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Morphology and oil quality of introduced olive cultivars (*Olea europaea* L.) in southwest China

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Summary

There are enormous benefits to olive cultivation in China. However, little research has been conducted into the characteristics of the morphology and oil quality of introduced olive cultivars in southwest China. This study investigates the morphological and biochemical characteristics of seven introduced olive cultivars and one indigenous cultivar grown in the county of Jintang in Sichuan Province. The results reveal that all cultivars have adapted to their new environment and exhibit unique characteristics. The Coratina, Koroneiki and Grossanne varieties have all proved to be excellent oil cultivars, with a fresh oil content of 20.42%, 18.58% and 16.46%, respectively. The free acidity and peroxide values of these olive oils are within the range of the extra virgin olive oil category, while the extracted oils are rich in unsaturated fatty acids, α-tocopherol, squalene, stigmasterol, β-sitosterol and phenolic compounds. Moreover, the olive cultivated in southwest China possesses a higher content of moisture, oleic acid and unsaturated fatty acids compared with the Mediterranean region. Therefore, the region around Jintang, a new environment, is shown to have tremendous potential for the cultivation and development of olives in the future. In addition, these results can provide theoretical guidance for olive planting and cultivar selection in southwest China.

Keywords: *Olea europaea* L., Introduced cultivar, Morphological characteristics, Oil quality, Chemical composition

Introduction

The olive tree (*olea europeae* L.) is a medium-sized evergreen tree and an important oil crop species, and planted originally in the Mediterranean region. (Ghanbari et al., 2012). Due to the nutritional benefits of olive oil and its great commercial value, the olive has been widely introduced elsewhere, such as the United States, Australia, South Africa and China, among others (Laaribi et al., 2017).

Since 1956, when they were introduced to China, olive trees have been regarded as an important woody oil plant. The first large-scale plantation of olive trees began in 1964. At present, the olive trees are mostly distributed in Yunnan, Gansu, Sichuan, Chongqing, Hubei, Jiangsu and Shaanxi provinces (Rao et al., 2019). After several decades of cultivation and domestication, plenty of introduced olives have adapted to the local environment, and then some new cultivars have been bred. In China, the planting regions of olive trees were increased to 800 km^2 in 2018, and the total areas are expected to be 1,670 km^2 by the end of 2020 (Deng, 2018).

Morphological characteristics, including aspects of the leaf, inflorescence, fruit and endocarp have been extensively used to describe and identify olive cultivars. Noting these is the first step in the classification of olive germplasm resources (Rotondi et al., 2003). Nevertheless, the morphological characteristics often vary greatly within an olive variety depending on environmental conditions, phenological stage, agricultural practices, and others (Zaher et al., 2011).

The production of olive oil is the principal purpose of planting olive trees. Olive oil, a key component of the traditional "Mediterranean diet" is extracted by mechanically pressing the olive fruit without any chemical treatment (Guasch-Ferré et al., 2014). The chemical composition of olive oil primarily consists of triacylglycerols (TAG, about 99%), followed by free fatty acids (FFA), diacylglycerols, and other bioactive components. Some of these compounds help contribute to the unique character of olive oil (Blekas et al., 2006). Because of the high content of monounsaturated fatty acid (MUFA) and various functional bioactive components in olive oil, long-term intake can reduce morbidity and mortality of cardiovascular disease (such as hypertension, coronary artery disease, etc.), and prevent skin cancer, breast cancer, neurodegeneration and others (Foscolou et al., 2018). However, the quality of olive oil is easily affected by geographic location, including climate (Mailer et al., 2010).

Previous works have reported on different olive cultivars grown in China. For example, the cold and drought resistance of young trees has been evaluated and the growth, fruit production, and oil quality of eight olive cultivars in Wudu in the southeast Gansu Province have also been assessed (Wang et al., 2018). Xiang et al. comprehensively valued the quality, composition, and antioxidant activity of virgin olive oil from four introduced varieties at Liangshan (Xiang et al., 2017). Authorities in southwest China, and notably Jintang County of Sichuan Province, aim to develop olive cultivation as a leading industry, integrating the construction of a complete olive industry into the huge tourism market of Sichuan, as well as encouraging a healthy pastoral lifestyle in the region (Chen et al., 2019). There have already been some studies on the cultivation techniques and photosynthetic characteristics of olive trees cultivated in Jintang. However, research into the morphological and oil qualitative characteristics of the introduced olive cultivars in southwest China is rare. Therefore, this study aims to characterize these regional olive cultivars and select the most superior ones. This work is expected to provide valuable information on olive cultivation and research to both olive growers as well as researchers.

Materials and methods

Plant materials

Seven introduced olive cultivars, including Arbequina (from Spain), Koroneiki (from Greece), Coratina (from Albania), Picholine (from France), Grossanne (from France), Leccino (from Italy), Manzanilla (from Israel), as well as the indigenous olive cultivar Ezhi-8 (from China) have been planted in southwest China (Jintang County of Sichuan Province, 30°45'30.03'' N; 04°32'52.07'' E, at an altitude of 800-1100 m. The average annual precipitation is 1000 mm, the mean annual temperature is 16 °C, and during harvest time, the temperature fluctuates between 9 °C (minimum) and 25 °C (maximum). In

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the orchards identified for this study, the olive trees are six years old, and are planted with spacing of 5×5 m, with consistent cultivation conditions. The analysis was conducted as described in the following sections.

Morphological characteristics and chemical composition of fruits

Morphological characteristics were assessed according to the primary descriptor methodology of olive trees (Hosseini-Mazinani and Samaee, 2004). The leaf characters (leaf length, leaf width and leaf area), inflorescence characters (number of flowers/inflorescence, perfect flowers percentage/inflorescence and blooming periods), fruit and endocarp characters (fruit weight, stone weight and pulp/stone ratio), yield per tree, moisture and oil contents of olive fruit were measured and recorded. Three olive trees of each cultivar were randomly selected for determination with uniform cultivation conditions and tree shape. For each tree, 100 mature leaves, 10 branches and 30 olive fruits were hand-picked from the inner and outer part of the four subdivided quadrants of the canopy with uniform characteristics in total from the orchard (Fayek et al., 2014). Five olive trees from each cultivar were randomly selected for measurement of the yield. The contents of oil and moisture were measured according to national standard methods of China (GB 5009.6-2016) and previous reports, respectively (NSPRC, 2016; Cheng et al., 2017). Experiments were performed in triplicate for each cultivar.

