Chapter 4

Variability Characterization of the Olive Species Regarding Virgin Olive Oil Aroma Compounds by Multivariate Analysis of GC Data

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Additional information is available at the end of the chapter

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Abstract

Virgin olive oil is characterized by its unique aroma, which is synthesized when olive fruits are crushed during the industrial process used for oil production. The genetic variability of the major volatile compounds comprising the oil aroma was studied in a representative sample of olive cultivars from the World Olive Germplasm Collection (IFAPA, Cordoba, Spain). The analytical data demonstrated that a high degree of variability for the content of volatile compounds is found in the olive species and that most of the volatile compounds found in the oils were synthetized by the enzymes included in the so-called lipoxygenase pathway. The use of multivariate analysis to identify cultivars is particularly interesting in terms of volatile composition and deduced organoleptic quality. It can be used for identification of old olive cultivars that give rise to oils with a high organoleptic quality and in parent selection for olive breeding programs.

Keywords: *Olea europaea* L., virgin olive oil, volatile compounds, variability, quality

1. Introduction

Virgin olive oil (VOO) is an essential component of the traditional Mediterranean diet that attracts the interest of the scientific community for its health-promoting properties. This diet is associated with a lower incidence of a number of diseases related to inflammatory processes such as cardiovascular diseases, diabetes, metabolic syndrome, arthritis, Alzheimer's

disease and certain types of cancer [1–6]. Among other plant oils, VOO is unique for its high levels of monounsaturated fatty acids and the presence of a wide range of minor components that are largely responsible for both their health-promoting properties and organoleptic characteristics. As for the organoleptic characteristics, phenolic compounds are closely related to the pungent and bitter sensory notes while volatile minor components are consequently responsible for the aroma of VOO. Curiously, a possible interacting effect of phenolic compounds on the VOO aroma release and perception has been recently reported [7].

About 25 years ago, we established that most of the volatile compounds present in VOO are synthesized when enzymes and substrates come together during the olive fruit milling in the oil extraction process, and that the enzymatic activities within the lipoxygenase (LOX) pathway are involved in this synthesis [8]. Aldehydes and alcohols of six straight-chain carbons (C6), as well as their corresponding esters, are the most important compounds in VOO aroma, either qualitatively or quantitatively [9, 10]. Linoleic (LA) and linolenic (LnA) acids are the main substrates for this synthesis. As displayed in **Figure 1**, LOX enzymes catalyze the production of 13-hydroperoxide derivatives in the first step of this pathway, which are subsequently cleaved heterolytically by hydroperoxide lyase (HPL) enzyme to form C6 aldehydes [8, 11, 12]. C6 aldehydes are then reduced by alcohol dehydrogenase (ADH) enzymes to C6 alcohols [8, 13], and they are finally transformed into the corresponding esters by alcohol acyltransferase (AAT) enzymes [8, 14]. Angerosa et al. [10] also demonstrated the relevance of five straight-chain carbon (C5) compounds in the aroma of olive oil. They are supposedly generated through the production of a 13-alcoxyl radical in an additional branch of the LOX pathway, as demonstrated in soybean seeds [15]. This 13-alcoxyl radical would be homolytically cleaved to form a 1,3-pentene allylic radical. The latter can be chemically dimerized to generate pentene dimers (PD) or reacts with hydroxyl radicals to form C5 alcohols, which are in turn oxidized to C5 carbonyl compounds by ADH enzyme activities, as believed to occur also in soybean [16]. The synthesis of these volatile compounds seems to depend mainly on the availability of fatty acid substrates to be catabolized through the LOX pathway during the VOO extraction process. In addition, LOX activity also proved to be an important limiting factor for the synthesis of these volatile compounds, and this limitation is seemingly characteristic of each olive cultivar [17, 18].

One of the key characteristics of the olive species is its wide genetic patrimony. The establishment of *ex-situ* germplasm banks has received much attention for the collection and conservation of olive genetic resources. In this sense, the World Olive Germplasm Collection (WOGC, Cordoba, Spain) is an international reference due to a high number of cultivars included in its database as well as a high degree of evaluation and identification of cultivars by molecular markers and agronomical traits [19]. This high genetic diversity of the olive germplasm collection could be very useful to recuperate old cultivars, which produce oils with outstanding aromas, or for the selection of optimal parents for olive breeding programs with the aim of finding new cultivars with improved olive oil aroma. New olive cultivars with improved organoleptic quality might further stimulate VOO consumption. In this sense, olive breeding programs have been lately addressing the selection for sensory and nutritional quality of VOO [20, 21] in addition to the traditional improvement of agronomic traits [22].

