin olive oil quality. Past, present and future—An overview. *Trends Food Sci Technol* 25: 13–23. https://doi.org/10.1016/j.tifs.2011.11.004
56. Pardo JE, Rabadán A, Suárez M, et al. (2021) Influence of olive maturity and season on the quality of virgin olive oils from the area assigned to the protected designation of origin of 'Aceite de la Alcarria' (Spain). *Agronomy* 11: 1439. https://doi.org/10.3390/agronomy11071439
57. Özcan MM, Fındık S, AlJuhaimi F, et al. (2019) The effect of harvest time and varieties on total phenolics, antioxidant activity and phenolic compounds of olive fruit and leaves. *J. Food Sci Technol* 56: 2373–2385. https://doi.org/10.1007/s13197-019-03650-8
58. Breschi C, Guerrini L, Zanoni B, et al. (2022) Simulation of transport under different temperature conditions: Effects on extra virgin olive oil quality. *Eur J Lipid Sci Tech* 124: 2100242. https://doi.org/10.1002/ejlt.202100242
59. Hamed M, Abdallah IA, Alaa Bedair, et al. (2023) Sample preparation methods for determination of quercetin and quercetin glycosides in diverse matrices. *Microchem J* 194: 109233. https://doi.org/10.1016/j.microc.2023.109233
60. Rad SAG, Jalili M, Ansari F, et al. (2023) Maturity impact on physicochemical composition and polyphenol properties of extra virgin olive oils obtained from *Manzanilla*, *Arbequina*, and *Koroneiki* varieties in Iran. *Food Sci Nutr* 11: 5396–5408. https://doi.org/10.1002/fsn3.3497
61. Sulastri E, Zubair MS, Anas NI, et al. (2018) Total phenolic, total flavonoid, quercetin content and antioxidant activity of standardized extract of Moringa oleifera leaf from regions with different elevation. *Pharmacogn J* 10: s104–s108. https://doi.org/10.5530/pj.2018.6s.20
62. Andjelkovic M, Van Camp J, Pedra M, et al. (2008) Correlations of the phenolic compounds and the phenolic content in some Spanish and French olive oils. *J Agri Food Chem* 56: 5181–5187. https://doi.org/10.1021/jf0724419
63. Ninfali P, Bacchiocca M, Biagiotti E, et al. (2002) Validation of the oxygen radical absorbance capacity (ORAC) parameter as a new index of quality and stability of virgin olive oil. *J Am Oil Chem Soc* 79: 977–982. https://doi.org/10.1007/s11746-002-0590-7
64. Bakhouche A, Lozano-Sánchez J, Beltrán-Debón R, et al. (2013) Phenolic characterization and geographical classification of commercial Arbequina extra-virgin olive oils produced in southern Catalonia. *Food Res Int* 50: 401–408. https://doi.org/10.1016/j.foodres.2012.11.001
65. Uluata S, Altuntaş Ü, Özçelik B (2016) Biochemical characterization of Arbequina extra virgin olive oil produced in Turkey. *J Am Oil Chem Soc* 93: 617–626. https://doi.org/10.1007/s11746-016-2811-z

66. Kennedy FKA, Anjo FA, Matumoto-Pintro PT, et al. (2025) Field and processing conditions of olive fruits of 'Arbequina' cultivar on the oil's quality sold in Brazil. *Eur J Lipid Sci Technol* 127: E70054. https://doi.org/10.1002/ejlt.70054
67. García A, Brenes M, García P, et al. (2003) Phenolic content of commercial olive oils. *Eur Food Res Technol* 216: 520–525. https://doi.org/10.1007/s00217-003-0706-3
68. Allalout A, Krichène D, Methenni K, et al. (2009) Characterization of virgin olive oil from Super Intensive Spanish and Greek varieties grown in northern Tunisia. *Sci Hortic* 120: 77–83. https://doi.org/10.1016/j.scienta.2008.10.006
69. Škevin D, Rade D, Štrucelj D, et al. (2003) The influence of variety and harvest time on the bitterness and phenolic compounds of olive oil. *Eur J Lipid Sci Technol* 105: 536–541, https://doi.org/10.1002/ejlt.200300782
70. Seydou S, Koca G, Onar O, et al. (2022) Antioxidant activities of Turkish extra virgin olive oils. *Commun Fac Sci Univ Ank Ser C* 31: 26–38. https://doi.org/10.53447/communc.1069705