Olive oil quality characteristics

Oil extraction

Some 5 kg of olive fruits were collected during harvest time and extracted according to the previous method (Xiang et al., 2017). The fruits were crushed, and the crushed slurry was fused in a hot water bath for 30 min at 30 °C, then centrifuged at 3,000 r/min for 5 min to obtain an oil-water mixture. Finally, the olive oil was separated from the mixture after the mixture was placed at 4 °C overnight. The collected oil was then stored in dark glass bottles at 4 °C for further analysis, described below.

Free acidity and peroxide value

The free acidity and peroxide value of the olive oil samples were determined according to international standards (ISO 660-2009 and ISO 3960-2007, respectively) (ISO, 2007; 2009).

Fatty acid composition

The fatty acid composition was evaluated by gas chromatography mass spectrometry (GC-MS) (Issaoui et al., 2011). Firstly, the oil was simply methyl esterified (FAMEs). Then, the GC-MS analysis was conducted using an Agilent 7890A gas chromatograph and 5977C mass spectrometry (Agilent Technologies, USA), equipped with a capillary column HP-5MS (30 m×0.25 mm; 0.25 μm, Agilent Technologies, USA).

Detection conditions were listed as follows: capillary column temperature program was set from 80 °C, holding for 5 min, and increased at 10 °C/min to 180 °C. holding for 2 min, then increased to 260 °C at a rate of 5 °C/min, maintained for 3 min. The carrier gas was helium at a flow rate of 0.6 mL/min with a split ratio of 1:10. The injector temperature was 245 °C, and the temperature of the detector was 260 °C. EI ion source and mass scan ranged from 45 to 550 m/z. The FAMEs profiles were identified by comparing them with the database of the National Institute of Standard Technology Library, NIST. In addition, the individual fatty acid content was expressed as a percentage of the total fatty acid.

Contents of α-tocopherol, squalene, stigmasterol and β-sitosterol

The results of the α-tocopherol, squalene, stigmasterol and β-sitosterol analysis were determined using an Agilent 1260 HPLC (Agilent Technologies, USA) equipped with a ZORBAX SB-C18 column (150×4.6 mm, 5.0 μm).

The content of α-tocopherol was evaluated according to the previous method (Cao et al., 2015). A 1 g oil sample was dissolved in n-hexane, the volume fixed to 10 mL, then mixed and filtered for HPLC analysis. Detection conditions included a fluorescence detector; the excitation wavelength was 295 nm, and the emission wavelength was 325 nm; the mobile phase was methanol at a flow rate of 0.8 mL/min, and the column temperature was 35 °C.

The content of squalene was evaluated as described in previous studies (Liu, 2017). Firstly, the oil was saponified using a potassium hydroxide-ethanol solution, then the sample was analysed by HPLC. The detection conditions were set as follows: an ultraviolet detector, a wavelength of 325 nm, and a column temperature of 30 °C; the mobile phase was methanol: acetonitrile (60:40, v:v) at a flow rate of 1.0 mL/min.

The contents of stigmasterol and β-sitosterol were evaluated according to the previous method with some modifications (Sivakumar et al., 2006). Firstly, the oil sample was briefly saponified. Then, detection conditions were set as follows: an ultraviolet detector, with a wavelength of 210 nm and column temperature of 35 °C; the mobile phase was methanol at a flow rate of 1.0 mL/min.

Total polyphenol and phenolic compounds

The total polyphenol fraction was extracted according to the previous method described by Bouarroudj (Bouarroudj et al., 2016). The mixture was vortexed and centrifuged at 4000 rpm for 15 min. The extraction was repeated three times and concentrated by rotary evaporator at 40 °C, then adjusted to 10 mL with methanol.

The content of total polyphenol was determined by the Folin-ciocalteu method described by Baiano with some modifications (Baiano et al., 2009). A 0.1 mL polyphenol extract was mixed with 0.02 mL of Folin-ciocalteu and a 0.08 mL 10% sodium carbonate solution for 5 min. The absorbance of the mixture was read at 765 nm by Spectra Max M2 microplate reader (Molecular Devices Corp., CA) after incubation in dark for 1 h. The polyphenol quantity was given as milligram gallic acid equivalents per kilogram.

The phenolic compounds analysis was carried out in accordance with previous studies (Xiang et al., 2017). The analytical equipment used is mentioned in section 2.3.4. The conditions for analysis were set as follows: wavelength at 280 nm; column temperature of 35 °C; mobile phase: (A) water: acetic acid (99.5:0.5, v:v), (B) methanol, and (C) isopropyl alcohol, with a flow rate of 1 mL/min. Gradient elution: 0 to 14 min 92% (A), 4% (B), 4% (C); 14 to 45 min 82% (A), 9% (B), 9% (C) and 45 to 60 min 70% (A), 15% (B),15% (C).

Statistical analysis

The average values between different cultivars of oil samples were compared using Duncan's multiple tests, and significant differences were established at $P<0.05$. The IBM SPSS Statistics version 20.0 (SPSS Inc., Chicago, IL, USA) was used to perform analysis of variances (ANOVA).

Results and discussion

Morphological characteristics and chemical analyses of fruits

Leaf and flower characteristics

Leaves are the main sites of photosynthesis in plants, playing an important role in the growth and development of fruits and trees (Liu et al., 2011). The adult leaf length of the eight olive cultivars

ranged from 45.80 to 64.24 mm, and the leaf width varied from 10.53 to 14.73 mm (Tab. 1). The leaf area of Coratina was the biggest (674.80 mm^2) while Arbequina was the smallest (395.06 mm^2). In addition, as shown in Tab. 1, the number of flowers per inflorescence differed among the eight cultivars, ranging from 3 to 36. More importantly, the numbers of perfect flowers are closely related to the fruit set percentage. The percentage of perfect flowers per inflorescence of eight olive cultivars varied from 58.76 to 82.12%. Accordingly, the fruit set percentage of Arbequina was the highest and Manzanilla was the lowest. Olive production depends mainly on this fruit set percentage (MEZGHANI et al., 2012).

Most olive cultivars are self-incompatible and have low self-pollination rates (SAUMITOU-LAPRADE et al., 2017). However, an overlap of blooming periods exists in the eight cultivars. For example, the blooming periods of Koroneiki are closer to those of Leccino. Planting cultivars with similar blooming periods together can therefore improve the pollination rate when growing olives.