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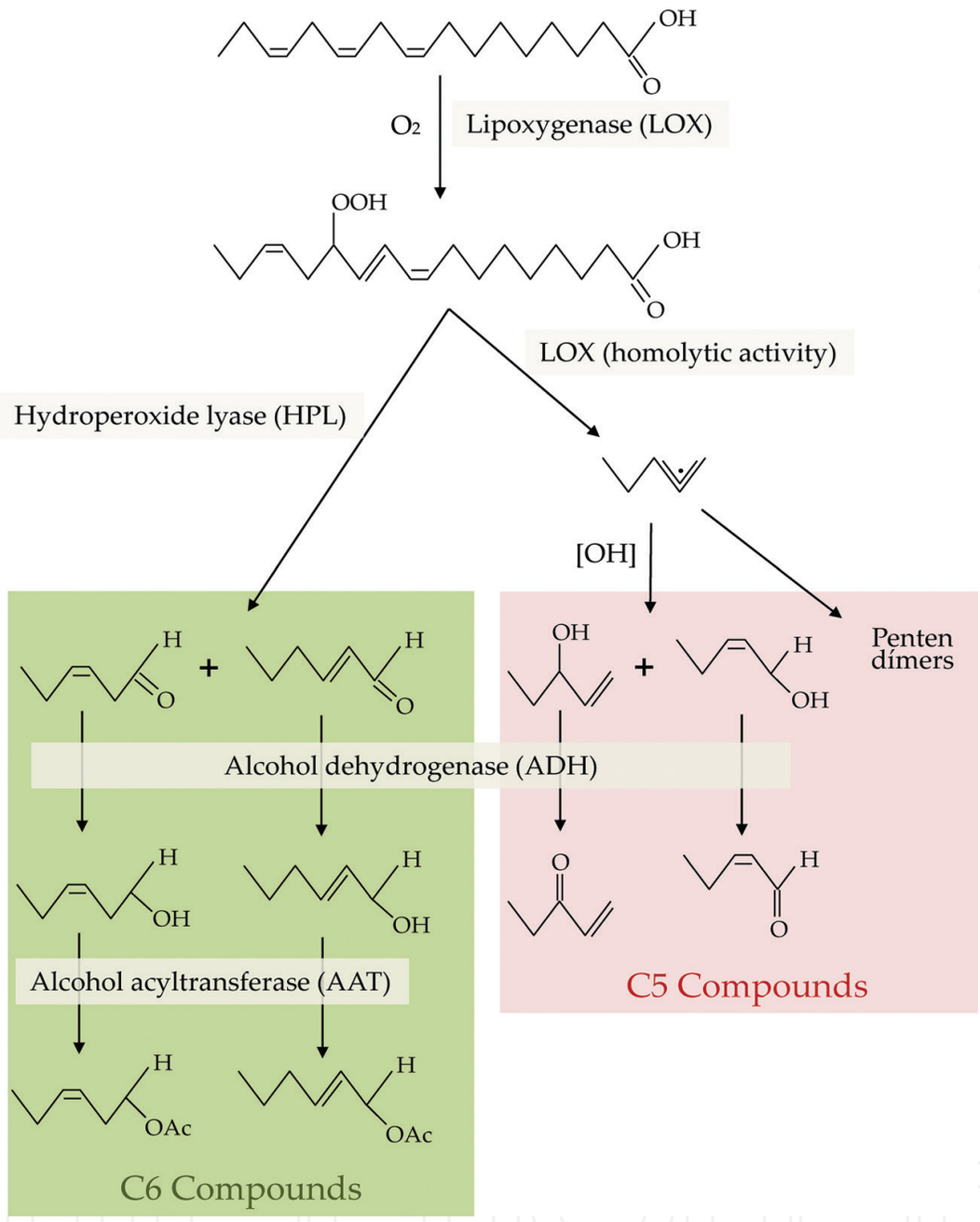

Figure 1. Lipoxygenase pathway on linolenic acid.

2. Sensory properties

In addition to its possible health benefits, the excellent organoleptic properties may well explain the continued increase in the demand for high-quality VOO [23]. As mentioned earlier, volatile compounds are responsible for the aroma of this product, which is basically composed, when obtained from sound fruits, of a mixture of green and fruity odor notes spiced with some other positive notes, making it a unique edible oil. Odor perception and pleasantness

are determined by the size, shape, conformation, type and position of the functional groups in the volatile compound [24, 25]. In this sense, Aparicio and Morales [26] developed a statistical sensory wheel (SSW) to understand the relationship between volatile compounds and odor attributes in VOO, through a compilation of the data obtained from trained VOO sensory panels across Europe. As a result, odor notes with a similar semantic description are clustered into sectors together with volatile compounds identified by a given sensory perception. Among the most relevant to VOO aroma, this sensory wheel includes the green or ripe fruit odor notes. Moreover, the sensory attribute of each volatile compound depends on its concentration and odor threshold in the oil. The ratio between the concentration of the volatile compound and its odor threshold is the odor activity value (i.e. OAV). Those volatile compounds with an OAV below one do not theoretically contribute to the aroma of VOO.

Among the components of the volatile fraction of VOO, C6 compounds derived from LnA (C6/LnA) are considered the main contributors to its aroma. However, those compounds derived from LA (C6/LA) provide unpleasant sensations according to literature, especially the hexan-1-ol [10, 26, 27]. As mentioned earlier, C5 compounds derived from LnA (C5/LnA) seem to have also a notable involvement in the VOO aroma [10]. Among them, pent-1-en-3-one and pent-2-en-1-ols are especially noteworthy [28]. The aroma of pent-2-en-1-ol is described as green-fruity, the typical basic perception of VOO, reminiscent of healthy and fresh olive fruits harvested at the right ripening stage. However, the aroma of pent-1-en-3-one is described as green pungent and provides unpleasant sensations according to literature [10, 26]. Volatile esters, which are significant constituents of the aroma of many fruits, are also important components of the VOO aroma. The VOO ester fraction is formed mainly by acetate esters, such as the hexyl, (*E*)-hex-2-en-1-yl and (*Z*)-hex-3-en-1-yl acetates, from alcohol moieties synthesized through the LOX pathway (LOX esters). These esters are grouped among those VOO aroma compounds with green-fruity perceptions and in the limits of the sweet perception according to canonical correlations reported in [28]. Also, the aldehydes derived from the metabolism of branch-chained amino acids (BC), such as 2- and 3-methyl-butanal, provide green-fruity odor notes as they are located in the green and ripe fruit sectors of the SSW [26]. However, the alcohol derivative 2-methyl-butan-1-ol seems to be related to the fusty defects of VOO aroma [27]. Finally, terpenes found in the volatile fraction of VOO seem not to be important contributors to VOO aroma due to their low concentration and high odor threshold.

