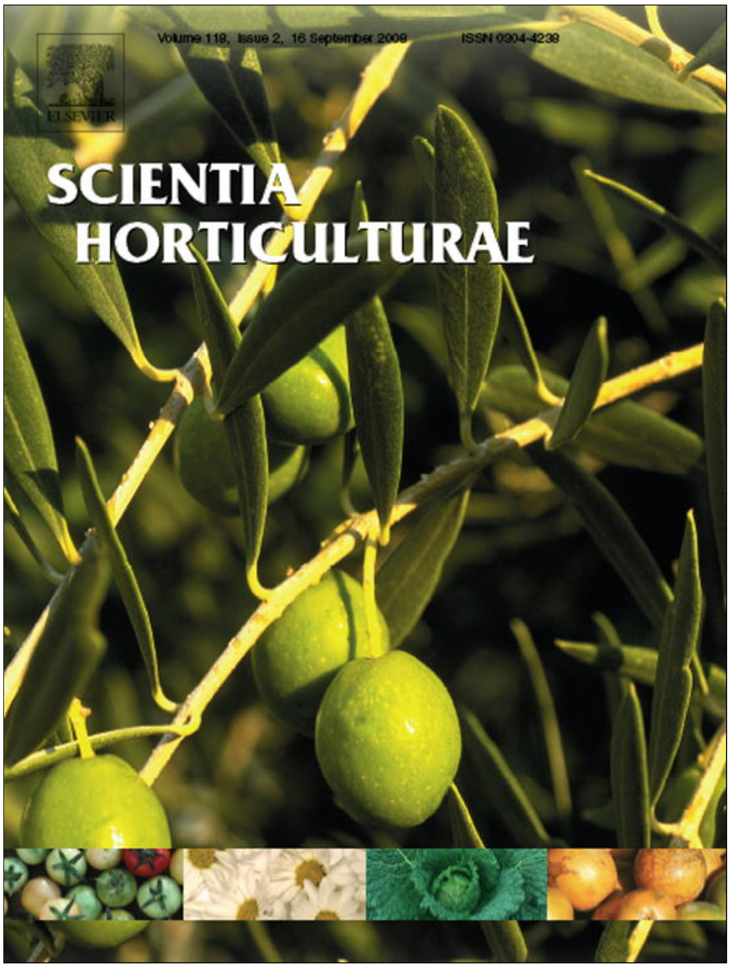
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Cultivar influence on virgin olive (*Olea europea* L.) oil flavor based on aromatic compounds and sensorial profile

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A B S T R A C T

Sensory quality is an important property of virgin olive oil and is affected by different volatile and phenolic compounds. Their levels may be influenced by many factors, and one of the most important is the cultivar. Volatiles and phenols were correlated to sensory notes in virgin olive oils from 18 local cultivars in northern Italy assessed for 4 years in the same orchard.

Most of the volatile and phenolic compounds showed an average content higher than odor and taste thresholds, explaining the correlations to sensory attributes. Some volatile compounds (e.g. ethanol, 2-methyl-propan-1-ol, pentan-1-ol, *cis*-2-penten-1-ol, *cis*-3-hexen-1-ol and octan-1-ol) and sensory attributes (e.g. 'flowers', 'banana', 'apple', 'walnut', 'hay', 'butter', 'sweet', 'floral' and 'fruity' notes) were found as cultivar dependent. Some cultivars, with a similar aromatic content, showed also analogous sensorial profile. 'Favarol', 'Casaliva 1', 'Raza', 'Casaliva 2', 'Gargnà', 'Mitria', 'Miniol', and 'Rossanello' resulted in the same aromatic group, characterized by an average volatiles content, and in three close affinity groups with a middle sensorial profile. Moreover, 'Maurino' was always isolated, showing peculiar profiles. Local cultivars 'Casaliva 1', 'Cornarol', 'Grignano', 'Trepp' and 'Regina' overall have shown peculiar flavor profiles. Therefore, some of these often-underutilized cultivars could be employed in the new orchards in order to take advantage of their superior oil quality traits, in addition to some positive horticultural aspects. This could be particularly crucial for the Protected Designation of Origin (PDO) oils, where the mere geographical origin could not be enough in favoring olive oil characterization and consumption, if sensorial and/or nutritional attributes are also not differentiated within a standard commercial commodity.

1. Introduction

The extra virgin olive oil is the principal source of fat in the Mediterranean diet with important nutraceutic effects due to its abundance of oleic acid, a monounsaturated fatty acid controlling the cholesterol level, and an adequate content of linoleic and linolenic acids, the major essential fatty acids that lower the risk of coronary heart diseases and cancers (Galli and Visioli, 1999). Virgin olive oil is the only vegetal fat that can be eaten crude (also called "olive juice") with no refining operations. This allows to preserve its natural composition, including the minor, non-saponificable compounds, making up to 1–2% of total content, e.g. hydrocarbons, phenols, alcohols, sterols, pigments, tocopherols and vitamins. These compounds are crucial both for the oil oxidative stability (improving the shelf life) and for its unique flavor. Aroma and taste are the only parameters that consumers can appraise directly, while other quality features (e.g. chemical composition) are not always labelled on the bottle.

Two recent works reviewed the several factors influencing aromatic quality of virgin olive oil, i.e. biogenesis and composition of volatiles, relationships with sensory notes, possible influence of agronomic and processing factors, and oil oxidation (Kalua et al., 2007; Angerosa et al., 2004). All these findings show that volatiles content, mainly C_6- and C_5-skeleton compounds from the lipoxygenate pathway, are strongly influenced by the genetic origin (cultivar) for the enzymatic expression and by horticultural and processing parameters for the enzyme activity. The unique flavor of virgin olive oil is mainly attributed to the volatiles that develop during and after oil extraction from the fruit. These compounds become less important during oil storage due to

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oxidation. These changes on volatile composition, together with genetic, horticultural and processing influences, explain quality differences in olive oils (Harwood and Aparicio, 2000).

In a previous study (Tura et al., 2007), the antioxidant profile was found to be firstly influenced by the cultivar, and then by the site of cultivation. The oxidative stability was correlated to phenols, tocopherols and saturated on unsaturated fatty acids.

In another study several olive accessions from a local cultivars collection in the lake Garda area (northern Italy) were successfully classified by oil sensory profile (Tura et al., 2002). Moreover, these sensorial attributes resulted correlated to some volatile and phenolic compounds. A similar cultivar assessment was scored by a principal components analysis and eight aromatic compounds were found to be the more significant in varietal characterization, e.g. *cis*-3-hexen-1-ol, hexan-1-ol, pentan-3-one and *trans*-2-hexen-1-ol (Pedò et al., 2002). Furthermore, an in-depth study on the two main cultivars in the above region found that on the basis of a similar fruit ripening stage, the 'Leccino' oil showed a higher aromatic compounds content compared to 'Casaliva'. But due to local practice, 'Leccino' is usually harvested at full maturation ('black' stage), when most volatiles are gone and antioxidants are low, while 'Casaliva' is picked at an early stage, even before the veraison, in order to avoid oil being negatively affected by possible early winter frost on fruits. This is why commercial 'Leccino' oil, very often, is less flavored and has lower antioxidant attribute than 'Casaliva' (Pedò et al., 2003). Thus, the olive ripening stage at harvest is a crucial step in determining the oil quality. Other findings (Tura et al., in press, 2005) confirmed that the volatile compounds in 'Casaliva' and 'Leccino' oils are highly and negatively correlated to the maturity stage of the fruits, as already shown in the above report. Mere in detail, 'Casaliva' oils were also affected by the season thermal course during ripening: oils from olives at the same maturity stage were higher in phenols, tocopherols and volatiles in years with higher heat summation.