Fruit and stone characteistics

At harvest, as shown in Tab. 2, the fruit weight, stone weight and ratio of pulp on stone differed significantly between the eight olive cultivars. The fruit weight ranged from 1.37 g to 4.06 g. The stone weight ranged from 0.22 g (Koroneiki) to 0.84 g (Ezhi-8). The Coratina was recorded as the highest value (6.59) in terms of pulp/stone ratio, followed in order by Manzanilla, Koroneiki, Arbequina, Grossanne, Picholine, Leccino and Ezhi-8 (5.55, 5.23, 4.97, 4.61, 4.52, 4.12 and 2.65, respectively). The fruit weight of Coratina, Koroneiki and Arbequina was higher than that of previous research results (CHENG et al., 2017). However, the fruit weight of Ezhi-8 and Manzanilla was lower than previous studies (WANG et al., 2018). Simultaneously, Tab. 2 shows that the fruit yield per tree of Grossanne was the highest (11.79 kg per tree), followed by Picholine (8.37 kg per tree), while the lowest was Manzanilla (4.19 kg per tree).

The fruit moisture content of eight cultivars ranged from 56.02 to 65.77% (Tab. 2). In addition, the fresh fruit oil content was highest in Coratina (20.42%), followed in descending order by Koroneiki (18.58%), Grossanne (16.46%), Picholine (15.89%), Arbequina (15.54%), Leccino (15.07%), Ezhi-8 (14.27%) and lastly Manzanilla (13.05%). In this study, the moisture content of olive fruit was much higher and the fresh fruit oil content was low compared with other studies (LEE et al., 2018; DABBOU et al., 2009). Proietti et al. have indicated that sufficient irrigation in the fruiting stage would raise the fruit water content (PROIETTI and ANTOGNOZZI, 1996). In addition, irrigation has also been reported to affect oil content (RINALDI et al., 2010). Hence, the difference of moisture and oil content between this study and previous research may be caused by climate, especially precipitation.

On the basis of this current study, the Manzanilla cultivar is considered to be promising for its use for table or eating olives because of its low oil content and high pulp/stone ratio. The result is in agreement with previous research reported by Del Río' (DEL RÍO and CABALLERO, 2008). Similarly, the high pulp/stone ratio and the moderate oil content of Picholine and Arbequina demonstrate that both of them could be applied as dual-purpose cultivars (for both oil and table olives), while Koroneiki, Coratina and Grossanne remain excellent oil cultivars.

Oil qualitative characteristics

Free acidity and peroxide value

The free acidity and peroxide values are an important index of quality in olive oil (GOMEZ-CARAVACA et al., 2016). Above all, free acidity has been used exclusively as the traditional classification criterion for olive oil. The free acidity and peroxide values of eight cultivars were shown in Tab. 3. The different olive oils show significant differences in terms of free acidity, ranging from 0.24 to 0.47%. Their peroxide value ranged from 9.08 to 14.66 meq/kg. The

Tab. 1: Leaf and inflorescence characteristics of eight cultivars

	Leaf length/mm	Leaf width/mm	Leaf area/mm^2	Number of flowers/ inflorescence	Perfect flowers percentage/ inflorescence (%)	Blooming periods
Arbequina	45.80±0.79^{a}	10.98±0.54^{ab}	395.06±25.25^{a}	9~27	82.12±2.33^{e}	April 19 to May 04
Koroneiki	49.24±1.11^{b}	11.36±0.60^{ab}	439.45±33.16^{a}	6~30	70.27±0.61^{c}	April 22 to May 08
Coratina	62.29±1.56^{d}	13.81±1.24^{c}	674.80±55.81^{e}	6~36	73.70±2.34^{c}	April 15 to 29
Picholine	57.30±0.97^{c}	11.55±0.52^{ab}	519.76±32.33^{bc}	4~24	67.28±1.47^{b}	April 17 to 30
Grossanne	64.24±1.60^{d}	12.38±0.90^{b}	624.82±59.82^{de}	8~29	75.92±0.98^{d}	April 21 to May 06
Leccino	51.43±1.39^{b}	14.73±1.11^{c}	595.48±59.41^{cd}	3~19	73.61±1.39^{c}	April 23 to May 09
Manzanilla	54.82±1.81^{c}	10.53±0.58^{a}	452.72±20.24^{ab}	5~25	58.76±1.67^{a}	April 16 to May 01
Ezhi-8	48.78±3.68^{ab}	14.45±0.32^{c}	553.08±39.26^{cd}	3~31	77.99±2.14^{d}	April 16 to May 03

Data are expressed as the mean±standard deviations, n=3. Different letters in the same column indicate significantly different values, *P<0.05*.

Tab. 2: Fruit characteristics and yield per tree of eight cultivars

	Fruit weight (g)	Stone weight (g)	Pulp/stone ratio	Fruit yield (kg/tree)	Moisture content (%)	Fresh fruit oil content (%)
Arbequina	1.91±0.09^{b}	0.32±0.00^{b}	4.97±0.04^{d}	6.53±0.66^{bc}	60.91±2.09^{c}	15.54±0.35^{cd}
Koroneiki	1.37±0.03^{a}	0.22±0.01^{a}	5.23±0.11^{e}	6.24±1.52^{abc}	59.24±1.79^{bc}	18.58±0.42^{e}
Coratina	4.63±0.26^{f}	0.61±0.02^{d}	6.59±0.07^{g}	8.36±0.76^{c}	57.19±0.99^{ab}	20.42±0.54^{f}
Picholine	3.59±0.05^{e}	0.65±0.01^{e}	4.52±0.04^{c}	8.37±1.23^{c}	64.32±1.57^{d}	15.89±0.35^{cd}
Grossanne	2.02±0.04^{c}	0.36±0.01^{c}	4.61±0.13^{c}	11.79±1.87^{d}	59.06±1.08^{bc}	16.46±0.11^{d}
Leccino	3.02±0.07^{d}	0.59±0.01^{d}	4.12±0.05^{b}	5.18±0.60^{ab}	56.02±1.55^{a}	15.07±0.23^{bc}
Manzanilla	4.06±0.37^{e}	0.62±0.01^{d}	5.55±0.18^{f}	4.19±0.50^{a}	65.77±0.72^{d}	13.05±0.48^{a}
Ezhi-8	3.07±0.10^{d}	0.84±0.03^{f}	2.65±0.08^{a}	7.89±1.17^{c}	64.05±1.54^{d}	14.27±0.60^{b}

Data are expressed as the mean±standard deviations, n=3. Different letters in the same column indicate significantly different values, *P<0.05*.