71. Yıldırım F, Yıldırım AN, Özkan G, et al. (2020) Early harvest effects on hydrophilic phenolic components of extra virgin olive oils cvs. 'Ayvalık', 'Memecik' and 'Topakaşı'. *Biochem Genet* 58: 981–992. https://doi.org/10.1007/s10528-020-10008-9
72. O Soufi, Romero C, Hadid M, et al. (2018) Characterization of phenolic profile and antioxidant potential of some Algerian olive oils cultivars. *J Food Qual Hazards Control* 5: 49–53. https://doi.org/10.29252/jfqhc.5.2.4
73. Franco MN, Galeano-Díaz T, Sánchez J, et al. (2014) Total phenolic compounds and tocopherols profiles of seven olive oil varieties grown in the south-west of Spain. *J Oleo Sci* 63: 115–125. https://doi.org/10.5650/jos.ess13098
74. Ballus CA, Quirantes-Piné R, Bakhouche A, et al. (2015) Profile of phenolic compounds of Brazilian virgin olive oils by rapid resolution liquid chromatography coupled to electrospray ionisation time-of-flight mass spectrometry (RRLC–ESI-TOF-MS). *Food Chem* 170: 366–377. https://doi.org/10.1016/j.foodchem.2014.08.054
75. Medina G, Sanz C, L. León, et al. (2021) Phenolic variability in fruit from the 'Arbequina' olive cultivar under Mediterranean and Subtropical climatic conditions. *Grasas Aceites* 72: e438–e438. https://doi.org/10.3989/gya.1002202
76 Talhaoui N, Gómez-Caravaca AM, León L, et al. (2014) Determination of phenolic compounds of 'Sikitita' olive leaves by HPLC-DAD-TOF-MS. Comparison with its parents 'Arbequina' and 'Picual' olive leaves. *LWT-Food Sci Technol* 58: 28–34. https://doi.org/10.1016/j.lwt.2014.03.014
77. Oğraş ŞŞ (2022) Comparative study of phenolic compounds in olive oils from different geographic regions. *Turk J Agric For* 46: 318–326. https://doi.org/10.55730/1300-011X.3005
78. Xiang C, Xu Z, Liu J, et al. (2017) Quality, composition, and antioxidant activity of virgin olive oil from introduced varieties at Liangshan. *LWT* 78: 226–234. https://doi.org/10.1016/j.lwt.2016.12.029
79. Malheiro R, Rodrigues N, José Alberto Pereira (2015) Olive oil phenolic composition as affected by geographic origin, olive cultivar, and cultivation systems. In: *Olive and olive oil bioactive constituents* 93–121. https://doi.org/10.1016/B978-1-63067-041-2.50010-
80. Esti M, Cinquanta L, Notte EL (1998) Phenolic compounds in different olive varieties. *J Agric Food Chem* 46: 32–35. https://doi.org/10.1021/jf970391+

81. Ghasemi S, Koohi DE, Emmamzadehhashemi MSB, et al. (2018) Investigation of phenolic compounds and antioxidant activity of leaves extracts from seventeen cultivars of Iranian olive (*Olea europaea* L.). *J Food Sci Technol* 55: 4600–4607. https://doi.org/10.1007/s13197-018-3398-1
82. Vinha AF, Ferreres F, Silva BM, et al. (2005) Phenolic profiles of Portuguese olive fruits (*Olea europaea* L.): Influences of cultivar and geographical origin. *Food Chem* 89: 561–568. https://doi.org/10.1016/j.foodchem.2004.03.012
83. Banco AP, Puertas CM, Trentacoste ER, et al. (2022) Promising olive varieties for extra virgin oil production in Mendoza, Argentina. *J Saudi Soc Agric Sci* 22: 62–70. https://doi.org/10.1016/j.jssas.2022.06.003
84. Soufi O, Romero C, Motilva MJ, et al. (2016) Effect of dry salting on flavonoid profile and antioxidant capacity of Algerian olive cultivars. *Grasas Aceites* 67: e132. http://doi.org/10.3989/gya.0641152
85. Djemaa-Landri K, Hamri-Zeghichi S, Belkhiri-Beder W, et al. (2021) Phenolic content, antioxidant and anti-inflammatory activities of some Algerian olive stone extracts obtained by conventional solvent and microwave-assisted extractions under optimized conditions. *J Food Meas Charact* 15: 4166–4180. https://doi.org/10.1007/s11694-021-00992-w
86. Mansouri F, Ben Moumen A, Houmy N, et al. (2014) Evaluation of the oxidative stability of blends of 'Arbequina' olive oils with other monovarietal olive oils. *Olivae* 23–30.