A study on volatile profile of Australian virgin olive oils has shown cultivar as the single-most important factor in determining aromatic oil quality (Tura et al., 2004). Other works confirmed the cultivar strong effect on aromatic quality. Dhifi et al. (2005) found that the different volatile composition in four Tunisian in oils was affected by the cultivar, showing also a close relation to the enzymatic profiling, that is genetically determined. Luna et al. (2006) characterized many virgin olive oils from several countries by volatile compounds and the sensory attributes. Berlioz et al. (2006) analyzed the volatile and flavor compositions of several French oils from Protected Designation of Origin (PDO) districts and standard commercial olive oils, developing a chemometric method able to discriminate the oils. Baccouri et al. (2007) demonstrated that the volatile profiles of oleaster oils (olive cultivars selected from wild olives, *Olea europea var. oleaster*) were different from standard European and Tunisian virgin oils from *Olea europea var. sativa*. Other peculiar differences in the composition of volatile in Tunisian and French PDO oils were found by Haddada et al. (2007) demonstrating that the building up of metabolites in oils from different cultivars was related to genetic origin. Vichi et al. (2003) found significant differences in volatile composition in oils of different cultivars and geographical origin in northern Italy.

Some authors compared different analytical techniques to assess the volatile compounds and/or sensory attributes in olive oils. Procida et al. (2005) arranged a chemometric approach to correlate volatile molecules with oil sensory defects. Also Morales et al. (2005) studied the correlations between volatile profiles and defects by olfactometry techniques. Cavalli et al. (2003) and Kanavouras et al. (2005) compared several methods for volatiles extraction from oils, i.e. static and dynamic headspace, solid phase micro-extraction (SPME), sorptive extraction and thermal desorption. Garcia-Gonzalez et al. (2004) tested the electronic nose coupled with SPME to distinguish different olive oils. Contini and Esti (2006) checked the effectiveness of HS-SPME for the volatiles analysis of virgin olive oils at different dilutions and Jimenez et al. (2006) applied this method to carry out a quality control of virgin olive oils from fruit picked either from the tree or from the ground.

In this paper, we have investigated the volatile composition and the sensory notes of monovarietals oils from local olive cultivars for an in-depth study of their aromatic pattern (Alfei, 2004). The main goal of this work was to deeply investigate the potential of often-neglected germoplasm at risk of extinction that could play a crucial role in improving the flavor attributes of commercial products. There is an increasing interest on extraction olive oil but there is a strong risk this demand is not matched by high quality products.

2. Materials and methods

2.1. Oils sampling

The study was carried for 4 years on oil samples obtained from 18 olive cultivars grown in the same orchard in the western coast of the Garda lake (northern Italy). The orchard is located in Raffa di Puegnago at 170 m a.s.l., 45°32′N of latitude and 10°31′E of longitude, its landscape being a coarse soil on moraine foothill with an annual mean temperature and rainfall of 13.6 °C and 937 mm, respectively. All oil samples were obtained from about 10 kg of olives at veraison stage by a standard discontinuous procedure within 1 day from picking. The olives were crushed with a stainless steel hammer crusher mill and malaxed for 30 min at 28 °C. The oil was extracted by hydraulic press (maximum 20 MPa) and

Table 1
Oil aromatic profiling (3–4 years average): number of samples, value range, mean, standard deviation and expected variance component due to cultivar and its interactions

Compound	*N*	Range (mg/kg)	Mean (mg/kg)	S.D. (mg/kg)	Variance (%)
n-Octane	60	0.33–33.3	3.39	n.r.	25
Ethyl acetate	60	0.28–80.9	13.4	n.r.	0
2-Methyl-butanal	60	0.05–37.7	0.33	n.r.	6
3-Methyl-butanal	60	0.05–43.9	5.64	n.r.	5
Ethanol	60	3.47–217.7	30.6	n.r.	53
Pentan-3-one	60	0.88–119.6	20.6	n.r.	4
1-Penten-3-one	60	0.81–27.8	9.54	5.97	37
Hexanal	60	0.53–144.2	35.2	31.8	27
2-Methyl-propan-1-ol	60	0.05–2.69	0.76	0.59	76
trans-2-pentenal	60	0.09–32.4	7.48	6.91	39
1-Penten-3-ol	60	1.63–74.1	28.7	19.7	9
3-Methyl-butan-1-ol	60	0.38–15.1	6.14	3.98	17
trans-2-Hexenal	60	1.25–1863.5	543.4	514.7	28
Pentan-1-ol	60	0.04–6.77	1.05	n.r.	67
cis-2-Penten-1-ol	60	1.61–139.9	22.3	19.8	50
Hexan-1-ol	60	1.08–89.5	17.4	n.r.	3
cis-3-Hexen-1-ol	60	1.83–258.6	41.3	n.r.	93
trans-2-Hexen-1-ol	60	0.22–304.4	33.8	n.r.	9
Acetic acid	60	0.04–1.14	0.33	0.25	1
Octan-1-ol	60	0.24–7.09	0.70	n.r.	92
Total alcohols	60	52.4–541.3	182.7	112.8	6
Total aldehydes	60	2.55–1926.4	596.2	533.7	27
Total ketones	60	3.63–127.2	30.1	23.9	5
Total C_5 compounds	60	4.54–198.8	68.0	40.9	8
Total C_6 compounds	60	23.9–1998.4	671.1	543.6	22
Total C_6 from LA	60	5.20–170.9	52.7	40.2	12
Total C_6 from LnA	60	18.3–1942.5	618.4	523.2	23
Total volatiles	60	62.8–2184.2	826.2	573.0	18
Total phenols[a]	61	55.4–615.5	235.5	128.4	12

n.r., not reported because frequency distributions were not normal according to Kolmogorov–Smirnov test ($P = 0.05$). LA, linoleic acid. LnA, linolenic acid.
[a] From Tura et al. (2007).

Table 2
Oil aromatic profiling: comparison among 18 cultivars (within brackets: number of cropping years)

Compound (mg/kg)	Baia (3)	Casaliva 1 (4)	Casaliva 2 (4)	Cornarol (3)	Favarol (4)	Frantoio (4)
n-Octane	5.03ab[a]	2.77ab	5.52ab	1.27a	1.67ab	9.38b
Ethyl acetate	7.80a	6.13a	5.97a	10.09a	30.13a	16.12a
2-Methyl-butanal	8.55a	2.09a	2.27a	6.96a	6.86a	1.58a
3-Methyl-butanal	8.23a	2.36a	3.72a	8.03a	9.49a	2.31a
Ethanol	92.35b	15.33a	22.17a	34.28a	28.75a	20.32a
Pentan-3-one	28.98ab	18.03ab	21.86ab	50.73b	28.10ab	36.92ab
1-Penten-3-one	13.97bcd	7.60abc	11.80abc	12.38abc	5.75ab	8.27abc
Hexanal	49.51abcd	43.50abcd	53.38bcd	48.58abcd	24.64abc	71.96d
2-Methyl-propan-1-ol	1.31b	0.48ab	0.59ab	0.97ab	0.62ab	0.59ab
trans-2-Pentenal	10.62ab	6.81a	6.62a	10.35ab	4.30a	7.48a
1-Penten-3-ol	31.01abc	33.17abc	36.93abc	28.92abc	20.41a	35.72abc
3-Methyl-butan-1-ol	8.97b	8.51b	6.87ab	4.37ab	7.50ab	9.16b
trans-2-Hexenal	211.2abc	1179.9g	1031.0efg	175.8ab	532.3abcdef	1112.4fg
Pentan-1-ol	0.81abc	1.45abc	1.26abc	0.60abc	0.31a	1.41abc
cis-2-Penten-1-ol	25.08a	21.38a	21.97a	27.02a	15.35a	20.37a
Hexan-1-ol	16.14a	9.67a	28.86a	21.27a	34.57a	26.41a
cis-3-Hexen-1-ol	83.88bcd	15.83ab	25.52ab	139.13d	12.39ab	13.12ab
trans-2-Hexen-1-ol	17.74a	34.28a	68.46ab	23.82a	60.88ab	55.38ab
Acetic acid	0.32a	0.34a	0.48a	0.34a	0.21a	0.38a
Octan-1-ol	0.60a	0.59a	0.56a	1.16a	0.78a	0.48a
Total alcohols	277.90a	140.69a	213.19a	281.53a	181.55a	182.96a
Total aldehydes	288.12ab	1234.69d	1097.04cd	249.76ab	577.56abcd	1195.73d
Total ketones	42.94a	25.62a	33.66a	63.11a	33.85a	45.19a
Total C_5 compounds	80.68ab	68.96ab	77.32ab	78.67ab	45.81a	71.84ab
Total C_6 compounds	378.48ab	1283.22b	1207.26b	408.63ab	664.75ab	1279.27b
Total C_6 from LA	65.66a	53.17a	82.24a	69.85a	59.22a	98.36a
Total C_6 from LnA	312.83ab	1230.05c	1125.02bc	338.78ab	605.53abc	1180.90bc
Total volatiles	622.1ab	1410.3c	1355.9c	606.1ab	825.0abc	1449.8c
Total phenols[b]	213.9d	131.3bc	150.0c	239.3de	128.8bc	143.4bc

