Research Article

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Sensory analysis and consumer acceptance of 140 high-quality extra virgin olive oils

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Abstract

BACKGROUND: Sensory analysis is a crucial tool for evaluating the quality of extra virgin olive oils. One aim of such an investigation is to verify if the sensory attributes themselves – which are strictly related to volatile and phenolic compounds – may permit the discrimination of high-quality products obtained by olives of different cultivars and/or grown in various regions. Moreover, a crucial topic is to investigate the interdependency between relevant parameters determining consumer acceptance and objective sensory characteristics evaluated by the panel test.

RESULTS: By statistically analysing the sensory results, a grouping – but not discriminatory – effect was shown for some cultivars and some producing areas. The preference map shows that the most appreciated samples by consumers were situated in the direction of the 'ripe fruity' and 'sweet' axis and opposite to the 'bitter' and 'other attributes' (pungent, green fruity, freshly cut grass, green tomato, harmony, persistency) axis.

CONCLUSION: Extra virgin olive oils produced from olives of the same cultivars and grown in the same areas shared similar sensorial attributes. Some differences in terms of expectation and interpretation of sensory characteristics of extra virgin olive oils might be present for consumers and panellists: most of the consumers appear unfamiliar with positive sensorial attributes, such as bitterness and pungency.

Supporting information may be found in the online version of this article.

Keywords: extra virgin olive oil; descriptive sensory analysis; consumer acceptance; aroma description; harmony evaluation

INTRODUCTION

Sensory analysis of virgin olive oil

In combination with chemical parameters, sensory analysis performed according to the official method reported in Regulation (EC) 640/2008[1] is an important tool for classifying the oils obtained from olives of different quality and commercial categories (extra virgin, virgin, lampante). This official methodology has been established as a result of international cooperative studies, supported by the International Olive Council (IOC), which has provided a sensory codified methodology for extra virgin olive oils (EVOOs), known as the IOC Panel Test.[2] Such an official sensory evaluation takes into account three attributes, which are characteristic (positive) for oils obtained from olives (1. fruity, perceived ortho- and retronasally being either 'more green' or 'more ripe'; 2. bitter; and 3. pungent) and five main defects (rancid, fusty–muddy sediment, metallic, musty, winey), extended with a list of additional ones. Actually, it can be enhanced by the use of a more detailed profile sheet, which considers additional positive attributes compared to the official ones,[1] in particular through the evaluation of the presence and the intensity of aromatic components (representing the diversity of the 'more green' and 'more ripe' fruity notes) as well as the evaluation of harmony and persistency (representing the complexity and the equilibrium within the positive characteristics of an oil). Such a complete and extended objective profiling has already been cross-validated by the German and the Swiss Olive Oil Panel (SOP).[3] The method allows a sensory differentiation of EVOOs of high quality compared to standard-level products, permitting the identification of quality differences within the range of EVOOs.[3] In a recent publication, Delgado and Guinard[4] proposed an innovative methodology – internal and external quality mapping – which is useful for investigating the sensorial attributes that contriubute to the quality perceived by experts. Experts showed homogeneity in their general concept of quality in EVOOs, ranking highly those EVOOs that were not defective and had the characteristics of fruitiness, bitterness and pungency.

Chemical compounds, sensory attributes and consumer acceptance of extra virgin olive oils

As is well known, aromatic notes of EVOOs are strictly linked to many volatile compounds, which are perceptible if their