The volatile fraction of VOO is also responsible for the off-flavors present in some oils. This is very important because VOO is the only food product that requires a sensory analysis to be classified into commercial categories. This classification is ruled by the European Official Regulations for olive oil [29] and carried out by trained test panels, in which the evaluation of aroma defects plays a very important role. When VOO was obtained from infested olive fruits or fruits picked from the ground, or if VOO was inadequately processed or stored, the volatile fraction of VOO is altered and may include compounds that are responsible for off-flavors. They are predominantly carboxylic acids or aliphatic C8-C11 carbonyls and alcohols [30, 31] produced by chemical oxidation or through the activity of exogenous enzymes, usually due to microbial activity present in non-sound fruits. The presence of such compounds is commonly associated with sensory defects in the oils.

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3. Natural variation of aroma compounds

As mentioned earlier, the extensive genetic patrimony of the olive tree is one of the main attributes of this crop, which is represented by thousands of cultivars from specific areas in the Mediterranean basin where they were originally cultivated. This genetic heritage is currently used in different olive breeding programs, but it is only that the sensory properties of VOO are considered as main traits, in addition to the agronomic traits [20, 22, 32]. Regarding these sensory properties, the natural variation of aroma compounds in VOO was studied using the WOGC olive cultivar collection. For this purpose, a quarter of this germplasm collection (**Table 1**) was considered. This subset included cultivars from the Core-36 collection from WOGC, which preserves most of the genetic diversity found in this germplasm collection [19]. To better compare the different olive accessions, the olive trees from this collection were cultivated in the same edaphoclimatic conditions and only healthy fruits were picked at the turning stage during a period of 3 years. In addition, mild operating conditions were employed for the oil extraction process to minimize the production of compounds that cause sensory defects in the oils.

Solid-phase microextraction (SPME) of the head space (HS) in combination with gas chromatography and mass spectrometry (GC–MS) is a very powerful technique that is used quite frequently for the analysis of volatile compounds in foods. HS-SPME–GG–MS has been applied to study the aroma of products derived from the olive fruit, such as oil or table olives [18, 33–35]. Actually, SPME-GC–MS is the method of reference to validate the discriminating power of new e-sensing technologies such as the electronic nose for olive oil [36–38]. Analysis of volatile compounds in VOO from the WOGC olive cultivar collection was performed by HS-SPME-GC–MS according to Pérez et al. [33]. Olive oil samples (0.5 g) were prepared in 10-mL vials and were conditioned to room temperature before being placed in a vial heater at 40°C for a 10-min equilibration time. Volatile compounds from the headspace were adsorbed onto SPME fiber DVB/Carboxen/PDMS 50/30 μm (Supelco Co., Bellefonte, PA). Sampling time was carried out at 40°C for 50 min. Desorption of volatile compounds was completed directly into the GC injector. Volatile compounds were identified out on a 7820A/GC-5975/MSD system (Agilent Technologies), equipped with a DB-Wax capillary column (60 m × 0.25 mm i.e., film thickness, 0.25 μm: J&W Scientific, Folsom, CA) and under the following conditions: the injection port was operated in splitless mode at 250°C; He was used as the carrier gas and the flow rate was 1 mL/min; the column was held for 6 min at 40°C and then programmed at 2°C min^{-1} to 168°C; the mass detector was operated in the electronic impact mode at 70 eV, the source temperature was set at 230°C and the mass spectra were scanned at 2.86 scans/s in the m/z 40–550 amu range. Compound identification was performed by matching against the Wiley/NBS Library and by comparing GC retention time against standards. For quantitative purposes, the volatile fraction was analyzed three times on a HP-6890 GC apparatus (Agilent Technologies, Santa Clara, CA, USA), which was equipped with a similar column and operated under the following operating conditions in order to reproduce the same retention times for volatile compounds as those obtained with the 7820A/GC-5975/MSD system: N_2 was used as the carrier gas at a constant pressure of 17 psi; the injector and detector were maintained at 250°C; the column was held for 6 min at 40°C and then programmed at 2°C min^{-1} to 168°C. For quantification, calibration curves for each compound were made in re-deodorized high-oleic sunflower oil.