Compound (mg/kg)	Gargnà (3)	Grignano (3)	Leccino (4)	Less (3)	Maurino (3)	Miniol (4)
n-Octane	3.09ab	2.17ab	1.57ab	1.84ab	4.97ab	2.47ab
Ethyl acetate	30.20a	9.15a	8.08a	7.75a	18.89a	18.81a
2-Methyl-butanal	1.90a	2.12a	9.28a	3.20a	1.09a	5.30a
3-Methyl-butanal	2.76a	2.31a	14.13ab	4.28a	0.93a	7.42a
Ethanol	29.39a	33.79a	23.29a	30.36a	25.98a	38.42a
Pentan-3-one	22.48ab	30.27ab	21.43ab	7.53a	19.03ab	10.33a
1-Penten-3-one	11.98abc	5.05ab	9.70abc	5.58ab	15.30cd	5.91ab
Hexanal	21.27ab	23.64ab	32.58abcd	19.43ab	66.18cd	10.80a
2-Methyl-propan-1-ol	0.85ab	0.80ab	0.94ab	0.47ab	2.13c	0.81ab
trans-2-Pentenal	4.44a	6.92a	5.88a	4.77a	15.51bc	7.53a
1-Penten-3-ol	26.14ab	17.51a	19.07a	25.87ab	26.21ab	19.80a
3-Methyl-butan-1-ol	5.03ab	8.23b	7.08ab	6.77ab	4.03ab	5.70ab
trans-2-Hexenal	528.3abcdef	59.9a	790.8cdefg	451.0abcde	211.3abc	42.8a
Pentan-1-ol	1.10abc	2.86c	0.56abc	0.91abc	2.66bc	0.55ab
cis-2-Penten-1-ol	16.42a	65.06b	12.81a	13.58a	20.96a	27.16a
Hexan-1-ol	23.36a	16.82a	16.10a	11.29a	23.18a	5.90a
cis-3-Hexen-1-ol	5.34a	95.91cd	12.54ab	10.95a	148.32d	42.70abc
trans-2-Hexen-1-ol	35.45a	10.62a	57.82ab	11.14a	11.70a	2.63a
Acetic acid	0.12a	0.29a	0.29a	0.27a	0.47a	0.33a
Octan-1-ol	0.57a	0.59a	0.57a	0.51a	0.49a	0.47a
Total alcohols	143.65a	252.20a	150.79a	111.85a	265.68a	144.14a
Total aldehydes	558.72abcd	94.85ab	852.66bcd	482.72abcd	295.02ab	73.83a
Total ketones	34.46a	35.32a	31.12a	13.12a	34.33a	16.24a
Total C_5 compounds	58.99ab	94.54ab	47.46ab	49.80ab	77.99ab	60.40ab
Total C_6 compounds	613.77ab	206.84a	909.83ab	503.85ab	460.69ab	104.81a
Total C_6 from LA	44.63a	40.45a	48.68a	30.72a	89.36a	16.70a
Total C_6 from LnA	569.14abc	166.39a	861.15abc	473.12abc	371.32abc	88.11a
Total volatiles	770.2abc	394.0ab	1044.5bc	617.5ab	619.4ab	255.8a
Total phenols[b]	104.1ab	159.3c	250.7de	160.4c	243.9de	126.3abc

Compound (mg/kg)	Mitria (4)	Pendolino (3)	Raza (3)	Regina (3)	Rossanello (3)	Trepp (2)
n-Octane	3.18ab	5.02ab	3.03ab	1.09a	2.97ab	2.80ab
Ethyl acetate	25.41a	7.81a	6.07a	6.19a	9.31a	11.46a
2-Methyl-butanal	1.19a	5.36a	2.21a	4.80a	2.65a	19.78b
3-Methyl-butanal	1.67a	5.80a	2.50a	5.37a	2.52a	22.85b
Ethanol	27.48a	20.19a	26.07a	25.13a	38.18a	33.30a
Pentan-3-one	12.12ab	25.12ab	7.43a	11.34a	6.93a	5.91a
1-Penten-3-one	8.08abc	10.29abc	9.24abc	21.71d	6.35abc	4.08a

Table 2 (*Continued*)

Compound (mg/kg)	Mitria (4)	Pendolino (3)	Raza (3)	Regina (3)	Rossanello (3)	Trepp (2)
Hexanal	18.67ab	42.29abcd	25.03abc	39.73abcd	14.63ab	20.01ab
2-Methyl-propan-1-ol	0.37ab	0.93ab	0.45ab	0.86ab	0.38ab	0.31a
trans-2-Pentenal	5.45a	5.24a	5.94a	18.63c	4.38a	6.07a
1-Penten-3-ol	45.05bc	13.48a	34.20abc	49.86c	23.95ab	25.26ab
3-Methyl-butan-1-ol	4.68ab	5.55ab	6.76ab	2.49ab	1.14a	5.20ab
trans-2-Hexenal	583.7abcdef	610.5abcdefg	826.9defg	253.7abcd	43.1a	698.1bcdefg
Pentan-1-ol	0.27a	0.27a	1.85abc	0.52ab	1.39abc	0.33a
cis-2-Penten-1-ol	24.87a	8.78a	19.55a	31.38a	17.14a	13.10a
Hexan-1-ol	17.42a	36.32a	8.81a	2.75a	2.53a	1.50a
cis-3-Hexen-1-ol	26.82ab	38.41abc	17.08ab	61.04abc	25.14ab	2.61a
trans-2-Hexen-1-ol	26.95a	132.07b	12.54a	3.94a	1.88a	8.48a
Acetic acid	0.42a	0.28a	0.31a	0.24a	0.46a	0.35a
Octan-1-ol	0.63a	2.81b	0.40a	0.62a	0.53a	0.41a
Total alcohols	174.53a	258.81a	127.71a	178.57a	112.25a	90.50a
Total aldehydes	610.73abcd	669.18abcd	862.58bcd	322.25abc	67.33a	766.86abcd
Total ketones	20.19a	35.41	16.67	33.04	13.27	9.98
Total C_5 compounds	83.43ab	37.78a	68.93ab	121.57b	51.82ab	48.52ab
Total C_6 compounds	673.60ab	859.59ab	890.37ab	361.18ab	87.32a	730.74ab
Total C_6 from LA	36.09a	78.61a	33.85a	42.48a	17.16a	21.51a
Total C_6 from LnA	637.52abc	780.98abc	856.52abc	318.70ab	70.15a	709.23abc
Total volatiles	834.5abc	976.5bc	1016.4bc	541.4ab	205.6a	882.0abc
Total phenols[b]	326.2f	245.6de	128.4bc	269.9e	142.4bc	84.1a

LA, linoleic acid. LnA, linolenic acid.
[a] Rows: values with the same letters are not statistically different at $P = 0.05$.
[b] From Tura et al. (2007).

separated by centrifugation at 2000 rpm. The oils were classed as "virgin" because the acidity value, the peroxide number, K_{232}, K_{270} and ΔK of all oils were under the limits of the Commission Regulation (EC) no. 1989/2003. Due to alternate bearing, all oil samples were not available every year.