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concentration in the aromatic fraction exceeds the odour threshold.[5] Several factors can influence the composition of the volatile fraction of EVOO, such as genetic, agronomic, pedoclimatic, processing and storage variables.[5–7] Different studies show that it is possible to discriminate oils according to the growing region and the cultivar of the olives, on the basis of the qualitative and quantitative composition of the volatile profile.[8,9] Some previous studies regarding discrimination of EVOOs from different cultivars have been carried out by the use of sensory analysis in addition to chemical approaches.[10–13] Concerning the attributes perceived during the tasting phase of EVOOs, the bitter taste (primary taste of oil obtained from green olives or olives turning colour) has been related to the phenolic compounds, especially oleuropein aglycone and ligstroside aglycone derivatives[14–16] whereas the presence of the dialdehydic form of decarboxymethyl elenolic acid linked to tyrosol (oleocanthal) has been linked to the pungency of the EVOOs (biting tactile sensations characteristic of oils produced at the start of the crop year, primarily from olives that are still unripe).[17] Literature shows that it is also possible to discriminate oils produced from olive fruits of different cultivar and geographical origin, according to the phenolic composition.[18,19] Although several authors pointed out that phenolic compounds of EVOOs can play an important role in human health, due to their antioxidant, anti-carcinogenic and anti-inflammatory properties,[16] it is well known that the rejection of bitterness and pungency is a natural reaction for consumers, since poisonous or toxic substances tend to be bitter and pungent: this was confirmed recently by similar results found for American consumers.[20] This means that by research dissemination, great efforts can be made in order to enable consumers to appreciate bitterness and pungency as health-related substances: for example, Peyrot de Gaschos *et al.*[21] reported that high-quality EVOOs can be referred to as 'one cough' or 'two cough' oils (the latter being more highly prized), because of the peculiar pungency. Being successful in such a dissemination will not be easy, since some authors reported that consumers consider health benefits and flavour (including its use to enhance the taste of recipes) as the main motivators for their food consumption but nevertheless still second in importance behind packaging, price and size,[22,23] both in emerging and traditionally located markets. Some researchers suggested that people can transform an inherently unpleasant sensation into a positive one because it has beneficial health effects.[21] Moreover, Caporale *et al.*[24] reported that giving information to consumers about the origin of the product can lead to a positive expectation regarding specific attributes such as bitter and pungent.

Aims of the investigation

Since the phenolic and the volatile profiles of olive oils depend above all on the geographical origin and on the cultivar of olives,[5,16] one aim of this investigation was to also verify whether the sensory attributes themselves – which are strictly related to volatile and phenolic compounds – may permit discriminating EVOOs obtained from olives of different cultivar and/or grown in different regions; moreover, correlations among sensory attributes were investigated. Actually, a second goal was to investigate the overall liking of consumers who are unfamiliar with bitterness and pungency, for EVOOs that actually were all judged as 'medium–high' for the intensities of these descriptors by the trained panel: in particular, it was interesting to check if the overall liking can be correlated with the harmony or to other sensory attributes evaluated by the trained panel, in order to understand which type of EVOO is preferred by consumers. Another aim of this work was to evaluate if mono-cultivar EVOOs can be considered of 'higher quality' or can be discriminated from the blends made from more than one cultivar, considering the sensory attributes, the overall liking and the harmony value. The same effect of discrimination was tested also for Denomination of Origin (PDO) EVOOs versus EVOOs without PDO certification on the one hand and organic EVOOs versus conventional ones on the other.