No.	Cultivar	No.	Cultivar
1	Picudo	50	Sabatera
2	Lechín de Sevilla	51	Arbosana
3	Picual	52	Joanenca
4	Cornicabra	53	Menya
5	Blanqueta	54	Elmacik
6	Manzanilla de Sevilla	55	Kan Celebi
7	Jaropo	56	Yun Gelebi
8	Blanqueta-48	57	Kalokerida
9	Verdial de Vélez-Málaga	58	Agouromanakolia
10	Picholine	59	Amygdalolia Nana
11	Caninese	60	Mavreya
12	Coratina	61	Myrtolia
13	Frantoio	62	Kolybada
14	Leccino	63	Levantinka
15	Maurino	64	Lastovka
16	Cipresino	65	Barnea
17	Uslu	66	Aggezi Shami
18	Picholine Marroquí	67	Wardan
19	Kalamon	68	Azapa o Arauco
20	Megaritiki	69	Istarska Bjelica
21	Ouslati	70	Manzanillera de Huercal Overa
22	Zalmati	71	Torcio de Cabra
23	Chemial de Kabilye	72	Zaity
24	Merhavia	73	Figueretes
25	Galega Vulgar	74	Haouzia
26	Kaesi	75	Abou Kanani
27	Majhol-152	76	Abbadi Abou Gabra
28	Grappolo	77	Verdial de Badajoz
29	Koroneiki	78	Verdial de Vélez-Málaga
30	Morrut	79	Verde Verdelho
31	Llumeta	80	Piñonera
32	Rapasayo	81	Majhol-1013
33	Mastoidis	82	Barri

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No.	Cultivar	No.	Cultivar
34	Temprano	83	Abbadi Abou Gabra
35	Lentisca	84	Shami
36	Chorreao de Montefrío	85	Abou Satl Mohazam
37	Pecoso	86	Vinyols
38	Negrinha	87	Argudell
39	Dokkar	88	Curivell
40	Pequeña de Casas Ibañez	89	Ulliri i Kuq
41	Borriolenca	90	Klon-1081
42	Vallesa	91	Arbequina
43	Patronet	92	Jabali
44	Forastera de Tortosa	93	Maarri
45	Canetera	94	Shengeh
46	Corbella	95	Mari
47	Vera	96	Bosana
48	Palomar	97	Klon-1812
49	Vaneta		

Table 1. Cultivars from the WOGC subset.

The subset of the olive germplasm collection showed a high degree of variability in terms of the content of volatile compounds (**Figure 2** and **Table 2**). As mentioned earlier, most of the volatile compounds found in the oils were synthetized by the enzymes included in the so-called LOX pathway [8], and can be grouped according to the length of the chain, the fatty acid substrate (C6/LnA, C6/LA, C5/LnA, C5/LA) and the origin of the esters (LOX esters). Moreover, a group of compounds derived from amino acid metabolism, which has a branched-chain chemical structure (BC) and a terpene also contributed quantitatively to the volatile fraction of VOO. C6 compounds derived from linolenic acid (C6/LnA) represented on average about 70% of total volatile fraction in the oils (**Figure 2**). The C6/LnA compounds varied from 5.18 to 67.94 μg/g oil, a variability that broadly exceeded that found for oils produced from a collection of 39 olive cultivars cultivated in the same orchard under the same edaphoclimatic conditions (2.52–18.11 μg/g oil) [39]. The C6/LnA aldehyde group was the most abundant, being (*E*)-hex-2-enal as the main compound (93% of total C6/LnA compounds on average, **Figure 2**). The mean content of (*E*)-hex-2-enal in the oils was 23.78 μg/g oil, ranging from 4.00 to 65.03 μg/g oil. The large amount and the relatively low odor threshold [40] point to this C6/LnA compound as one of the main contributors to the aroma of the oils, which seems to be a common feature of the oils from the olive species [33, 39, 41].

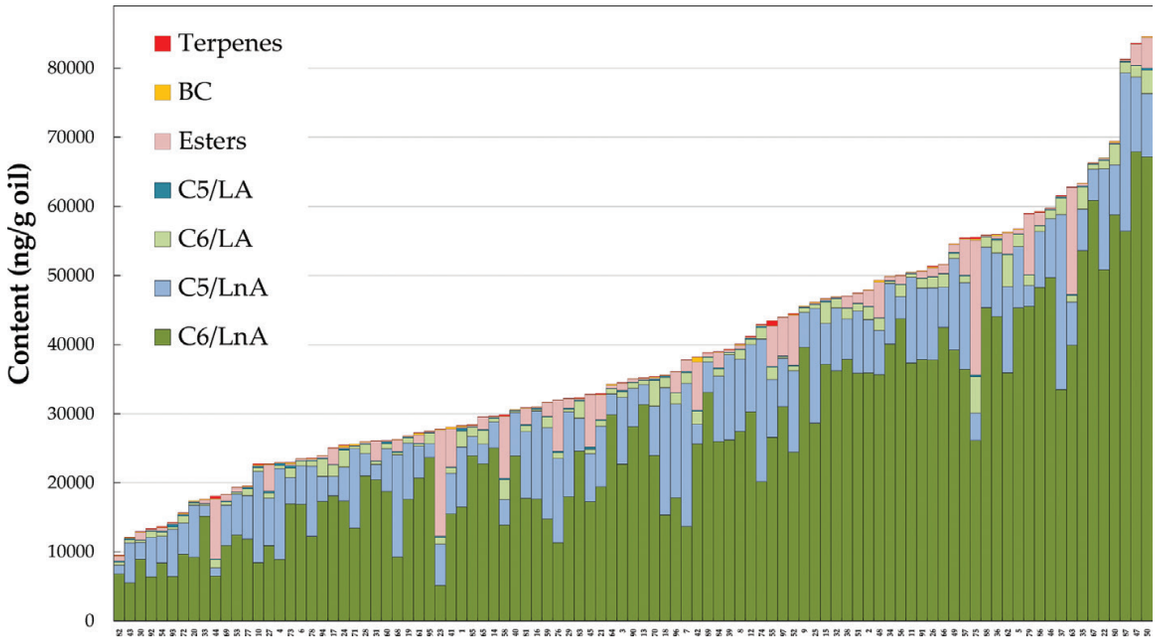

Figure 2. Content (ng/g oil) of the main groups of volatile compounds in the oils of WOGC cultivar subset. Numbers correspond to the WOGC cultivars displayed in **Table 1**.