Tab. 3: Free acidity and peroxide value of olive oil

	Free acidity (%)	Peroxide value (meq/kg)
Arbequina	0.38±0.01^{d}	14.66±0.21^{d}
Koroneiki	0.30±0.00^{b}	14.00±0.15^{c}
Coratina	0.30±0.01^{b}	9.08±0.09^{a}
Picholine	0.41±0.00^{e}	12.68±0.18^{b}
Grossanne	0.24±0.01^{a}	12.94±0.11^{b}
Leccino	0.46±0.02^{f}	12.66±0.18^{b}
Manzanilla	0.47±0.01^{f}	12.94±0.12^{b}
Ezhi-8	0.32±0.01^{c}	12.73±0.18^{b}

Data are expressed as the mean±standard deviations, n=3. Different letters in the same column indicate significantly different values, *P<0.05*.

free acidity and peroxide values of all olive oils tested were within the range of the extra virgin olive oil category (where free acidity ≤ 0.80% and peroxide value ≤ 20.0 meq/kg) (IOC, 2019). Therefore, the olive oil of eight cultivars is of excellent quality and can be ranked as extra virgin olive oil.

Fatty acid composition

The content of unsaturated fatty acids and saturated fatty acids in the olive oil are shown in Tab. 4 and 5, respectively. The main unsaturated fatty acid in olive oil is palmitoleic acid (C16:1, 0.40~3.44%), followed by heptadecenoic acid (C17:1, 0.09~0.26%), oleic acid (C18:1, 61.64~79.30%), linoleic acid (C18:2, 4.04~8.17%), linolenic acid (C18:3, 0.39~0.95%) and eicosenoic acid (C20:1, 0.14~0.40%). In addition, the main saturated fatty acid in olive oil was palmitic acid (C16:0, 10.76~19.48%), followed by heptadecanoic acid (C17:0, 0.11~0.31%), stearic acid (C18:0, 1.16~4.64%), arachidic acid (C20:0, 0.31~0.58%) and behenic acid (C22:0, 0.05~0.16%).

In this study, oleic acid was the mainly constituent in all oils tested, and a high dietary intake of oleic acid has been proved to reduce the risk of coronary artery disease (CAD), hypertension and other diseases (Bermudez et al., 2011). The oil of the eight cultivars were also rich in the essential fatty acids of linoleic acid and linolenic acid. Arbequina did not contain heptadecenoic acid. Arbequina, Picholine and Ezhi-8 were also short of heptadecanoic acid. There was also an absence of behenic acid in Coratina and Ezhi-8. Taken together, the fatty acid composition of the oil from the eight cultivars complies with the established limits of extra virgin olive oil (IOC, 2019). The results are also in agreement with the finding that the cultivar is closely related to the composition of fatty acids in olive oil (Chapagain et al., 2009).

The content of fatty acids in the olive oil samples from southwest China is different from other studies. For example, the regional content of oleic acid is higher than the results of other researches (Zarrouk et al., 2009). Previous studies have shown that geographic location seriously affects the fatty acid composition and content of olive oil (Mailer et al., 2010). It has also been discovered that olive fruits living at a high altitude and in cooler areas are apt to exhibit a high content of unsaturated fatty acids (Ouni et al., 2011). Previous studies report that the oil extracted from olives grown in high-temperature sites contains lower levels of oleic acid than olives grown in a milder environment (Nissim et al., 2020).

Tab. 4: Unsaturated fatty acid composition of olive oil (%)

	C16:1	C17:1	C18:1	C18:2	C18:3	C20:1
EVOO	0.30-3.50	≤0.60	55.00-83.00	2.50-21.00	≤1.00	≤0.40
Arbequina	0.58±0.02^{b}	-	77.20±0.80^{d}	5.94±0.65^{cd}	0.87±0.03^{d}	0.39±0.01^{d}
Koroneiki	2.36±0.08^{g}	0.09±0.01^{a}	73.01±1.14^{b}	6.12±0.54^{cd}	0.95±0.05^{e}	0.39±0.02^{d}
Coratina	1.64±0.05^{e}	0.21±0.01^{d}	73.66±1.23^{b}	5.24±0.66^{bc}	0.95±0.01^{e}	0.35±0.03^{c}
Picholine	2.17±0.05^{f}	0.15±0.01^{b}	75.63±0.94^{c}	4.04±0.55^{a}	0.94±0.07^{e}	0.27±0.01^{b}
Grossanne	1.35±0.06^{d}	0.22±0.01^{d}	79.21±0.36^{e}	4.62±0.50^{ab}	0.60±0.01^{c}	0.14±0.00^{a}
Leccino	0.40±0.01^{a}	0.16±0.01^{b}	74.74±0.62^{b}	6.85±0.52^{d}	0.47±0.01^{b}	0.25±0.01^{b}
Manzanilla	3.44±0.07^{h}	0.26±0.01^{e}	61.64±0.37^{a}	8.17±0.54^{e}	0.93±0.01^{e}	0.33±0.01^{c}
Ezhi-8	0.92±0.02^{c}	0.17±0.00^{c}	79.30±0.24^{e}	4.65±0.54^{ab}	0.39±0.01^{a}	0.40±0.02^{d}

Unsaturated fatty acid: C16:1, Palmitoleic acid; C17:1, Heptadecenoic acid; C18:1, Oleic acid; C18:2, Linoleic acid; C18:3, Linolenic acid; C20:1, Eicosenoic acid. The "-" represents not detected in the identification process. Data are expressed as the mean±standard deviations, n=3. Different letters in the same column indicate significantly different values, *P<0.05*.

Tab. 5: Saturated fatty acid composition of olive oil (%)

	C16:0	C17:0	C18:0	C20:0	C22:0
EVOO	7.5-20.00	≤0.40	0.50-5.00	≤0.60	≤0.20
Arbequina	13.47±0.67^{b}	-	1.16±0.02^{a}	0.31±0.01^{a}	0.08±0.00^{c}
Koroneiki	14.90±0.48^{c}	0.11±0.00^{a}	1.40±0.07^{a}	0.56±0.01^{e}	0.11±0.01^{d}
Coratina	14.81±0.58^{c}	0.31±0.01^{d}	2.33±0.09^{b}	0.49±0.01^{c}	-
Picholine	14.83±0.38^{c}	-	1.24±0.03^{a}	0.58±0.02^{f}	0.16±0.00^{e}
Grossanne	10.76±0.66^{a}	0.27±0.01^{c}	2.44±0.05^{b}	0.33±0.01^{a}	0.05±0.00^{a}
Leccino	14.64±0.39^{d}	0.16±0.00^{b}	1.75±0.05^{b}	0.41±0.01^{b}	0.16±0.01^{e}
Manzanilla	19.48±0.12^{e}	0.15±0.01^{b}	4.64±0.05^{c}	0.54±0.01^{d}	0.07±0.00^{b}
Ezhi-8	11.37±0.48^{a}	-	2.23±0.08^{b}	0.58±0.03^{g}	-

Saturated fatty acid: C16:0, Palmitic acid; C17:0, Heptadecanoic acid; C18:0, Stearic acid; C20:0, Arachidic acid and C22:0, Behenic acid. The "-" represents not detected in the identification process. Data are expressed as the mean±standard deviations, n=3. Different letters in the same column indicate significantly different values, *P<0.05*.