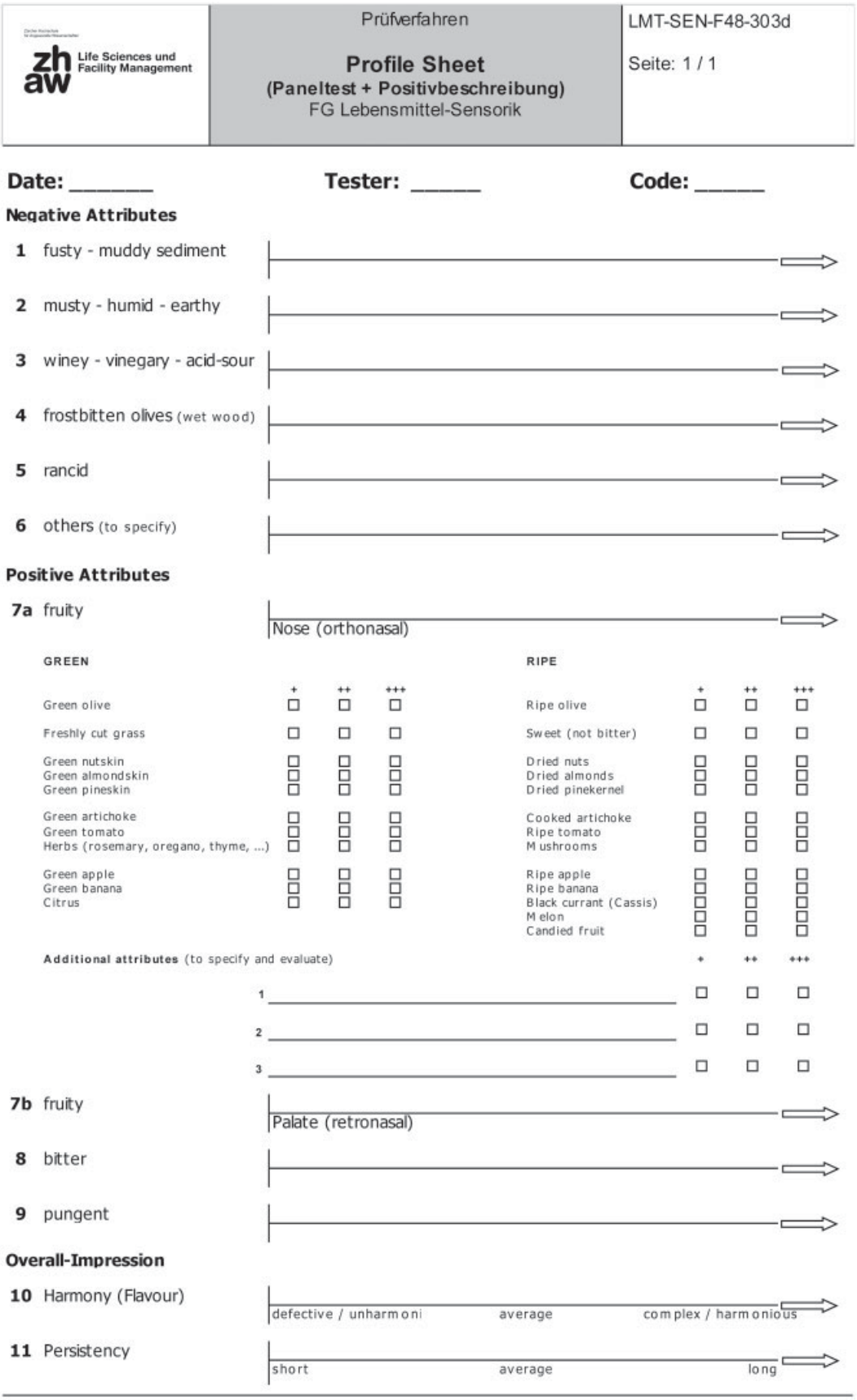
EXPERIMENTAL

Samples

This investigation focused on 140 EVOO samples, all participating in the IOOA (International Olive Oil Award – Zurich), a competition born in 2002 that involves many of the EVOOs on the Swiss market as well as many samples coming directly from producing countries. In particular, the samples came from five different producing countries: Italy (74 oils, of which 52 came from Sicily), Spain (43 oils, of which 24 came from Andalusia), Greece (15), Portugal (5) and Turkey (3). The samples were collected from four different harvests/crop years (2007–2010), so 35 samples were analysed per year (Table S1, in the supporting information). All oils were evaluated as 'extra virgin' quality (without defects) by the SOP. Among the samples, 55 oils were characterised by a PDO, 87 were mono-cultivar EVOOs, which means that they were obtained by only one cultivar of olives (22 different cultivars), 37 were produced by organic farming systems (Table S1, in the supporting information). Before the sensory analysis, all EVOOs were stored in bottles under dark conditions, protecting them from light and kept under thermostatted conditions at $12 \pm 1^{\circ}C$.