Only the C5/LnA compounds showed contents close to those of the C6/LnA compounds. The pentene dimers are the most important compounds in this group from a quantitative point of view. They are thought to be produced through the same branch of the LOX pathway as the rest of C5 compounds [42]. The pentene dimers represented 82% of the C5/LnA content on average (**Figure 2**), but seem to have a quite low or negligible sensory contribution to the VOO aroma according to the estimated odor thresholds for these compounds [33]. The rest of C5/LnA compounds seem to contribute to VOO aroma according to their OAVs (**Table 2**). Pent-1-en-3-one and pent-2-en-1-ols are especially remarkable. All the cultivars showed to have contents of pent-1-en-3-one above its odor threshold (0.73 ng/g oil). The odor of this compound provides an unpleasant sensation [10], while the aroma of pent-2-en-1-ol is described as green-fruity. Most of the olive accessions (79%) presented (*E*)-pent-2-en-1-ol contents above its odor threshold [33] (**Table 2**). On the contrary, (*Z*)-pent-2-en-1-ol contents suggest this compound is of little relevance to VOO aroma as it is present below its threshold concentration in the oils.

As mentioned previously, fruity odor notes are considered as positive attributes of the oil aroma. Volatile esters are the main compounds responsible for these odor notes, especially LOX esters. The LOX ester content in the olive collection subset was 1953 ng/g oil on average and is present in a range of 14–19,334 ng/g oil, much higher than those values found in a progeny of the cross of cultivars Picual and Arbequina [33]. Only a few accessions had contents of (*E*)-hex-2-en-1-yl acetate contributing to VOO aroma (OAV > 1, **Table 2**). However, (*Z*)-hex-3-en-1-yl acetate did seem to be an important contributor to VOO aroma in more than half of the olive collection subset (**Table 2**). Similar results were found in the analysis of the volatile aroma compounds of some Turkish cultivar oils [43].

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	Volatile compound	Code	Min	Max	Mean	% cv OAV > 1
C6/LnA aldehydes	(E)-hex-3-enal	6C-1	55	924	342	23
	(Z)-hex-3-enal	6C-2	52	4598	837	100
	(Z)-hex-2-enal	6C-3	101	1290	614	77
	(E)-hex-2-enal	6C-4	3998	65,029	23,780	100
C6/LnA alcohols	(E)-hex-3-enol	6C-5	0	836	32	0
	(Z)-hex-3-enol	6C-6	45	4306	586	12
	(E)-hex-2-enol	6C-7	43	3293	235	0
C6/LA aldehyde	hexanal	6C-8	166	4451	927	84
C6/LA alcohol	hexan-1-ol	6C-9	13	2725	339	25
C5/LnA carbonyls	pent-1-en-3-one	5C-1	68	1615	565	100
	(Z)-pent-2-enal	5C-2	4	175	47	0
	(E)-pent-2-enal	5C-3	22	226	93	0
C5/LnA alcohols	pent-1-en-3-ol	5C-4	29	634	228	7
	(Z)-pent-2-en-1-ol	5C-5	10	290	58	2
	(E)-pent-2-en-1-ol	5C-6	79	1908	480	79
Pentene dimers	pentene dimer - 1	5C-7	32	1195	406	0
	pentene dimer - 2	5C-8	26	1036	310	0
	pentene dimer - 3	5C-9	116	4840	1537	0
	pentene dimer - 4	5C-10	127	6363	1697	0
	pentene dimer - 5	5C-11	0	4513	1024	0
	pentene dimer - 6	5C-12	37	3909	1088	0
	pentene dimer - 7	5C-13	0	2847	571	0
C5/LA carbonyls	pentan-3-one	5C-14	17	335	89	0
	pentanal	5C-15	5	242	49	1
C5/LA alcohol	pentan-1-ol	5C-16	0	37	7	0
LOX esters	hexyl acetate	E-1	5	8165	670	15
	(E)-hex-2-en-1-yl acetate	E-2	7	2099	99	5
	(Z)-hex-3-en-1-yl acetate	E-3	0	11,120	1184	52
non-LOX esters	methyl acetate	E-4	5	42	18	0
	ethyl acetate	E-5	3	354	21	0
	methyl hexanoate	E-6	6	128	25	0
	ethyl hexanoate	E-7	0	359	37	0

	Volatile compound	Code	Min	Max	Mean	% cv OAV > 1
BC aldehydes	3-methyl-butanal	BC-1	6	351	40	100
	2-methyl-butanal	BC-2	5	342	25	100
BC alcohol	2-methyl-butan-1-ol	BC-3	5	159	34	0
Terpene	limonene	T-1	0	743	55	3

Table 2. Content of the volatile compounds (ng/g oil) and their distribution in the oils from the WOGC cultivar subset.