2.2. Volatile compounds analysis

The volatile composition was determined following the extraction procedure and GC analysis described in Angerosa et al. (1997).

2.3. Sensorial analysis

The sensory evaluation was carried out by the procedures described in the enclosure XII of the Commission Regulation (EC) no. 796/2002, but modifying the sensorial profile sheet according to a parametric non-structured assessment based on many olfactory, gustatory and tactile descriptors. About 15–20 mL of oil were put in blue glasses warmed at 28–30 °C. Eight trained tasters from three different panel groups evaluated the sensory notes of all samples. Data was expressed in arbitrary units (A.U.). 'Green' notes include the following descriptors: 'lawn', 'leaf',

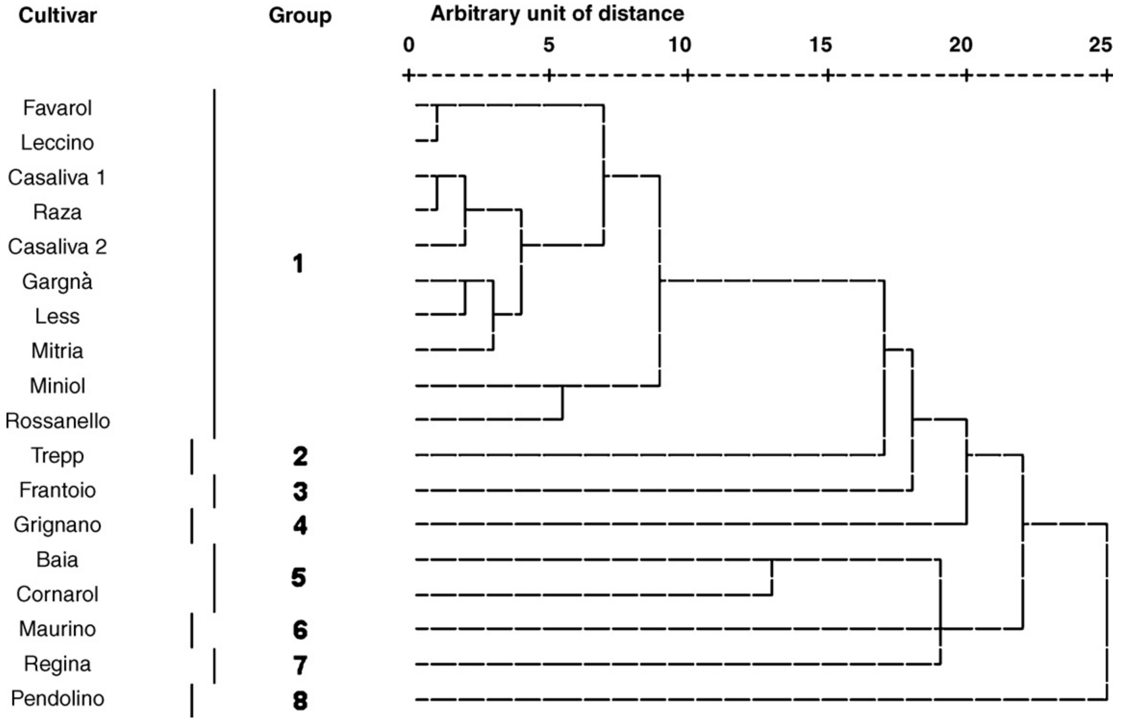

Fig. 1. Oil aromatic profiling: similarity groups dendrogram.

Table 3
Oil aromatic profiling: volatile composition of similarity groups within 18 olive cultivars (see Fig. 1)

Group	Compounds (mg/kg)															
	n-Octane	2-Methyl-butanal	3-Methyl-butanal	Ethanol	Pentan-3-one	1-Penten-3-one	Hexanal	2-methyl-Propan-1-ol	*trans*-2-Pentenal	1-Penten-3-ol	3-Methyl-butan-1-ol	*trans*-2-Hexenal	Pentan-1-ol	*cis*-2-Penten-1-ol	*cis*-3-Hexen-1-ol	*trans*-2-Hexen-1-ol	Octan-1-ol
1	2.81	3.69	5.09	27.94	15.62	8.20	26.39	0.59	5.61	28.46	6.00	601.0	0.96	19.02	19.43	31.20	0.56
2	2.80	**19.78**	**22.85**	33.30	5.91	4.08	20.01	**0.31**	6.07	25.26	5.20	698.1	0.33	13.10	2.61	8.48	0.41
3	9.38	1.58	2.31	20.32	36.92	8.27	**71.96**	0.59	7.48	35.72	**9.16**	1112.4	1.41	20.37	13.12	55.38	0.48
4	2.17	2.12	2.31	33.79	30.27	5.05	23.64	0.80	6.92	17.51	8.23	59.9	**2.86**	**65.06**	95.91	10.62	0.59
5	3.15	7.76	8.13	63.32	39.85	13.17	49.05	1.14	10.48	29.97	6.67	193.5	0.71	26.05	111.51	20.78	0.88
6	4.97	**1.09**	**0.93**	25.98	19.03	15.30	66.18	**2.13**	15.51	26.21	4.03	211.3	2.66	20.96	**148.32**	11.70	0.49
7	**1.09**	4.80	5.37	25.13	11.34	21.71	39.73	0.86	**18.63**	**49.86**	2.49	253.7	0.52	31.38	61.04	3.94	0.62
8	5.02	5.36	5.80	20.19	25.12	10.29	42.29	0.93	5.24	**13.48**	5.55	610.5	0.27	**8.78**	38.41	**132.07**	**2.81**

'artichoke', 'walnut' and 'hay'. 'Floral' notes include 'flowers' and 'butter' descriptors. 'Fruity' notes include 'olives', 'banana', 'tomato', 'almond' and 'apple' descriptors. 'Taste' notes include 'bitter', 'pungent' and 'astringency'. 'Satisfaction' is the overall hedonistic score considering all together the attributes of aroma, taste and flavor.

2.4. Statistical analysis

Normal distribution of chemical and physical variables was checked by the Kolmogorov–Smirnov test. When distribution was not normal, the standard deviation was not reported in summary tables. Outliers data, however, were not excluded in order to keep track of the peculiar composition of oils from diverse cultivar. In order to test the significance of the differences among chemical and sensory variables in relation to cultivars, data were processed by a general linear model which included it as sources of variability. Means were separated according to Duncan's multiple comparison test. The magnitude of variability in chemical oil composition and sensory notes, due to the cultivar, was quantified in terms of the expected components of the variance.

In order to group cultivars according to oil chemical composition and sensory evaluation, the four-year data was processed by cluster analysis via the square Euclidean distance and the average linkage between groups as clustering method. Results were represented with rooted dendrograms. A rooted dendrogram is a bidimensional graph representing the results of the classification of the single case into hierarchical groups. The level of each branching along the distance axe represents the distance between the groups, according to the adopted distance measure and clustering method. Data from panel test were normalized by panelist via normal score transformation: $z = (x - \mu)/\sigma$. z represents an arbitrary unit that, for our data, ranged between -1 and +1. To express sensory score with a positive scale, data were transformed according to the following linear function: $z_1 = (z + 1)^* 5$.