Sensory evaluation by the Swiss Olive Oil Panel

The sensory analysis was carried out by the SOP of ZHAW (Zurich University of Applied Sciences, Department of Life Sciences and Facility Management, Sensory Science Group), from 2007 to 2010. The SOP, recognised by the IOC (International Olive Council) and accredited according to EN/ISO/IEC 17025,[25] consists of 36 regularly trained panellists at present. The evaluation of the samples was performed according to the rules established by Regulation (EC) 640/2008[1] and followed the extended profile sheet reported and validated in the previous paper.[3] For the correct evaluation of the aroma description as well as the evaluation of the 'harmony' and 'persistency', special training lectures have been held in order to teach panellists to recognise the relevant aspects. In particular 'harmony' is defined by the degree of complexity given through a variety of aromatic components combined with a more or less balanced appearance; 'persistency' represents the lasting and strength of 'harmony' after spitting the oil sample. Samples intended for tasting were kept in the standardised tasting glasses at $28^{\circ}C \pm 2^{\circ}C$ throughout the test, as reported in IOC/T.20/Doc.No15/Rev.4/2011. The tests were conducted in the sensory laboratory of the Institute of Food and Beverage Innovation at the Department of Life Sciences and Facility Management in Wädenswil, Switzerland, at room temperature ($20^{\circ}C \pm 2^{\circ}C$) and $60\% \pm 5\%$ relative air humidity. The profile sheet followed by the trained panellists is reported in Fig. 1. First of all, each assessor has to evaluate the presence and the intensity of the standard defects of the oils (rancid, fusty–muddy sediment,



Life Sciences und Facility Management

Prüfverfahren

Profile Sheet
(Paneltest + Positivbeschreibung)
FG Lebensmittel-Sensorik

LMT-SEN-F48-303d

Seite: 1 / 1

Date: _____ **Tester:** _____ **Code:** _____

Negative Attributes

1 fusty - muddy sediment

2 musty - humid - earthy

3 winey - vinegary - acid-sour

4 frostbitten olives (wet wood)

5 rancid

6 others (to specify)

Positive Attributes

7a fruity

Nose (orthonasal)

GREEN	+	++	+++	RIPE	+	++	+++
Green olive	☐	☐	☐	Ripe olive	☐	☐	☐
Freshly cut grass	☐	☐	☐	Sweet (not bitter)	☐	☐	☐
Green nutskin	☐	☐	☐	Dried nuts	☐	☐	☐
Green almondskin	☐	☐	☐	Dried almonds	☐	☐	☐
Green pineskin	☐	☐	☐	Dried pinekernel	☐	☐	☐
Green artichoke	☐	☐	☐	Cooked artichoke	☐	☐	☐
Green tomato	☐	☐	☐	Ripe tomato	☐	☐	☐
Herbs (rosemary, oregano, thyme, ...)	☐	☐	☐	Mushrooms	☐	☐	☐
Green apple	☐	☐	☐	Ripe apple	☐	☐	☐
Green banana	☐	☐	☐	Ripe banana	☐	☐	☐
Citrus	☐	☐	☐	Black currant (Cassis)	☐	☐	☐
				Melon	☐	☐	☐
				Candied fruit	☐	☐	☐

Additional attributes (to specify and evaluate) + ++ +++

1 _____ ☐ ☐ ☐

2 _____ ☐ ☐ ☐

3 _____ ☐ ☐ ☐

7b fruity

Palate (retronasal)

8 bitter

9 pungent

Overall-Impression

10 Harmony (Flavour)

defective / unharmoni — average — complex / harmonious

11 Persistency

short — average — long

Figure 1. Profile sheet used for the objective evaluation by the Swiss Olive Oil Panel.