The levels of the branched-chain (BC) compounds in the different accessions of the olive collection subset are also important. They could have a profound impact on the aroma of the oils despite the fact that they are present at low concentrations in the oils (average 100 ng/g oil, range of 20–740 ng/g oil). The 2 and 3-methyl-butanal contents suggest that these BC aldehydes contribute decisively to the VOO aroma, since they have OAV values higher than one in all the accessions. Their aroma significance for VOO is especially notable because they are located in the ripe fruit sector of the SSW [26]. However, 2-methyl-butan-1-ol, which is responsible for the fusty off-flavor of the oil [27], was found below its odor threshold in all the cultivars assessed (**Table 2**). Thus, it should not contribute to the aroma of the oils. Finally, limonene seems not to be an important contributor to VOO aroma since only three cultivars of the olive collection subset had an OAV above one for this terpene (**Table 2**).

Factor analysis allowed explaining the pattern of correlations within different volatile compounds in the olive oils. **Figure 3** displays the factor analysis considering only those factors with eigenvalues higher than one and using the normalized Varimax method. Those factors explained 77.46% of the total variance. First factor explained 21.73% of the variance and second factor 12.60%. As shown, most of the C6 compounds spread along Factor 2 (green ellipse), while most of the C5 compounds distributed along Factor 1. Three different groupings may be distinguished for the latter (**Figure 2**, pink ellipses), which correspond to C5/LnA alcohols, aldehydes and pentene dimers, respectively. The group of C5/LnA alcohols partially overlaps the space of the C6 compounds. This indicates a greater metabolic proximity than other C5/LnA subgroups, which would support the hypothesis that C5/LnA alcohols are the first products formed from the homolytic branch of the LOX pathway [42], parallel to the pentene dimers formation, and finally oxidized enzymatically to C5/LnA carbonyls. Moreover, it was found previously that the pentene dimer content did not correlate with the C5/LA carbonyl or alcohol contents, suggesting that pentene dimers were only produced from LnA [44]. Accordingly, those compounds are located in **Figure 3** far from the group of pentene dimers.

On the other hand, the esters are grouped together overlapping the space of the C6 compounds, where the main precursors of esters are located [(hexan-1-ol (6C-9) and (*Z*)-hex-3-enol (6C-7)]. This might be indicative of a disconnection with the mainstream LOX pathway, which reflects the limitation of alcohol synthesis during VOO production due to the inactivation of ADH during the oil extraction process as we have previously demonstrated [45].

The PCA approach explains the correlations among the different classes of volatile compounds assessed in the oils of the olive collection subset and allows us to distinguish those olive cultivars that are especially rich in some of them (**Figure 4**). The first two PCs carried

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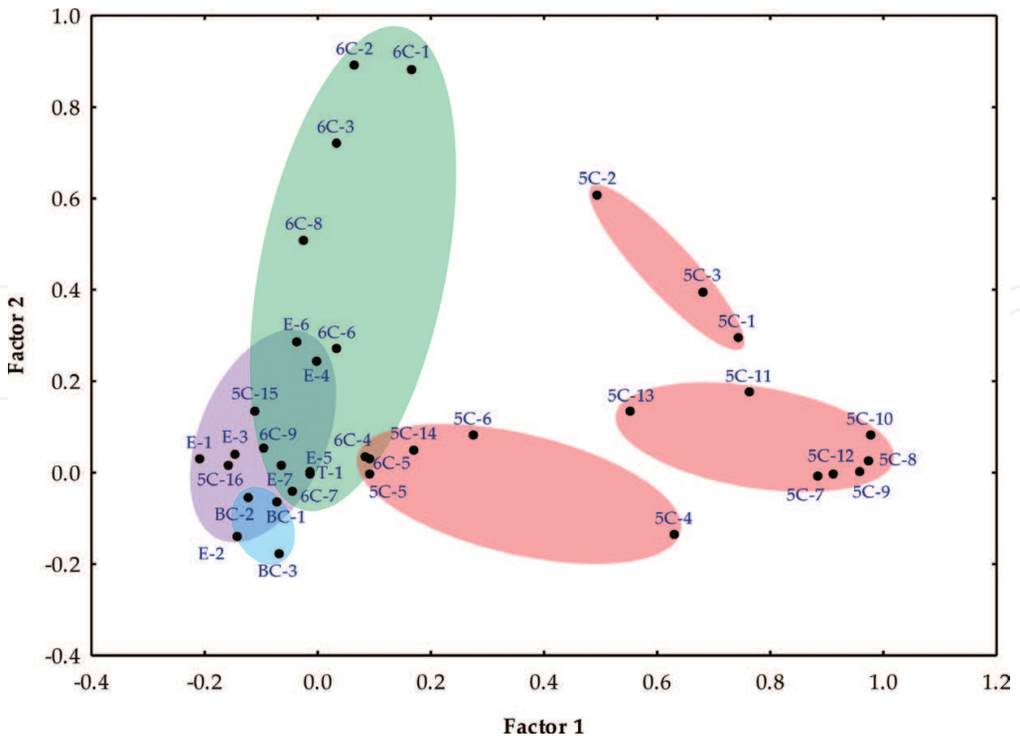

Figure 3. Factor analysis. Position of the main volatile compounds in the oils from the WOGC cultivar subset on the first two factors using the normalized Varimax method.