Relationships between the sensory attributes and the oil chemical composition were tested by simple linear regression analysis. Moreover, other multiple linear regression models based

Table 4
Oil sensorial profiling (3–4 years average): number of samples, value range, mean, standard deviation (expressed as arbitrary unites: A.U.) and expected variance component due to cultivar and its interactions

Descriptor	*N*	Range (A.U.)	Mean (A.U.)	S.D. (A.U.)	Variance (%)
Lawn	60	0.74–14.8	5.56	2.71	9
Leaf	60	2.25–9.76	5.34	2.04	12
Olives	60	0.27–11.0	5.33	2.76	42
Flowers	60	4.04–12. 9	5.30	n.r.	75
Banana	60	2.97–14.9	5.26	n.r.	82
Tomato	60	3.23–10.9	5.39	2.09	32
Almond	60	2.98–11.9	5.27	n.r.	1
Artichoke	60	2.70–12.3	5.42	n.r.	9
Apple	60	4.39–10.4	5.16	n.r.	77
Walnut	60	2.00–14. 5	5.37	n.r.	79
Hay	60	3.11–11.9	5.28	n.r.	94
Butter	60	3.71–10.8	5.19	n.r.	63
Bitter	60	0.95–16.3	5.76	2.62	13
Sweet	60	1.11–10.6	5.08	1.94	69
Pungent	60	1.27–9.5	5.22	2.10	10
Astringency	60	2.67–10.5	5.28	n.r.	0
Green notes	60	16.6–39.7	27.0	4.85	31
Floral notes	60	7.77–21.8	10.5	n.r.	81
Fruity notes	60	18.5–36.0	26.4	4.41	68
Taste notes	60	6.72–26.4	16.3	4.73	1
Satisfaction	60	0.00–24.2	10.2	6.81	4

n.r., not reported because frequency distributions were not normal according to Kolmogorov–Smirnov test ($P = 0.05$).

Table 5
Oil sensorial profiling: comparison among 18 cultivars (within brackets: number of cropping years)

Descriptor (A.U.)	Baia (3)	Casaliva 1 (4)	Casaliva 2 (4)	Cornarol (3)	Favarol (4)	Frantoio (4)
Lawn	4.77ab[a]	6.15bc	6.14bc	8.81d	4.70ab	5.51abc
Leaf	6.91d	**7.51**d	5.60abcd	5.71abcd	5.96abcd	5.85abcd
Olives	6.74ef	6.12cdef	5.93cdef	**7.02**f	5.59bcdef	6.88ef
Flowers	5.85ab	5.21ab	4.28a	4.57a	5.75ab	4.66a
Banana	**4.06**a	4.53a	5.59ab	4.94a	4.49a	5.63ab
Tomato	4.26abc	4.54abc	6.14cd	**9.08**e	7.15d	4.15abc
Almond	**3.96**a	5.41ab	5.36ab	4.88ab	4.75ab	5.47ab
Artichoke	4.59abc	4.98abc	4.21abc	7.65de	7.46de	3.60ab
Apple	7.11cd	4.57a	5.00ab	5.29ab	5.13ab	5.12ab
Walnut	6.17bcd	5.72abc	4.79ab	5.26abc	5.33abc	4.53ab
Hay	**3.82**a	6.73bc	4.31a	4.61a	5.14ab	5.00ab
Butter	4.25ab	4.64ab	4.33ab	4.65ab	4.62ab	**6.98**d
Bitter	**8.26**e	5.62bcd	5.34bcd	4.79abcd	6.10cde	5.89bcde
Sweet	4.73abc	5.09abc	5.61abcd	4.98abc	3.87a	4.44abc
Pungent	**8.48**f	6.20e	4.47abcde	5.63cde	5.32bcde	6.59ef
Astringency	**4.09**a	5.29abcd	4.83abcd	5.32abcd	6.09cde	4.98abcd
'Green' notes	26.26abc	31.09bc	25.05abc	**32.05**c	28.58abc	24.49abc
'Floral' notes	10.11abcde	9.85abcd	8.61ab	9.23abc	10.36bcdef	11.64efg
'Fruity' notes	26.13bcd	25.16abc	28.02bcde	31.21de	27.11bcde	27.25bcde
'Taste' notes	20.84a	17.11a	14.64a	15.74a	17.51a	17.45a
Satisfaction	9.09bcdef	11.95defgh	**17.30**h	15.04gh	6.30abc	7.40abcde

Descriptor (A.U.)	Gargnà (3)	Grignano (2)	Leccino (4)	Less (3)	Maurino (3)	Miniol (4)
Lawn	5.22abc	**3.16**a	3.92ab	3.17a	5.17abc	5.41abc
Leaf	5.06abcd	**3.40**a	5.58abcd	4.29abc	3.79ab	6.22bcd
Olives	6.36cdef	2.96ab	3.72abcd	3.61abc	5.99cdef	5.37bcdef
Flowers	**4.21**a	**8.18**c	5.89ab	5.64ab	4.56a	4.86a
Banana	6.98bc	6.96bc	4.96a	5.02a	7.29bc	**7.52**c
Tomato	4.76abc	4.01abc	4.67abc	4.25abc	5.87bcd	**3.51**a
Almond	6.22bc	5.16ab	5.90abc	**7.67**c	4.58ab	4.51ab
Artichoke	3.28a	3.84abc	5.20abc	4.32abc	**3.23**a	7.32de
Apple	4.83ab	**4.51**a	4.57a	6.31bc	**7.90**d	4.57a
Walnut	7.20cd	6.01bc	4.77ab	5.23abc	5.37abc	5.76abc
Hay	5.05ab	4.27a	**7.13**c	5.73abc	5.68abc	5.19abc
Butter	5.62abcd	5.95bcd	6.57cd	5.06abc	5.27abcd	4.78ab
Bitter	7.33de	**2.69**a	4.13abc	5.46bcd	5.45bcd	6.85de
Sweet	4.13ab	**7.47**d	6.64cd	4.59abc	4.84abc	5.71abcd
Pungent	4.88abcde	3.07ab	3.72abc	6.13de	3.80abcd	4.42abcde
Astringency	5.02abcd	4.32ab	4.53abc	4.74abc	6.39de	**7.11**e
'Green' notes	25.82abc	**20.69**a	26.60abc	22.74ab	23.24ab	29.90bc
'Floral' notes	9.83abcd	**14.13**h	12.46gh	10.70cdefg	9.83abcd	9.64abcd
'Fruity' notes	29.14cde	23.59ab	23.82ab	26.86bcde	**31.63**e	25.48abc
'Taste' notes	17.23a	10.09a	12.37a	16.33a	15.65a	18.38a
Satisfaction	13.40fgh	6.98abcd	7.20abcde	11.27cdefg	6.82abcd	11.97defgh

Descriptor (A.U.)	Mitria (4)	Pendolino (3)	Raza (3)	Regina (3)	Rossanello (3)	Trepp (3)
Lawn	7.42cd	3.32a	5.70bc	**9.26**d	4.83ab	5.90bc
Leaf	6.49cd	3.43a	5.04abcd	5.71abcd	3.82ab	4.13abc
Olives	5.95cdef	**1.86**a	6.47def	5.43bcdef	4.67bcdef	4.16abcde
Flowers	5.55ab	4.97a	4.25a	6.59b	5.47ab	5.42ab
Banana	4.19a	4.69a	4.44a	4.41a	5.63ab	4.61a
Tomato	4.65abc	3.92ab	6.02bcd	6.88d	7.54de	6.04bcd
Almond	5.16ab	5.88abc	3.99a	4.07a	4.45ab	6.51bc
Artichoke	5.56bcd	4.86abc	**7.74**e	5.11abc	5.91cde	7.65de
Apple	4.99ab	4.63a	5.03ab	5.49ab	4.90ab	4.55a
Walnut	**3.75**a	**8.00**d	4.48ab	4.57ab	6.32bcd	6.28bcd
Hay	5.84abc	4.41a	5.75abc	3.95a	4.51a	5.79abc
Butter	4.82abc	6.05bcd	**4.06**a	5.39abcd	4.59ab	5.94bcd
Bitter	6.02cde	3.32ab	5.15bcd	6.34cde	7.07de	6.58cde
Sweet	4.16ab	5.30abcd	6.15abcd	**3.75**a	4.89abc	6.51bcd
Pungent	5.09abcde	**2.82**a	6.30ef	6.39ef	6.45ef	5.51cde
Astringency	5.28abcd	4.10a	4.81abcd	5.84bcde	5.79bcde	5.23abcd
'Green' notes	29.06abc	24.02abc	28.72abc	28.59abc	25.40abc	29.76bc
'Floral' notes	10.37bcdef	11.02defg	**8.31**a	11.98fgh	10.06abcde	11.36cdef
'Fruity' notes	24.93abc	**20.97**a	25.94abcd	26.28bcd	27.19bcde	25.86abc
'Taste' notes	16.38a	10.24a	16.26a	18.56a	19.31a	17.32a
Satisfaction	5.24ab	**2.88**a	15.80gh	12.61efgh	10.72bcdefg	8.76bcdef

[a] Rows: values with the same letters are not statistically different at $P = 0.05$.

on the different technique (i.e. enter, stepwise forward and backward elimination method) were assayed, although without any significant result.