metallic, musty, winey, other defects), the fruitiness, the bitterness and the pungency, using the well-known 10 cm scales.[1] Also 17 aromatic descriptors (ortho- and retronasally perceived) were evaluated by the SOP as either green fruity (e.g. freshly cut grass, green nut-skin/-shell, green almond-skin/-shell, green pine-skin/-shell, green artichoke, green tomato, herbs, green apple, green banana) or ripe fruity (e.g. dried nut kernel, dried almond kernel, ripe tomato, ripe apple, ripe banana and cassis). The gustatory descriptor sweet was also evaluated, meaning the absence of bitterness. A definition of most of the attributes used is reported in IOC T20 Doc. 22/ 2005,[26] in IOC T20 Doc.15/Rev.2/ 2007[27] and in the sensory wheel described by Aparicio and Morales.[28] A four-point scale was used to measure the intensity of each aromatic component and sweet as well, from 0 to 3: 0 (zero) means that a component is 'not detectable'; 1 (one) means that it is 'slightly detectable'; 2 (two) stands for a 'noticeable' sensation; and, finally, 3 (three) describes an 'intense' sensation.[3] Panellists were also asked to evaluate two other objective sensory descriptors for each EVOO, namely harmony and persistency, on 10 cm bipolar scales.[3] In order to assure valid results for harmony and persistency, at least six single panellist results are necessary for the statistical evaluation.[3] For considering results as valid and acceptable, related to the intensities evaluated by the panellists on the specific (bipolar) 10 cm scales for harmony and persistency (Fig. 1), their robust coefficient of variation (CVr) has to be below 10%. Also for the other attributes evaluated on 10 cm scales (standard defects of the oils, fruitiness, bitterness and pungency), the robust coefficient of variation (CVr) has to be below 10%. Regarding the profiling of aromatic attributes, at least 33% of tasters have to recognise the same descriptor (e.g. green apple, banana or fresh almonds) in order to include it as part of the sensory description of the oil. For the intensity of these selected attributes, the median values of each attribute were taken into account.

The 'OLIO', a consumer test at the trade fair 'Gourmesse' (Zurich)

The 140 samples of this study were evaluated in four different consumer tests sessions over four consecutive years, on the occasion of the Gourmesse, a famous trade fair in Zurich. Each year, 35 different oils were tested for acceptance by 68 consumers each. So, over the four consecutive years, all 140 considered oils took part in the 'incomplete block' design of our consumer test. Consumers were not selected for specific target group criteria in advance, since everyone who visits the trade fair Gourmesse is allowed to participate in the consumer test. However, visitors to Gourmesse are 'a priori' food interested consumers and gourmets, so interesting criteria as there are – olive oil consumption, food quality interest, etc. – were supposed as given. During the test, some information from consumers was collected, so it was possible to characterise certain consumer insights and demographic aspects in retrospect. Consumers were distributed into 51% male and 49% female participants. The ages of all consumers involved during the 4 years covered a wide range: 5–10 years (0.4%), 11–20 years (6.2%), 21–30 years (20.9%), 31–40 years (22.2%), 41–50 years (21.0%), 51–60 years (18.0%), 61–70 years (8.7%), and 71–80 years (2.6%). Most of the consumers were Swiss (79.9%), followed by German (10.3%) and Italian (3.0%); the remaining (6.8%) came from other countries (mostly USA and Australia). Samples were served in small plastic cups to consumers. Bread was offered for neutralisation. Each consumer was asked to evaluate a maximum of six samples. A nine-point hedonic scale was used for evaluating the overall liking of each oil (1 = do not like at all, 9 = like very much).

Statistical analysis

Analysis of variance (ANOVA), correlation matrix (Pearson's correlation, $P < 0.05$), principal component analysis (PCA) and preference mapping were performed for the results related to both objective sensory analysis (considering only some selected attributes, as reported in the 'Results and discussion' section) and overall liking (coming from consumer tests), by means of the statistical software XLSTAT 2011 (Addinsoft, New York, NY, USA).

RESULTS AND DISCUSSION

Calculation and evaluation of harmony and persistency

No defects were found for all 140 selected samples, according to evaluation by the European Official Sensory Panel Test.[1] All samples were characterised by a high level of harmony (above 5.2) and persistency (above 5.8), reflecting a strong degree of balance of all positive characteristics of these EVOOs, either from an aromatic, a tactile and a kinaesthetic point of view as well as concerning their long length in the 'after-taste' phase As reported in a previous study,[3] the harmony and persistency attributes were combined, calculating a new weighted attribute (called 'H & P'), counting the harmony twice and persistency once, as validated by Bongartz and Oberg[3]. Considering the 'H & P' values of the 140 examined EVOOs, 130 were within the harmony category 'very good/premium > 6.4', so they show a very complex and balanced aroma profile, representing a pronounced harmony and persistency which can be considered as 'very good' up to 'excellent'.[3] Considering these results, a further quality class could be introduced, which is 'excellent > 7.4', representing oils with an excellent flavour profile, distinguishable from the very good/premium EVOOs for particular aromatic or gustatory notes and a complex equilibrium that take them to an 'upper level': 63 samples (45% of all 140) could be classified in this class, confirming their excellent sensory quality (Fig. 2A). With regard to this finding, it was surprising to see that only 27 samples (19.3%) were evaluated as 'liked' by the consumers (overall liking > or equal to 6.00) and even 33 EVOOs (23.6%) showed an overall liking below or equal to 5.00 (Fig. 2B). Of course the questions we asked consumers and trained panellists were different, but either way such a result might be a first hint to the fact that there are some differences in expectation and interpretation of the sensory characteristics of olive oils between consumers and trained panellists.[20,29]