a moderate amount of important information, with the first factor and second factor correspondingly explaining 21.46% and 15.14% of the variance. We previously found quite similar values when assessing the content of the main volatile compounds in the oils of the progeny of the cross of cultivars Picual and Arbequina (21.03% and 17.29% for factor 1 and 2, respectively) [33]. Cultivars giving rise to oils with high C6/LnA aldehyde contents are situated around the center of the plot, while those producing oils with high C5/LnA contents are located along the negative axis of the second factor. Moreover, the oils from cultivars located along the first factor axis would have high C6/LnA aldehydes content as well as high levels of LOX esters or BC aldehydes. These compounds might act synergistically to increase the green-fruity odor notes. Most of the compounds included in those volatile classes are located in the green and ripe fruit sectors of the SSW [26]. Thus, it is possible to select cultivars from the germplasm collection subset, whose oils have a potential dominant green aroma, such as those cultivars located in the bisector of the first quadrant.

Table 2 shows that only a few volatile compounds are present in the olive cultivar subset at levels indicating that they may contribute to the oil aroma (OAV > 1). However, other volatile compounds contribute to just a given number of the oil cultivars. PCA was performed considering as variables only those volatile compounds that might contribute to the aroma of the oil in more than 10% of the cultivars (**Figure 5**). Most of these compounds were considered desirable for the aroma of VOO, except for hexan-1-ol (6C-9) and pent-1-en-3-one (5C-1), which provide unpleasant sensations according to literature [10, 26, 27]. The volatile compounds used as variables in **Figure 5** have been previously identified as key contributors to the aroma of various monovarietal olive oils from Spain, Italy, Argentina or Iran [46–49]. Factors 1 and 2 explain 46% of the data variation, quite similar to what was found for the progeny of the cross

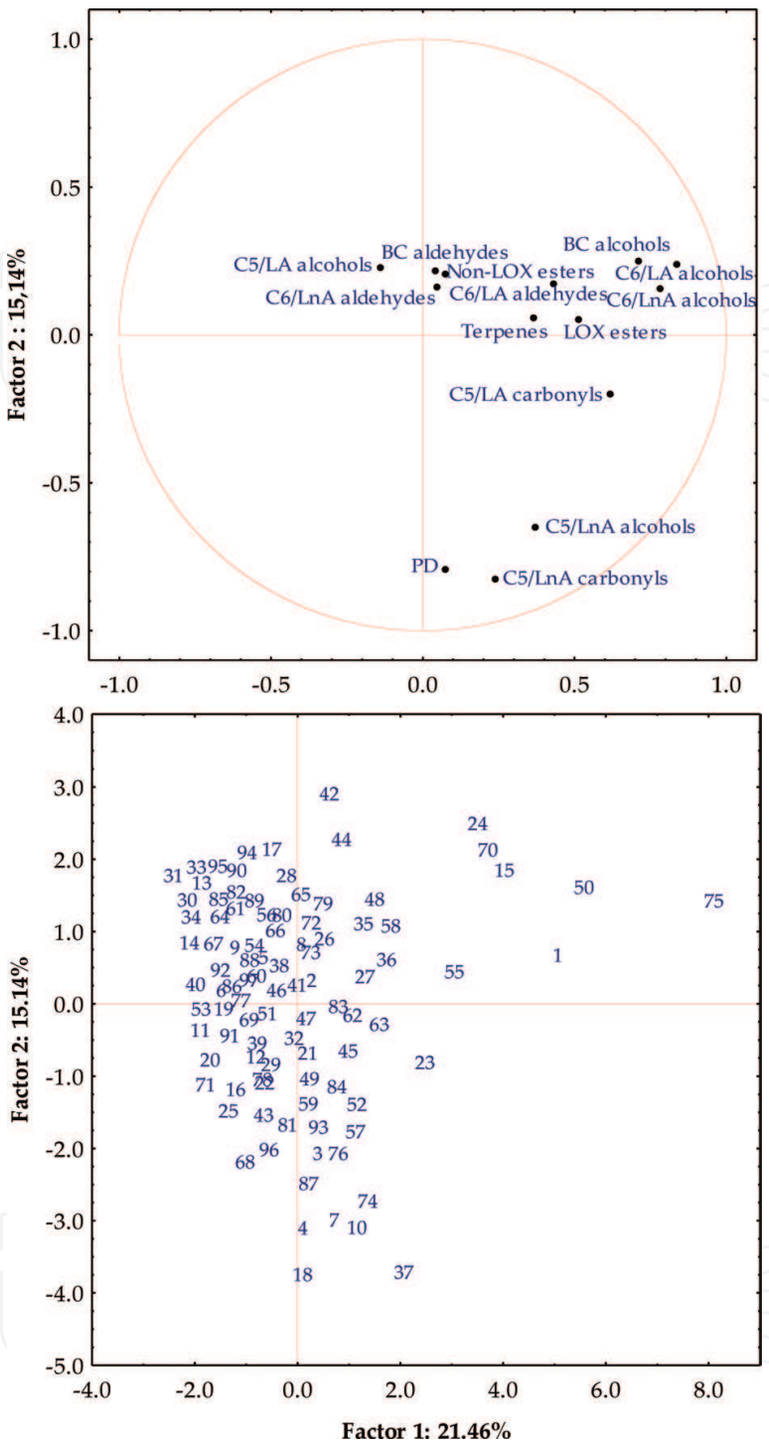

Figure 4. Principal component analysis of the main groups of volatile compounds in the oils from the WOGC cultivar subset. Up, vector distribution of the volatile compounds. Bottom, distribution of the cultivars. References for the cultivars are listed in **Table 1**.

of cultivars Picual and Arbequina [33]. When using as variables the volatile compounds that contribute to the aroma (OAV > 1) of the oils, the cultivars are distributed mainly along the bisectors of the second and fourth quadrants. The distribution of vectors in **Figure 5** allows identifying cultivars that presumably give rise to oils with remarkable sensory properties.