Data were processed by an SPSS statistical package (version 14.0 for Window-SPSS Inc., Chicago, Illinois, 2006).

Only the average data were reported, in order to highlight the cultivar patterns, independently from season influences.

3. Results

3.1. Aromatic profiling

For a better understanding of the aromatic profile of each cultivar, the total content of volatile compounds with chemical affinity or similar biosynthetic pathway was taken in account (Table 1). The total volatile compounds ranged from 62.8 mg/kg ('Rossanello' in 1998) to 2184.2 mg/kg ('Casaliva 1' in 2001). Among the major compounds, total alcohols ranged from 52.4 mg/kg to 541.3 mg/kg, including ethanol, which is a precursor of several aroma compounds; total aldehydes ranged from 2.55 to 1926.4, including 2- and 3-methyl-butal that are not originated from lipoxygenase pathway (LOX); total ketones, ranged from 3.63 to 127.2. Considering the volatiles from LOX, the total amount of C_5 and C_6 compounds from linolenic acid (LnA) oxidation ranged from 4.54 to 198.8 and from 18.3 to 1942.5, respectively; and the total amount of C_6 compounds, from linoleic acid (LA) oxidation ranged from 5.20 to 170.9.

The volatiles composition of the oil head-space for each cultivar is reported in Table 2. Differences in ethyl acetate, hexan-1-ol, acetic acid, total alcohols and ketones, and the total amount of C_6 compounds (from LOX of LA) were not significant in distinguishing among cultivars. Some cultivars showed a peculiar aromatic profile, e.g. 'Baia', high content of ethanol; 'Casaliva 1', high *trans*-2-hexenal, total aldehydes and C_6 volatiles and low ethanol; 'Cornarol', high pentan-3-one; 'Favarol', low *trans*-2-pentanal; 'Frantoio', high *n*-octane, hexanal, 3-methyl-butanal-1-ol and total volatiles; 'Grignano', high pentan-1-ol and *cis*-2-penten-1-ol; 'Maurino', low 2- and 3-methyl-butanal, and high 2-methyl-propan-1-ol and *cis*-3-hexen-1-ol; 'Miniol', low hexanal and *trans*-2-hexenal; 'Mitria', high total phenols; 'Pendolino', low 1-penten-3-ol, *cis*-2-penten-1-ol and total C_5 compounds, and high *trans*-2-hexen-1-ol and octan-1-ol; 'Raza', low octan-1-ol; 'Regina', low *n*-octane, and high 1-penten-3-one, *trans*-2-pentenal, 1-penten-3-ol and total C_5 compounds; 'Rossanello', low 3-methyl-butan-1-ol, *trans*-2-hexen-1-ol, total aldehydes, total C_6 compounds and total volatiles; 'Trepp', high 2 and 3-methyl-butanal, and low pentan-3-one, 1-penten-3-one, 2-methyl-propan-1-ol, *cis*-3-hexen-1-ol and total phenols.

According to unique aromatic profile eight affinity groups were built (Fig. 1, Table 3). Group 1 featured by a medium aromatic

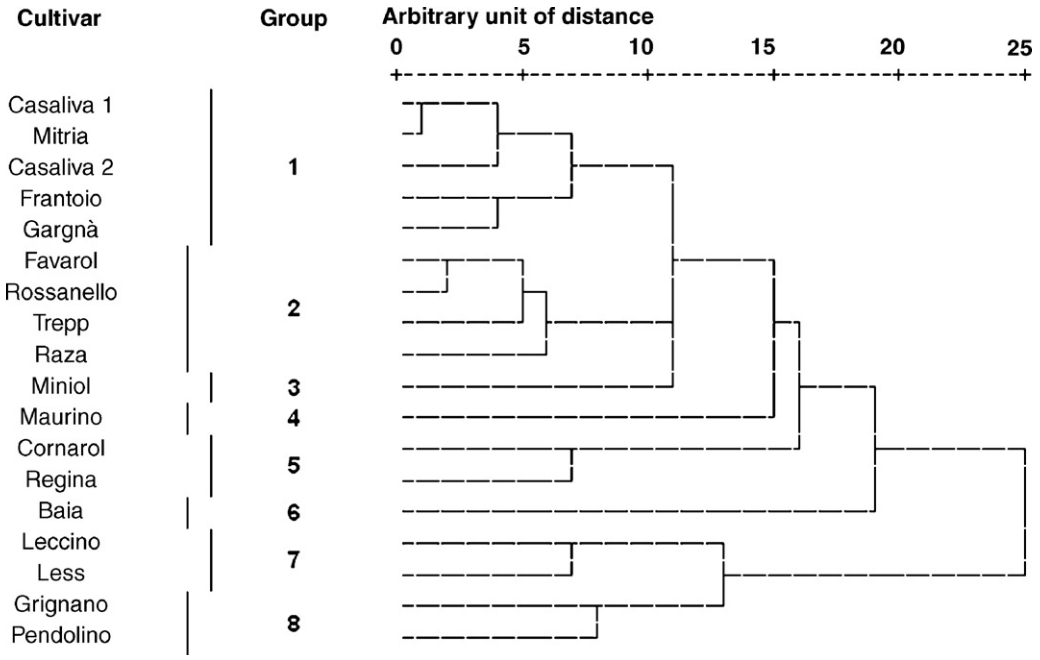

Fig. 2. Oil sensorial profiling: similarity groups dendrogram.

Table 6
Oil sensorial profiling: sensory notes of similarity groups within 18 olive cultivars (see Fig. 2)

Group	Descriptor (A.U.)															
	Lawn	Leaf	Olives	Flowers	Banana	Tomato	Almond	Artichoke	Apple	Walnut	Hay	Butter	Bitter	Sweet	Pungent	Astringency
1	6.09	6.10	6.25	4.78	5.38	4.85	5.52	4.33	4.90	5.20	5.39	5.28	6.04	4.69	5.44	5.08
2	5.28	4.74	5.22	5.22	4.79	6.69	4.92	7.19	4.90	5.60	5.30	4.80	6.23	5.36	5.90	5.48
3	5.41	6.22	5.37	4.86	**7.52**	**3.51**	4.51	7.32	4.57	5.76	5.19	4.78	6.85	5.71	4.42	**7.11**
4	5.17	3.79	5.99	4.56	7.29	5.87	4.58	**3.23**	**7.90**	5.37	5.68	5.27	5.45	4.84	3.80	6.39
5	**9.03**	5.71	6.22	5.58	4.68	**7.98**	4.47	6.38	5.39	**4.91**	4.28	5.02	5.56	**4.36**	6.01	5.58
6	4.77	6.91	6.74	5.85	**4.06**	4.26	**3.96**	4.59	7.11	6.17	**3.82**	4.25	**8.26**	4.73	**8.48**	**4.09**
7	3.54	4.94	3.67	5.76	4.99	4.46	**6.79**	4.76	5.44	5.00	**6.43**	5.82	4.80	5.62	4.92	4.63
8	**3.24**	**3.41**	**2.41**	**6.57**	5.83	3.96	5.52	4.35	4.57	**7.01**	4.34	**6.00**	**3.01**	**6.39**	**2.95**	4.21

composition ('Favarol', 'Leccino', 'Casaliva 1', 'Raza', 'Casaliva 2', 'Gargnà', 'Less', 'Mitria', 'Miniol' and 'Rossanello') and group 5 by a high content of ethanol and pentan-3-one ('Baia' and 'Cornarol'). The following cultivars showed a unique profile: 'Trepp', 'Frantoio', 'Grignano', 'Maurino', 'Regina' and 'Pendolino'.