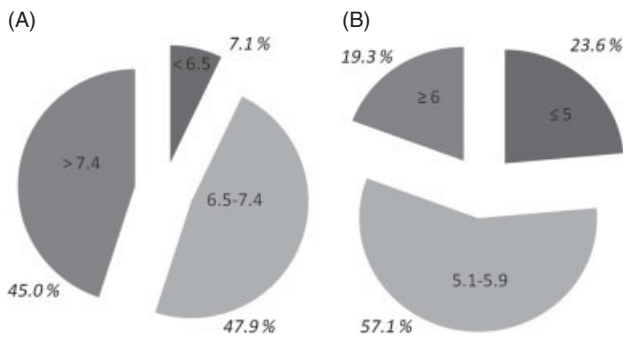


Figure 2. Intensity of harmony and persistency (H&P) (A) and overall liking evaluated by consumers (B) expressed as percentage on the total of samples of the analysed samples, expressed as percentage on the total of samples.

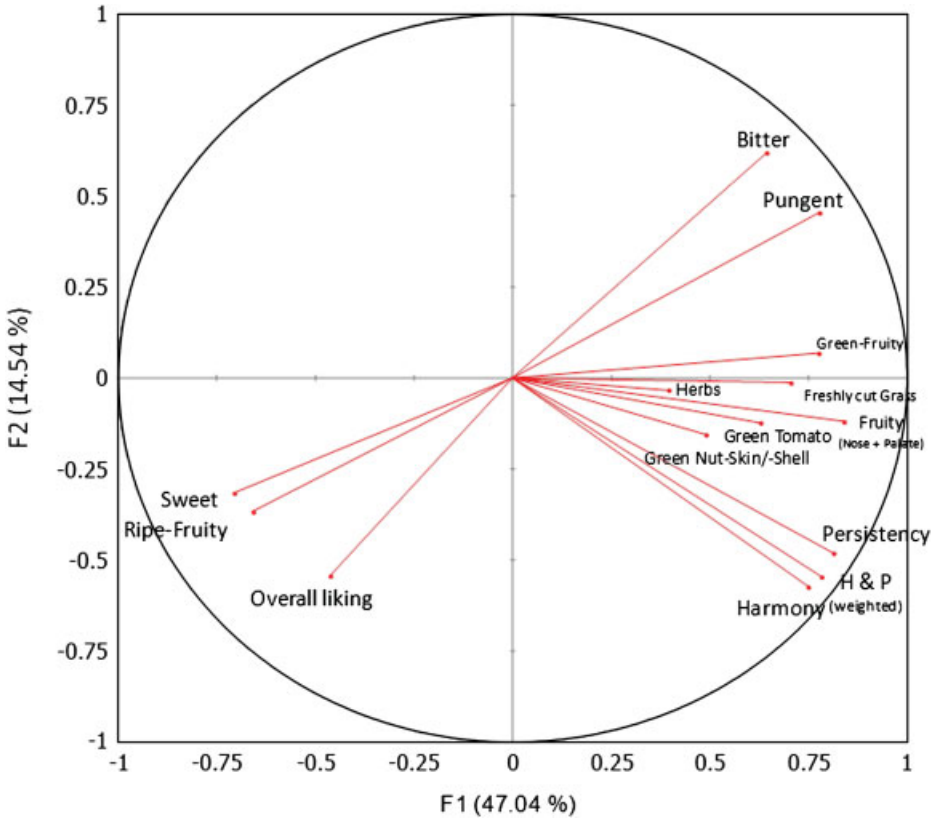


Figure 3. Principal component analysis: correlation circle showing a projection of the selected variables in the factors plane. Overall liking was evaluated by consumers.