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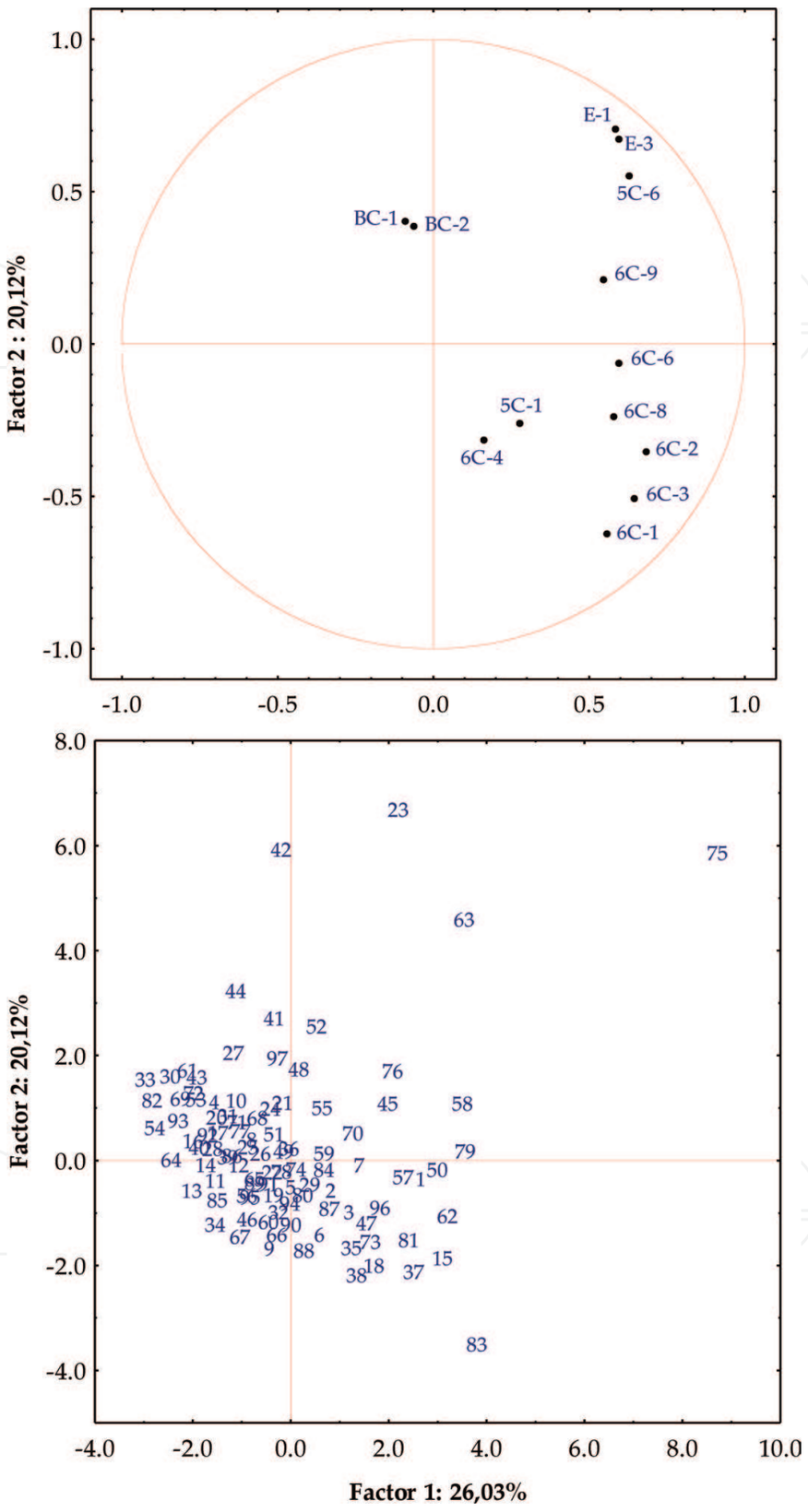

Figure 5. Principal component analysis of the volatile compounds contributing to the aroma (OAV > 1) of the WOGC cultivar subset. Up, vector distribution of the volatile compounds. Codes for the volatile compounds are listed in **Table 2**. Bottom, distribution of the cultivars from the collection. References for the cultivars are listed in **Table 1**.

4. Conclusions

Data demonstrated that the olive species presents a high level of variability in terms of the volatile fraction of the oils and, presumably, of the aroma quality. This aroma variability and the high genetic diversity of the cultivar germplasm collection suggest that it is possible both to identify old olive cultivars that give rise to oils with a high organoleptic quality and to select optimal parents for olive breeding programs with the aim of finding new cultivars with improved oil aroma. Multivariate analysis seems to be a particularly interesting tool for this purpose.

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Conflict of interest

The authors declare no conflicts of interest.

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