3.2. Sensorial profiling

The sensorial traits of the oils are shown in Table 4. 'Green' notes ranged from 16.6 A.U. to 39.7 A.U.; 'floral' notes from 7.77 to 21.8; 'fruity' notes, from 18.5 to 36.0; 'taste' notes, from 6.72 to 26.4; 'satisfaction', from 0 ('Maurino' in 1999) to 24.2 ('Casaliva 2' in 2000).

The monovarietal oils were discriminated by their sensorial traits, except for the 'taste' notes (Table 5). 'Baia' showed low notes of 'banana', 'almond', 'hay' and 'astringency', and high of 'bitter' and 'pungent'; 'Casaliva 1', low in 'leaf'; 'Casaliva 2', the highest for 'satisfaction'; 'Cornarol', high in 'olives', 'tomato' and 'green' notes; 'Frantoio', high in 'butter'; 'Gargnà', low in 'flowers'; 'Grignano', low in 'lawn', 'leaf', 'apple', 'bitter' and 'green' notes, and high in 'flowers', 'sweet' and 'floral' notes; 'Leccino', high in 'hay'; 'Less', high in 'almond'; 'Maurino', low in 'artichoke', and high in 'apple' and 'fruity' notes; 'Miniol', high in 'banana' and 'astringency', and low in 'tomato'; 'Mitria', low in 'walnut'; 'Pendolino', low in 'olives', 'pungent', 'fruity' notes and 'satisfaction', and high in 'walnut'; 'Raza', high in 'artichoke', and low in 'butter' and 'floral' notes; 'Regina', high in 'lawn' and low in 'sweet'.

When grouping cultivars according to their sensorial profile, eight affinity groups with a characteristic sensorial profile were distinguished (Fig. 2, Table 6). Group 1 showing a low-medium content of sensory notes ('Casaliva 1', 'Mitria', 'Casaliva 2', 'Frantoio' and 'Gargnà'); group 2, with a high-medium sensorial profile ('Favarol, 'Rossanello', 'Trepp' and 'Raza'); group 5, with high notes of 'lawn' and 'tomato', and low in 'walnut' and 'sweet' ('Cornarol' and 'Regina'); group 7, with high notes of 'almond' and 'hay' ('Leccino' and 'Less'); group 8, with low notes of 'lawn', 'leaf', 'olives', 'bitter', 'pungent', and high in 'flowers', 'walnut', 'butter' and 'sweet' ('Grignano' and 'Pendolino'). 'Miniol', Maurino' and 'Baia' were not grouped due to their peculiar profiles.

4. Discussion

The range of aromatic and sensorial attributes of the oils from the 18 assessed cultivars was in accordance with whose reported in the available literature (Dhifi et al., 2005; Luna et al., 2006; Berlioz et al., 2006; Haddada et al., 2007; Pedò et al., 2002, 2003). The variability of volatile compounds and sensory notes varied largely as a consequence of cultivar, year and their interactions, as already shown in previous works (Tura et al., in press, 2005). It was pointed out that olives ripening under higher heat courses produced oils containing more volatiles and phenols than the ones made from olives with similar maturity index. The variability of the following parameters depends mainly on cultivar: ethanol, 2-methyl-propan-1-ol, pentan-1-ol, *cis*-2-penten-1-ol, *cis*-3-hexen-1-ol and octan-1-ol, for the chemical compounds; 'flowers', 'banana', 'apple', 'walnut', 'hay', 'butter', 'sweet', 'floral' and 'fruity' notes for the sensorial attributes.

4.1. Cultivar characteristics

Some oils from local cultivars showed a peculiar aromatic and sensorial profile. 'Casaliva 1' has a flavor of 'leaf' for its high content of *trans*-2-hexenal, total aldehydes and many C_6 compounds. 'Cornarol' features flavor of 'olives', 'tomato' and 'green' notes for high pentan-3-one content. 'Grignano' has a mild flavor for its 'flowers', 'sweet' and 'floral' notes, and high content of pentan-1-ol and *cis*-2-penten-1-ol. 'Maurino' has flavor of 'apple' and 'fruity' notes probably due to a high content of 2-methyl-propan-1-ol and *cis*-3-hexen-1-ol. 'Pendolino' has flavor of 'walnut' most likely explained by a high content of *trans*-2-hexen-1-ol. 'Regina' has flavor of 'lawn' probably for its high content of pentan-3-one, *trans*-2-pentenal, 1-penten-3-ol and C_5 compounds.

4.2. Cultivar similarity

It is important to note that some cultivars, with a similar aromatic content, showed also an analogous sensorial profile. 'Favarol', 'Casaliva 1', 'Raza', 'Casaliva 2', 'Gargnà', 'Mitria', 'Miniol', and 'Rossanello' resulted in the same aromatic group, characterized by an average volatiles content, and in three close affinity groups (1–3), with a middle sensorial profile. Moreover, 'Maurino' was always isolated, showing peculiar profiles. Some of these similarities between volatiles and sensory notes confirmed previous findings (Pedò et al., 2002; Tura et al., 2002), supplying them with further details.

4.3. Aromatic compounds and sensory notes correlations

After assessing the chemical and sensorial characteristics of monovarietal olive oil and their similarity, some considerations can be drawn about correlations between volatile compounds and sensorial attributes (Table 7). The 'green' notes of 'lawn' and 'leaf' were correlated with hexanal, *trans*-2-pentanal, 1-penten-3-ol and total phenols; the 'fruity' notes of 'olives', 'banana', 'almond' and

Table 7
Linear correlations among oils sensory notes (descriptors) and aromatic chemical compounds

Descriptor	Compound	*r*	sig.
Lawn	Hexanal	0.27	0.04
	trans-2-Pentenal	0.39	0.00
	1-Penten-3-ol	0.43	0.00
Olives	Ethyl acetate	0.26	0.05
	trans-2-Pentenal	0.27	0.04
	1-Penten-3-ol	0.37	0.00
Banana	Pentan-1-ol	0.25	0.06
	cis-2-Penten-1-ol	0.42	0.00
	cis-3-Hexen-1-ol	0.26	0.05
Almond	Pentan-3-one	0.28	0.03
	trans-2-Hexen-1-ol	0.33	0.01
	Octan-1-ol	0.25	0.06
Apple	2-Methyl-propan-1-ol	0.42	0.00
	cis-3-Hexen-1-ol	0.36	0.01
	Ethanol	0.34	0.01
Leaf	1-Penten-3-ol	0.30	0.02
	Total phenols	0.28	0.03
Butter	3-Methyl-butan-1-ol	0.27	0.04
	n-Octane	0.29	0.03
Sweet	2-Methyl-butanal	0.34	0.01
	3-Methyl-butanal	0.37	0.00
	Pentan-3-one	0.31	0.02
	Pentan-1-ol	0.25	0.06
	cis-2-Penten-1-ol	0.36	0.01
Pungent	Ethyl acetate	0.30	0.02
	Ethanol	0.33	0.01
	1-Penten-3-ol	0.38	0.00
	Pentan-1-ol	0.25	0.05
Astringency	Ethyl acetate	0.52	0.00
Satisfaction	1-Penten-3-ol	0.32	0.01

Table 8
Relationships among sensory notes and aromatic chemical compounds in olive oils found by several authors (Burdock, 2002; Kalua et al., 2007; Angerosa et al., 2004)