Principal component analysis: projection of the variables in the space

For the elaboration of the principal component analysis (PCA) on the 23 positive sensory attributes considered in the extended profile sheet for each EVOO (Fig. 1), it was decided to delete 11 aromatic attributes that (1) showed very low correlations with overall liking scores of consumers, with harmony and as well the other main aromatic attributes, and (2) were found very rarely in the analysed EVOOs. Therefore the sensory attributes considered for performing the PCA finally were: bitter, pungent, fruity (nose + palate, which means perceived ortho- and retronasally, as reported in Regulation (EC) 640/2008[1]), green fruity, ripe fruity, sweet, freshly cut grass, green nut-skin/-shell, green tomato, herbs, harmony and persistency. The consumers' overall liking was additionally considered in this statistical elaboration. The first two factors (F1 and F2) permitted 61.58% of the initial variability of the considered data to be represented. Looking at the correlation circle (Fig. 3), one can investigate the relationships among the variables that are confirmed in Table 2; on the one hand the 'overall liking' vector is situated far from the centre, and directly opposite to the vectors for 'bitter' and 'pungent', showing that it is negatively correlated with both. On the other hand the 'overall liking' vector is situated near the vectors for 'ripe fruity' and 'sweet', suggesting a positive correlation. It is interesting to observe the orthogonal position of the vector 'harmony', almost independent from the vectors for 'bitter', 'pungent' and 'sweet' on one side as well as the vectors for 'ripe fruity' and 'overall liking' on the other side. Nevertheless harmony is strictly correlated with persistency, since both vectors are located far from the centre and one close to each other (Fig. 3).

Correlations among sensory attributes

As expected (Fig. 3), bitter and pungent were highly correlated ($r = 0.808$) (Table 1); this is proven by the fact that, usually, EVOOs that are very bitter are also very pungent, since these two sensory attributes share the same 'chemical origin', namely phenolic compounds.[16] Bitter and green fruity were also positively correlated ($r = 0.590$), as reported in previous studies,[30] supporting the statement that the green odour note has a positive significant effect on the perception of bitterness.[31] It was also interesting to underline that bitter was negatively correlated with ripe fruity ($r = -0.592$), which is actually a more typical and common attribute for sweet EVOOs (see the positive correlation between ripe fruity and the attribute sweet ($r = 0.574$). At the same time, both ripe fruity and sweet were negatively correlated with pungent (respectively, $r = -0.609$ and $r = -0.652$). The relationships between attributes perceived during smell and taste phases were not easy to be explained. It seems highly probable that taste and aroma interact in a specific way, with synergetic, antagonistic or independent effects.[32] Considering the descriptor harmony, first it was interesting to observe a very high correlation with persistency ($r = 0.920$), confirming that it was correct and useful to summarise them in only one weighted attribute as reported in Bongartz and Oberg.[3] Harmony was not highly correlated with bitter ($r = 0.175$) or pungent ($r = 0.337$), confirming that a bitter and pungent oil is not always characterised by high harmony values. This means that EVOOs with high harmony scores cannot automatically be defined as having unique sensory characteristics, for example in terms of high bitterness and high pungency scores. On the other hand, it was interesting to underline that harmony and persistency were not linked to the

Table 1. Correlations among the sensory attributes (Pearson's correlation, $P < 0.05$)