Analysis of the contents of α-tocopherol, squalene, stigmasterol and β-sitosterol

Tocopherols are important components in olive oil and contribute to its nutritional values. They also play a key role in preserving oil from rancidity during storage. The antioxidant a-tocopherol, the main tocopherol homolog found in olive oil, can reduce the risk of cardiovascular diseases and cancers (Malheriro et al., 2009). In this study, the content of a-tocopherol ranged from 97.54 mg/kg in Arbequina oil to 164.47 mg/kg in oil from the Leccino cultivar (Tab. 6). These values are consistent with previously reported results (Casal et al., 2010; Xiang et al., 2017). The content of α-tocopherol is associated with plenty of factors, such as cultivar, climatic condition, agronomic practice and extraction processes, etc. (Beltrăn et al., 2010). The content of α-tocopherol varies greatly among different cultivars (Psomisdou et al., 2000).

Tab. 6: α-tocopherol, squalene, stigmasterol and β-sitosterol contents of olive oil (mg/kg)

	α-tocopherol	Squalene	Stigmasterol	β-sitosterol
Arbequina	97.54±2.37^{a}	1794.27±34.39^{b}	90.67±2.83^{h}	231.95±11.80^{b}
Koroneiki	130.65±3.77^{d}	2296.10±74.61^{c}	62.33±0.46^{e}	286.81±8.98^{c}
Coratina	120.26±3.39^{c}	1924.71±124.64^{b}	58.64±2.00^{d}	1135.28±45.88^{g}
Picholine	121.71±2.67^{c}	2292.19±88.73^{c}	31.76±0.65^{a}	502.49±20.07^{d}
Grossanne	101.86±2.20^{a}	1617.07±23.20^{a}	47.13±0.80^{c}	685.82±23.47^{f}
Leccino	164.47±2.41^{e}	2398.33±151.36^{c}	40.83±1.09^{b}	144.45±11.56^{a}
Manzanilla	113.79±1.18^{b}	1802.97±48.21^{b}	66.74±1.36^{f}	574.91±22.86^{e}
Ezhi-8	161.71±1.98^{e}	3152.04±14.12^{d}	86.74±2.43^{g}	667.60±25.02^{f}

Data are expressed as the mean±standard deviations, n=3. Different letters in the same column indicate significantly different values, *P<0.05*.

Olive oil is one of the richest sources of squalene. The squalene content in virgin olive oil typically ranges from 200 to 7500 mg/kg (Cayuela and García, 2018). In this study, the content of squalene in olive oil from eight cultivars is summarised in Tab. 6. The highest content of squalene was found in Ezhi-8 (3152.04 mg/kg oil), while the lowest results are for Grossanne (1617.07 mg/kg oil). These results are consistent with Owen et al. but higher than those reported by Sagratini et al. (Owen et al., 2000; Sagratini et al., 2012). Squalene is a triterpene hydrocarbon and natural antioxidant, which possesses antitumor activity against different cancer types and is used as a component of parenteral emulsions for drugs and vaccines (Fox, 2009). In addition, it may be useful for the treatment of cardiovascular diseases (Spanova and Daum, 2011). Therefore, the oil from cultivars such as Ezhi-8 that contain a high proportion of squalene could be applied in the manufacture of food supplements and the pharmacological industry.

Sterols are the major components of the unsaponifiable fraction in olive oil. And stigmasterol and β-sitosterol are dominant sterols in olive oil, especially β-sitosterol, which accounts for more than 80% of total sterols (Lukic et al., 2013). As shown in Tab. 6, the stigmasterol in the olive oils tested ranged from 31.76 mg/kg (Picholine) to 90.67 mg/kg (Arbequina). It was interesting that β-sitosterol content exhibited significant differences between the eight cultivars. The highest was Coratina, up to 1135.28 mg/kg, while the lowest was Leccino, with 144.45 mg/kg. These results are consistent with other studies that show the existence of differences according to cultivar (Sivakumar et al., 2006). The sterol component and content contribute significantly to evaluating the nutritional value and quality control of olive oil, as they are typically used as the reference measures to detect adulteration (Ilyasoglu et al., 2010).

Total phenol and phenolic composition

The phenolic compounds present in olive oil, consisting of all kinds of natural antioxidants, have been proved to possess anti-oxidation, anti-inflammatory and anti-cancer activities (Martín-Peláez et al., 2013). In olive oil, phenolic compounds contribute to olive oil's oxidative stability and can extend its shelf life, as well as to its sensory characteristics, such as its bitter, astringent and pungent tastes (Alarcon Flores et al., 2012). The main classes of phenols present in olive oil are phenolic acids, phenolic alcohols, flavonoids, secoiridoids and lignans (Servili and Montedoro, 2002). In this study, the total phenols and common phenolic compositions, together with their contents, are shown in Tab. 7. The total phenolic contents of the eight oil samples exhibit significant differences. The highest proportion was detected in Arbequina, with 102.21 mg/kg, followed by Ezhi-8, with 93.88 mg/kg, while the lowest was in Picholine with 28.83 mg/kg. These results are lower than previous data (Cioffi et al., 2010; Loubiri et al., 2016).