Descriptor	Chemical compound
Green notes	2-Methyl propan-1-ol; *cis*-2-penten-1-ol; 2-hexen-1-ol; 3-hexen-1-ol 2-Pentenal; hexanal; 2-hexenal; 3-hexenal; *trans*-2-octenal Pentan-3-one; 4-methyl-pentan-2-one; nonan-2-one Methyl acetate; buthyl acetate; hexyl acetate; 3-hexenyl acetate; ethyl propionate; methyl decanoate 1-Octene; ethyl furano
Olive fruity	Pentan-1-ol; 4-methyl-1-penten-3-ol; hexan-1-ol 3-methyl-butanal; 2-methyl-2-butenal; *cis*-2-pentenal; *cis*-2-hexenal; *trans*-3-hexenal; 2,4-hexadienal Butan-2-one; eptan-2-one; 6-methyl-5-epten-2-one; octan-2-one; nonan-2-one 3-Methyl-butyl acetate; hexyl acetate; 3-hexenyl acetate; 2-methyl-buthyl propionate; ethyl-methyl butirrate; 3,4-dimethyl-3-pentenyl furano; ethyl cyclohexanoate; methyl benzene; ethyl benzene
Apple	*trans*-2-Pentenal; hexanal; 3-hexenal Butan-2-one; nonan-2-one; ethyl propinate; 2-methyl-buthyl propionate
Flowers	*trans*-3-Hexenal
Artichoke	*trans*-3-Hexenal
Almond	2-Hexenal
Hay	2-Methyl-4-pentenal
Banana	*cis*-2-Penten-1-ol; *cis*-3-hexen-1-ol; 3-methyl-buthyl acetate; 3-hexenyl acetate
Sweet	4-Methyl-1-penten-3-ol; 3-methyl-butanal; hexanal Pentan-3-one; 1-penten-3-one; 4-methyl-pentan-2-one; nonan-2-one Ethyl acetate; buthyl acetate; hexyl acetate; ethyl propinate; ethyl furano
Bitter	2-Methyl-3-buten-1-ol; *trans*-3-hexen-1-ol; 2-methyl-4-pentenal; 2-hexenal 6-Methyl-5-hepten-2-one; 3-methyl-buthyl acetate; 2-methyl-buthyl propionate; methyl decanoate Dodecene; tridecene; ethyl benzene; phenols
Pungent	Pentan-1-ol; 2-methyl-4-pentenal; buthyl acetate; phenols

'apple' were correlated with ethyl acetate, *trans*-2-pentenal, 1-penten-3-ol, pentanol-1-ol, *cis*-2-penten-1-ol, *cis*-3-hexen-1-ol, pentan-3-one, *trans*-2-hexen-1-ol, octan-1-ol, 2-methyl-propan-1-ol and ethanol; the 'taste' notes of 'pungent' and 'astringency' were correlated with ethyl acetate, ethanol, 1-penten-3-ol and pentan-1-ol. Some of these correlations confirm previous results (Tura et al., 2002): 'lawn' correlated with 1-penten-3-ol, 'banana' with *cis*-2-penten-1-ol, 'apple' with *cis*-3-hexen-1-ol and ethanol, and 'butter' with *n*-octane. In this way, many correspondences were found between sensory notes and chemical compounds, most of them in agreement with the literature: Burdock (2002), Kalua et al. (2007), Angerosa et al. (2004) and Morales et al. (2005)

Table 9
Relationships among aromatic chemical compounds and sensory notes with odor and taste thresholds found by several authors (Burdock, 2002; Kalua et al., 2007; Morales et al., 2005)

Chemical compound	Sensory descriptor	Odor/taste thresholds (mg/kg)
Alcohols		
Ethanol	Alcohol, apple, sweet, winey	30/n.f.
2-Methyl-propan-1-ol	Green	–
3-Methyl-butan-1-ol	Sweet, undesirable, whiskey, woody, yeast	0.1/n.f.
Pentan-1-ol	Balsamic, fruity, pungent, ripe fruit, sticky, strong	0.47–3/n.f.
1-Penten-3-ol	Butter, fruity, green, hay, lawn, soft green, undesirable, wet earth	0.4/15
cis-2-Penten-1-ol	Almond, banana, fruity, grass, green	0.25/n.f.
Hexan-1-ol	Banana, fruity, soft, tomato, undesirable[a]	0.4/n.f.
trans-2-Hexen-1-ol	Apple, flowers, fruity, grass, green, leaves, sweet, undesirable[a]	5–8/30
cis-3-Hexen-1-ol	Apple, banana, fresh, grass, green, leaf	0.070–1.1–6/30
Octan-1-ol	Green, fusty, musty, sweet, waxy	0.042–0.480/2
Aldehydes		
2-Methyl-butanal	Apple, malty, pungent	0.0052/n.f.
3-Methyl-butanal	Apple, fruity, malty, ripe fruit, sweet	0.0054/n.f.
trans-2-Pentenal	Almond, apple, bitter, fruity, green, ripe fruit, soft fruit	0.0015–0.3/20
Hexanal	Apple, banana, grass, green, green fruit, sweet	0.004–0.02–0.08–0.4/n.f.
trans-2-Hexenal	Almond, apple, astringent, bitter, fruity, green, lawn, leaf, sweet	0.030–0.42–1.125/10
Ketones		
Pentan-3-one	Fruity, green, sweet	70/n.f.
1-Penten-3-one	Bitter, green, mustard, pungent, strawberry, sweet, tomato	0.001–0.013–0.050/n.f.
Others		
Ethyl acetate	Aromatic, bitter, fruity, pleasant, pungent, sticky, sweet, undesirable	0.005–0.94–5/100
n-Octane	Butter, sweet	0.94/n.f.
Acetic acid	Pungent, sour, strong, vinegary	0.124–0.5–10–60–522/n.f.
Phenols	Astringency, bitter, pungent, strong, sweet, walnut husk	5.5/n.f.

n.f., threshold not found.
[a] An high concentration of chemical compound gives an undesirable sensory note.

(Tables 8 and 9). Most of the volatile and phenolic compounds showed an average content higher than odor and taste thresholds, explaining the correlations to sensory attributes. Other volatile compounds, correlated to sensory attributes, showed concentrations different from odor and taste thresholds: pentan-3-one had a content lower than odor threshold; *trans*-2-pentanal, ethyl acetate and octan-1-ol showed a concentration higher than odor, but smaller than taste threshold; pentan-1-ol concentration was both higher and smaller than two odor thresholds found in literature; no thresholds were found for 2-methyl-propan-1-ol odor and/or taste. These volatiles were correlated to the sensory notes even if their concentration was smaller than a given thresholds, this could be due to: a synergic effect with other compounds for that specific sensory note; the odor threshold is possibly more effective than that taste; furthermore, it could be that only in few oils the content was over the thresholds, but the correlation was so strong that was general attributed to all samples.

5. Conclusions

The study carried for 4 years on 18 olive local cultivars grown in the same orchards has shown that the aromatic quality of virgin olive oil depends on the cultivar (genetic factor), this has been found particularly for some volatile compounds (ethanol, 2-methyl-propan-1-ol, pentan-1-ol, *cis*-2-penten-1-ol, *cis*-3-hexen-1-ol and octan-1-ol) and sensory attributes ('flowers', 'banana', 'apple', 'walnut', 'hay', 'butter', 'sweet', 'floral' and 'fruity' notes).

The oils from 'Casaliva 1', 'Casaliva 2' and 'Raza' showed a similar aromatic profile, in addition to genetic and chemometric similarity (Bassi et al., 2002). Furthermore, this research has characterized some monovarietal oils from local and minor, underutilized cultivars with a peculiar flavor profile, e.g. 'Casaliva 1', 'Cornarol', 'Grignano', 'Regina' and 'Trepp'. In particular, 'Regina' besides very good oil attributes (Tura et al., 2007), showed some positive horticultural traits (Bassi et al., 2003), although being scarcely cultivated.

Dissecting olive oil quality parameters could be a powerful tool in order to improve our understanding of oil quality, particularly in local and underutilized minor cultivars. They could thus be employed in the new orchards in order to take advantage of their positive horticultural and oil quality traits. This could be particularly crucial for the PDO oils, where the mere geographical origin could not be enough in improving olive oil characterization and consumption, especially if sensorial and/or nutritional attributes are not differentiated within a standard commercial commodity.

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