87. Mansouri F, Ben Moumen A, S. Aazza, et al. (2019) Quality and chemical profiles of virgin olive oils of three European cultivars suitable for super-high-density planting conditions in eastern Morocco. *Mater Today Proc* 13: 998–1007. https://doi.org/10.1016/j.matpr.2019.04.065
88. Khaliq A, Sabir SM, Ahmed SD, et al. (2015) Antioxidant activities and phenolic composition of Olive (*Olea europaea*) leaves. *J. Appl. Bot. Food Qual.* 88: 16–21. https://doi.org/10.5073/JABFQ.2015.088.004
89. Ribas JCR, Lazzari A, Gonzalez LBF, et al. (2023) Bioactive compounds and antioxidant activity of leaves from olive trees grown in Paraná, Brazil. *Pesq Agropec Bras* 58: e03025. https://doi.org/10.1590/S1678-3921.pab2023.v58.03025
90. da Fonseca Antunes B, Otero DM, Bonemann DH, et al. (2021) Evaluation of physicochemical, bioactive composition and profile of fatty acids in leaves of different olive cultivars. *Rev Ceres* 68: 511–520. https://doi.org/10.1590/0034-737X202168060002
91. Touss J, Romero A, Plana J, et al. (1997) Chemical and sensory characteristics of «Arbequina» olive oil obtained in different growing areas of Spain. *Grasas Aceites* 48: 415–424. https://doi.org/10.3989/gya.1997.v48.i6.814
92. Cavalheiro CV, Picoloto RS, Cichoski AJ, et al. (2015) Olive leaves offer more than phenolic compounds – Fatty acids and mineral composition of varieties from Southern Brazil. *Ind Crop Prod* 71: 122–127. https://doi.org/10.1016/j.indcrop.2015.03.054
93. Otero DM, Oliveira FM, Lorini A, et al. (2020) Oleuropein: Methods for extraction, purifying and applying. *Rev Ceres* 67: 315–329. https://doi.org/10.1590/0034-737X202067040009
94. Zagmutt S, Guzmán L, Orrego R, et al. (2015) Phenolic compound identification and antioxidant capacity of Alperujo extracts from region del Maule, Chile. *Int J Food Prop* 19: 2016–2025. https://doi.org/10.1080/10942912.2015.1092162

95. Palmeri R, Siracusa L, Carrubba M, et al. (2022) Olive leaves, a promising byproduct of olive oil industry: Assessment of metabolic profiles and antioxidant capacity as a function of cultivar and seasonal change. *Agronomy* 12: 2007. https://doi.org/10.3390/agronomy12092007
96. Dabbou S, Issaoui M, Esposto S, et al. (2009) Cultivar and growing area effects on minor compounds of olive oil from autochthonous and European introduced cultivars in Tunisia. *J Sci Food Agric* 89: 1314–1325. https://doi.org/10.1002/jsfa.3588
97. de los Angeles de Fernandez M, SotoVargas VC, Silva MF (2014) Phenolic compounds and antioxidant capacity of monovarietal olive oils produced in Argentina. *J Am Oil Chem Soc* 91: 2021–2033. https://doi.org/10.1007/s11746-014-2558-3
98. Manai-Djebali H, Krichène D, Ouni Y, et al. (2012) Chemical profiles of five minor olive oil varieties grown in central Tunisia. *J Food Compos Anal* 27: 109–119. https://doi.org/10.1016/j.jfca.2012.04.010
99. Bouaziz M, Chamkha M, Sayadi S (2004) Comparative study on phenolic content and antioxidant activity during maturation of the olive cultivar Chemlali from Tunisia. *J Agric Food Chem* 52: 5476–5481. https://doi.org/10.1021/jf0497004
100. Deraz MS, El-Kholany AS, et al. (2022) Chemical evaluation and biological activity of olive leaves extract. *Al-Azhar J Agric Res* 47: 35–45. https://doi.org/10.21608/ajar.2022.266482
101. Deng Y, Zhou J, Qu J, et al. (2025) Deep eutectic solvents and wall-breaking technique: A new frontier in the extraction of oleuropein and flavonoids from olive leaves with superior antioxidant and antitumor potential. *Molecules* 30: 1150. https://doi.org/10.3390/molecules30051150
102. Wang B, Shen S, Qu J, et al. (2021) Optimizing total phenolic and oleuropein of Chinese olive (*Olea europaea*) leaves for enhancement of the phenols content and antioxidant activity. *Agronomy* 11: 686. https://doi.org/10.3390/agronomy11040686
103. Uslu N, Özcan MM (2022) Effect of collection period and irrigation process on antioxidant activity and phenolic compounds of olive leaves. *Akademik Gıda* 20: 122–131. https://doi.org/10.24323/akademik-gida.1149746
104. Ben Salah M, Abdelmelek H, Abderraba M (2012) Study of phenolic composition and biological activities assessment of olive leaves from different varieties grown in Tunisia. *Med Chem* 2: 5. https://doi.org/10.4172/2161-0444.1000124
105. Khelouf I, Karoui IJ, Lakoud A, et al. (2023) Comparative chemical composition and antioxidant activity of olive leaves *Olea europaea* L. of Tunisian and Algerian varieties. *Heliyon* 9: e22217. https://doi.org/10.1016/j.heliyon.2023.e22217
106. Kiritsakis K, Kontominas MG, Kontogiorgis C, et al. (2009) Composition and antioxidant activity of olive leaf extracts from Greek olive cultivars. *J Am Oil Chem Soc* 87: 369–376. https://doi.org/10.1007/s11746-009-1517-x