Simultaneously, the common phenolic compounds were evaluated by HPLC including hydroxyltyrosol, p-hydroxybenzoic acid, caffeic acid, p-coumaric acid, ferulic acid, rutin and oleuropein (Tab. 7). There were significant differences in phenolic compounds among the eight cultivars. While p-hydroxybenzoic acid and caffeic acid were present in all oils, their content ranged from 0.70 mg/kg (Picholine) to 4.51 mg/kg (Arbequina) and 3.28 mg/kg (Ezhi-8) to 5.56 mg/kg (Grossanne), respectively. It was notable that rutin was detected in Arbequina and other five cultivars, ranging from 0.88 to 11.93 mg/kg, while it has scarcely been reported in previous research (Cioffi et al., 2010; Gutierrez-Rosales et al., 2003). In addition, hydroxytyrosol, p-coumaric acid, ferulic acid and oleuropein were also detected in different quantities in some cultivars, ranging from 0.26 to 2.75 mg/kg, 0.08 to 0.18 mg/kg, 3.11 to 9.19 mg/kg and 0.70 to 3.05 mg/kg, respectively. Vinha et al. have reported that the presence of phenolic compounds is strongly influenced by geographical origins and cultivars (Vinha et al., 2005). Furthermore, the phenolic compounds in

Tab. 7: Total phenol and phenolic composition in olive oil (mg/kg)

	Total phenol	Hydroxytyrosol	p-hydroxybenzoic acid	Caffeic acid	p-coumaric acid	Ferulic acid	Rutin	Oleuropein
Arbequina	102.21±3.10^{e}	-	4.51±0.11^{f}	4.19±0.10b^{c}	-	3.30±0.12^{a}	11.93±1.27^{c}	-
Koroneiki	37.90±1.17^{b}	-	3.76±0.08^{e}	4.77±0.12^{d}	0.18±0.01^{c}	-	2.64±0.25^{b}	0.97±0.06^{b}
Coratina	60.58±3.26^{c}	2.75±0.02^{d}	1.43±0.04^{c}	4.43±0.09^{bcd}	0.08±0.00^{a}	5.30±0.10^{b}	-	-
Picholine	28.83±1.51^{a}	0.26±0.01^{a}	0.70±0.02^{a}	4.56±0.08^{cd}	-	-	-	0.70±0.02^{a}
Grossanne	36.29±1.10^{b}	-	1.03±0.03^{b}	5.56±0.14^{e}	0.08±0.00^{a}	3.11±0.06^{a}	0.88±0.04^{a}	-
Leccino	30.59±0.68^{a}	-	1.46±0.03^{c}	4.15±0.53^{bc}	-	-	1.17±0.14^{a}	1.28±0.04^{c}
Manzanilla	93.07±4.40^{d}	0.74±0.02^{b}	2.43±0.06^{d}	4.00±0.10^{b}	0.13±0.00^{b}	5.86±0.36^{c}	2.98±0.15^{b}	1.84±0.04^{d}
Ezhi-8	93.88±1.94^{d}	2.28±0.05^{c}	1.10±0.03^{b}	3.28±0.51^{a}	-	9.19±0.14^{d}	-	3.05±0.07^{e}

Data are expressed as the mean±standard deviations, n=3. Different letters in the same column indicate significantly different values, *P<0.05*.

olive oil are also closely related to climate, fruit ripening, processing and storage methods (Ghanbari Shendi et al., 2018).

Conclusions

In this study, eight olive cultivars cultivated in southwest China showed excellent morphological and oil qualitative characteristics. They exhibit unique characteristics consistent with the climate of the region in which they are grown. The olive fruit from southwest China shows higher moisture content and lower fresh fruit oil content. In addition, the olive oil from all eight cultivars is ranked as extra virgin olive oil. All oils exhibited a high oleic content and were rich in various functional bioactive components. Conclusively, southwest China (Jintang) has a clear potential for the future development of olives. However, this study only records and measures the complete data for one year, which cannot fully reflect the morphological variability and stability of olive trees in a changing environment. In the following years, we will continue to record and measure the characteristics of olives cultivated in southwestern China.

Conflict of interests

No potential conflict of interest was reported by the authors

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References

Alarcon Flores, M.I., Romero-Gonzalez, R., Gaeeido Frenich, A., Martinea Vidal, J.L., 2012: Analysis of phenolic compounds in olive oil by solid-phase extraction and ultra high performance liquid chromatography-tandem mass spectrometry. Food Chem. 134, 2465-2472. DOI: 10.1016/j.foodchem.2012.04.058

Baiano, A., Gambacorta, G., Terracone, C., Preaitali, M.A., Lamacchia, C., La Notte, E., 2009: Changes in phenolic content and antioxidant activity of Italian extra-virgin olive oils during storage. J. Food Sci. 74, 177-183. DOI: 10.1111/j.1750-3841.2009.01072

Beltrăn, G., Jiměnez, A., Del Rio, C., Sănchez, S., Martínez, L., Uceda, M., Aguilera, M.P., 2010: Variability of vitamin E in virgin olive oil by agronomical and genetic factors. J. Food Compos. Anal. 23, 633-639. DOI: 10.1016/j.jfca.2010.03.003

Bermudez, B., Lopez, S., Ortega, A., Varela, L.M., Pacheco, Y.M., Abia, R., Muriana, F.J.G., 2011: Oleic acid in olive oil from a metabolic framework toward a clinical perspective. Curr. Pharm. Design 17, 831-843. DOI: 10.2174/138161211795428957

Blekas, G., Tsimidou, M., Boskou, D., 2006: Olive oil composition. 41-72. DOI: 10.1201/9781439832028.pt2

Bouarroudj, K., Tamendjari, A., Larbat, R., 2016: Quality, composition and antioxidant activity of Algerian wild olive (*Olea europaea* L. subsp. Oleaster) oil. Ind. Crop. Prod. 83, 484-491. DOI: 10.1016/j.indcrop.2015.12.081

Cao, J., Li, H., Xia, X., Zou, X.G., Li, J., Zhu, X.M., Deng, Z.Y., 2015: Effect of fatty acid and tocopherol on oxidative stability of vegetable oils with limited air. Int. J. Food Prop. 18, 808-820. DOI: 10.1080/10942912.2013.864674

Casal, S., Malheiro, R., Sendas, A., Oliveira, B.P., Pereira, J.A., 2010: Olive oil stability under deep-frying conditions. Food Chem. Toxicol. 48, 2972-2979. DOI: 10.1016/j.fct.2010.07.036

Cayuela, J.A., García, J.F., 2018: Nondestructive measurement of squalene in olive oil by near infrared spectroscopy. Lwt 88, 103-108. DOI: 10.1016/j.lwt.2017.09.047

Chapagain, B.P., Wiesman, Z., 2009: MALDI-TOF/MS finger printing of triacylglycerols (TAGs) in olive oils produced in the Israeli Negev desert. J. Agricul. Food Chem. 57, 1135-1142. DOI: 10.1021/jf8025277

Chen, M., Tang, Y.F., 2019: An analysis of the business model of Jufeng valley olive garden complex in Jintang County. Modern Agricul. 6, 50-53.

Cheng, Z.Z., Zhan, M.M., Yang, Z.S., Zumstein, K., Chen, H.P., Huang, Q.M., 2017: The major qualitative characteristics of olive (*Olea europaea* L.) cultivated in southwest China. Front. Plant Sci. 8, 1-8. DOI: 10.3389/fpls.2017.00559

Cioffi, G., Pesca, M.S., De Caprariis, P.D., Braca, A., Severino, L., De Tommasi, N., 2010: Phenolic compounds in olive oil and olive pomace from Cilento (Campania, Italy) and their antioxidant activity. Food Chem. 121, 105-111. DOI: 10.1016/j.foodchem.2009.12.013

Dabbou, S., Issaoui, M., Servili, M., 2009: Characterisation of virgin olive oils from European olive cultivars introduced in Tunisia. Eur. J Lipid Sci. Tech. 111, 392-401. DOI: 10.1002/ejlt.200800032

Del Río, C., Caballero, J.M., 2008: Variability and classification of olive cultivars by fruit weight, flesh stone ratio and oil percentage. Acta Hort. 791, 39-44. DOI: 10.17660/ActaHortic.2008.791.2

Deng, Y., 2018: The status quo and trends of China olive industry innovation-driven development and relevant countermeasures. Nonwood Forest Res. 36, 1-6. DOI: 10.14067/j.cnki.1003-8981.2018.02.001

Fayek, M.A., Abdel-Mohsen, M.A., Laz, S.I., El-Sayed, S.M., 2014: Morphological agronomical and genetic characterization of Egyptian olive clones compared with the international cultivars. Egypt. J. Hort. Vol. 41, 59- 82. DOI: 10.21608/EJOH.2014.1354

Foscolou, A., Critselis, E., Panagiotakos, D., 2018: Olive oil consumption and human health: A narrative review. Maturitas 118, 60-66. DOI: 10.1016/j.maturitas.2018.10.013

Fox, C.B., 2009: Squalene emulsions for parenteral vaccine and drug delivery. Molecules 14, 3286-3312. DOI: 10.3390/molecules14093286

Ghanbari, R., Anwar, F., Alkharfy, K.M., Gilani, A.H., Saari, N., 2012: Valuable nutrients and functional bioactives in different parts of olive (*Olea europaea* L.) – a review. Int. J. Mol. Sci. 13, 3291-3340. DOI: 10.3390/ijms13033291

Ghanbari Shendi, E., Sivri Ozay, D., Ozkaya, M.T., Ustunel, N.F., 2018: Changes occurring in chemical composition and oxidative stability of virgin olive oil during storage. Ocl 25, A602. DOI: 10.1051/ocl/2018052

Gomez-Caravaca, A.M., Maggio, R.M., Cerretani, L., 2016: Chemometric applications to assess quality and critical parameters of virgin and extra-virgin olive oil. A review. Anal. Chim. Acta 913, 1-21. DOI: 10.1016/j.aca.2016.01.025

Guasch-Ferrĕ, M., Hu, F., Martínez-Gonzălez, M.A., Fitó, M., Bulló, M., Estruch, R., Salas-Salvadó, J., 2014: Olive oil intake and risk of cardiovascular disease and mortality in the predimed study. BMC Med. 12, 1741-7015. DOI: 10.1186/1741-7015-12-78

Hosseini-Mazinani, S.M., Samaee, S.M., 2004: Evaluation of olive germplasm in iran on the basis of morphological traits assessment of 'Zard' and 'Rowghani' cultivars. Acta Hort. 634, 145-151. DOI: 10.17660/ActaHortic.2004.634.17

Ilyasoglu, H., Ozcelik, B., Van Hoed, V., Verhe, R., 2010: Characterization of aegean olive oils by their minor compounds. J. Am. Oil Chem. Soc. 87, 627-636. DOI: 10.1007/s11746-009-1538-5

IOC, 2019: Trade standrad applying to olive oils and olive pomace oils, Internatinal olive council. COI/T.15/NC No 3/Rev. 15. French

ISO, 2007: Animal and vegetable fats and oils-Determination of peroxide value-Iodometric(visual) endpoint determination, ISO 3960-2007. Switzerland

ISO, 2009: International standard, fourth edition. Animal and vegetable fats and oils-Determination of acid value and acidty. ISO 660-2009. Switzerland

Issaoui, M., Dabbou, S., Mechri, B., Nakbi, A., Chehab, H., Hammami, M., 2011: Fatty acid profile, sugar composition, and antioxidant compounds of table olives as affected by different treatments. Eur. Food Res. Technol. 232, 867-876. DOI: 10.1007/s00217-011-1455-3

Laaribi, I., Gouta, H., Mezghani Ayachi, M., Labidi, F., Mars, M., 2017: Combination of morphological and molecular markers for the characterization of ancient native olive accessions in Central-Eastern Tunisia. CR Biol. 340, 287-297. DOI: 10.1016/j.crvi.2017.03.003

Lee, C., Polari, J.J., Kramer, K.E., 2018: Near-infrared (NIR) spectrometry as a fast and reliable tool for fat and moisture analyses in olives. ACS Omega, 3, 16081-16088. DOI: 10.1021/acsomega.8b02491

Liu, L.W., 2017: Determination of squalene in camellia oil by high performance liquid chromatography. Modern Food, 84-85. DOI: 10.16736/j.cnki.cn41-1434/ts.2017.11.030

Liu, Y.F., Qi, H.Y., Bai, C.M., Qi, M.F., Xu, C.Q., Hao, J.H., Li, Y., Li, T.L., 2011: Grafting helps improve photosynthesis and carbohydrate metabolism in leaves of muskmelon. Int. J. Biol. Sci. 7, 1161-1170. DOI: 10.7150/ijbs.7.1161

Loubiri, A., Taamalli, A., Talhaoui, N., Mohamed, S.N., Carretero, A.S., Zarrouk, M., 2016: Usefulness of phenolic profile in the classification of extra virgin olive oils from autochthonous and introduced cultivars in Tunisia. Eur. Food Res. Technol. 243, 467-479. DOI: 10.1007/s00217-016-2760-7

Lukic, M., Lukic, I., Krapac, M., Sladonja, B., Pilizota, V., 2013: Sterols and triterpene diols in olive oil as indicators of variety and degree of ripening. Food Chem. 136, 251-258. DOI: 10.1016/j.foodchem.2012.08.005

Malheiro, R., Oliveira, I., Vilas-Boas, M., Falcao, S., Bento, A., Pereira, J.A., 2009: Effect of microwave heating with different exposure times on physical and chemical parameters of olive oil. Food Chem. Toxicol. 47, 92-97. DOI: 10.1016/j.fct.2008.10.014

Martín-Peláez, S., Isabel Covas, M., Fitó, M., Kušar, A., Pravst, I., 2013: Health effects of olive oil polyphenols Recent advances and possibilities for the use of health claims. Mol. Nutr. Food Res. 57, 760-771. DOI: 10.1002/mnfr.201200421

Mailer, R.J., Ayton, J., Greham, K., 2010: The influence of growing region, cultivar and harvest timing on the diversity of Australian olive oil. J. Am. Oil Chem. Soc. 87, 877-884. DOI: 10.1007/s11746-010-1608-8

Mezghani, M.A., Charfi, C.M., Gouiaa, M., 2012: Vegetative and reproductive behaviour of some olive tree varieties (*Olea europaea* L.) under deficit irrigation regimes in semi-arid conditions of Central Tunisia. Sci. Hortic. 146, 143-152. DOI: 10.1016/j.scienta.2012.07.030

NSPRC, 2016: National food safety standard, Determination of fat in food. GB 5009.6-2016. China

Nissim, Y., Shloberg, M., Biton, I., 2020: High temperature environment reduces olive oil yield and quality. PloS One 15, e0231956. DOI: 10.1371/journal.pone.0231956

Ouni, Y., Taamalli, A., Gomez-Caravaca, A.M., Segura-Carretero, A., Fernandez-Gutierrez, A., Zarrouk, M., 2011: Characterisation and quantification of phenolic compounds of extra-virgin olive oils according to their geographical origin by a rapid and resolutive LC-ESI-TOF MS method. Food Chem. 127, 1263-1267. DOI: 10.1016/j.foodchem.2011.01.068

Owen, R.W., Haubner, R., Wurtele, G., Hull, E., Spiegelhalder, B., Bartsch, H., 2004. Olives and olive oil in cancer prevention. Eur. J. Cancer Prev. 13, 319-326. DOI: 10.1097/01.cej.0000130221.19480.7e

Proietti, P., Antognozzi, E., 1996: Effect of irrigation on fruit quality of table olives (*Olea europaea*), cultivar 'Ascolana tenera'. New Zeal. J. Crop Hort. 24, 175-181. DOI: 10.1080/01140671.1996.9513950

Psomiadou, E., Tsimidou, M., Boskou, D., 2000: α-Tocopherol content of Greek virgin olive oils. J. Agricul. Food Chem. 48, 1770-1775. DOI: 10.1021/jf990993o

Rao, G.D., Zhang, J.G., Liu, X.X., Luo, Y., 2019: Identification of putative genes for polyphenol biosynthesis in olive fruits and leaves using full-length transcriptome sequencing. Food Chem. 300, 125246. DOI: 10.1016/j.foodchem.2019.125246

Rinaldi, R., Amodio, M.L., Colelli, G., 2010: Effect of deficit irrigation on fruit and oil quality of 'Konservolea' olives. Int. Hort. Congress Sci. Hort. People 924, 445-451. DOI: 10.17660/ActaHortic.2011.924.57

Rotondi, A., Cultrera, N.G.M., Mariotti, R., Baldoni, L., 2011: Genotyping and evaluation of local olive varieties of a climatically disfavoured region through molecular, morphological and oil quality parameters. Sci. Hortic. 130, 562-569. DOI: 10.1016/j.scienta.2011.08.005

Rotondi, A., Magli, M., Ricciolini, C., Baldoni, L., 2003: Morphological and molecular analyses for the characterization of a group of Italian olive cultivars. Euphytica 132, 129-137.

Sagratini, G., Allegrini, M., Caprioli, G., Cristalli, G., Giardina, D., Maggi, F., Ricciutelli, M., Sirocchi, V., Vittori, S., 2012: Simultaneous determination of squalene, α-tocopherol and β-carotene in table olives by solid phase extraction and high-performance liquid chromatography with diode array detection. Food Anal. Methods 6, 54-60. DOI: 10.1007/s12161-012-9422-6

Saumitou-Laprade, P., Vernet, P., Vekemans, X., Billiard, S., Gallina, S., Essalouh, L., Mhais, A., Moukhli, A., El Bakkali, A., Barcaccia, G., Alagna, F., Mariotti, R., Cultrera, N.G.M., Pandolfi, S., Rossi, M., Khadari, B., Baldoni, L., 2017: Elucidation of the genetic architecture of self-incompatibility in olive: Evolutionary consequences and perspectives for orchard management. Evol. Appl. 10, 867-880. DOI: 10.1111/eva.12457

Servili, M., Montedoro, G., 2002: Contribution of phenolic compounds to virgin olive oil quality. Eur. J. Lipid Sci. Technol. 104, 602-613. DOI: 10.1002/1438-9312(200210)104:9/10<602::AID-EJLT602>3.0.CO;2-X

Sivakumar, G., Bati, C., Perri, E., Uccella, N., 2006: Gas chromatography screening of bioactive phytosterols from mono-cultivar olive oils. Food Chem. 95, 525-528. DOI: 10.1016/j.foodchem.2005.04.003

Spanova, M., Daum, G., 2011: Squalene – biochemistry, molecular biology, process biotechnology, and applications. Eur. J. Lipid Sci. Technol. 113, 1299-1320. DOI: 10.1002/ejlt.201100203

Vinha, A.F., Ferreres, F., Silva, B.M., Valentão, P.C., Gonçalves, A., Pereira, J.A., Oliveira, M.B., Seabra, R.M., Andrade, P.B., 2005: Phenolic profiles of Portuguese olive fruits (*Olea europaea* L.): Influences of cultivar and geographical origin. Food Chem. 89, 561-568. DOI: 10.1016/j.foodchem.2004.03.012

Xiang, C.R., Xu, Z., Liu, J., Li, T., Yang, Z.S., Ding, C.B., 2017: Quality, composition, and antioxidant activity of virgin olive oil from introduced varieties at Liangshan. LWT 78, 226-234. DOI: 10.1016/j.lwt.2016.12.029

Zaher, H., Boulouha, B., Baaziz, M., Sikaoui, L., Gaboun, F.M., Udupa, S., 2011: Morphological and genetic diversity in olive (*Olea europaea* subsp. europaea L.) clones and varieties. POJ 4, 370-376

Zarrouk, W., Baccouri, B., Taamalli, W., 2009: Oil fatty acid composition of eighteen Mediterranean olive varieties cultivated under the arid conditions of Boughrara (southern Tunisia). Grasas Y Aceites 60, 500-508. DOI: 10.3989/gya.021109

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