Attribute	Bitter	Pungent	Green fruity	Ripe fruity	Sweet	Freshly cut grass	Green nut–skin / –shell	Green tomato	Herbs	Harmony	Persistency	Fruity (nose + palate)	H & P (weighted)	Overall liking
Bitter	**1**	**0.808**	**0.509**	**−0.592**	**−0.597**	**0.406**	**0.218**	**0.251**	**0.172**	**0.175**	**0.234**	**0.476**	**0.215**	**−0.544**
Pungent	**0.808**	**1**	**0.597**	**−0.609**	**−0.652**	**0.479**	**0.270**	**0.486**	**0.211**	**0.337**	**0.434**	**0.596**	**0.369**	**−0.530**
Green fruity	**0.509**	**0.597**	**1**	**−0.456**	**−0.491**	**0.551**	**0.276**	**0.440**	**0.341**	**0.495**	**0.576**	**0.630**	**0.533**	**−0.373**
Ripe fruity	**−0.592**	**−0.609**	**−0.456**	**1**	**0.574**	**−0.484**	**−0.251**	**−0.355**	**−0.188**	**−0.300**	**−0.359**	**−0.434**	**−0.330**	**0.359**
Sweet	**−0.597**	**−0.652**	**−0.491**	**0.574**	**1**	**−0.439**	**−0.260**	**−0.340**	−0.126	**−0.394**	**−0.443**	**−0.514**	**−0.404**	**0.420**
Freshly cut grass	**0.406**	**0.479**	**0.551**	**−0.484**	**−0.439**	**1**	**0.261**	**0.463**	**0.262**	**0.462**	**0.524**	**0.534**	**0.506**	**−0.233**
Green nut–skin / –shell	**0.218**	**0.270**	**0.276**	**−0.251**	**−0.260**	**0.261**	**1**	**0.313**	**0.406**	**0.349**	**0.380**	**0.449**	**0.348**	−0.129
Green tomato	**0.251**	**0.486**	**0.440**	**−0.355**	**−0.340**	**0.463**	**0.313**	**1**	0.139	**0.451**	**0.484**	**0.521**	**0.469**	**−0.179**
Herbs	**0.172**	**0.211**	**0.341**	**−0.188**	−0.126	**0.262**	**0.406**	0.139	**1**	**0.204**	**0.248**	**0.435**	**0.209**	**−0.218**
Harmony	**0.175**	**0.337**	**0.495**	**−0.300**	**−0.394**	**0.462**	**0.349**	**0.451**	**0.204**	**1**	**0.920**	**0.637**	**0.975**	−0.089
Persistency	**0.234**	**0.434**	**0.576**	**−0.359**	**−0.443**	**0.524**	**0.380**	**0.484**	**0.248**	**0.920**	**1**	**0.682**	**0.953**	**−0.205**
Fruity (nose + palate)	**0.476**	**0.596**	**0.630**	**−0.434**	**−0.514**	**0.534**	**0.449**	**0.521**	**0.435**	**0.637**	**0.682**	**1**	**0.667**	**−0.288**
H & P (weighted)	**0.215**	**0.369**	**0.533**	**−0.330**	**−0.404**	**0.506**	**0.348**	**0.469**	**0.209**	**0.975**	**0.953**	**0.667**	**1**	−0.129
Overall liking	**−0.544**	**−0.530**	**−0.373**	**0.359**	**0.420**	**−0.233**	−0.129	**−0.179**	**−0.218**	−0.089	**−0.205**	**−0.288**	−0.129	**1**

Values in bold type are different from 0 with a significance level $\alpha = 0.05$.
H & P, harmony and persistency attributes, together.

overall liking perception of the consumers. This suggested that an evident discrepancy existed between the consumer perception (acceptance) and the attribute evaluated as harmony by the trained panellists, even if the questions we asked consumers and trained panellists were different (see above). Overall liking was negatively correlated with bitter ($r = -0.544$) and pungent ($r = -0.530$). This means that, as reported in previous investigations, consumers' behaviour is rejecting very bitter oils[29] and, in general, considers the characteristic bitterness and pungency of EVOOs as rather negative (unpleasant) attributes.[20] In particular, bitterness is a very common perception for EVOOs but, at the same time, can further be considered as a quite unusual, atypical and 'different' sensation compared to pungent substances, since the latter are restricted to the throat and often lead to coughing and throat clearing.[21]

Principal component analysis: projection of the samples in the factors plane and classification of extra virgin olive oils

The interpretation of the projection of the samples on the orthogonal plane was difficult, since a lot of samples were integrated into this evaluation, just forming a faint 'cloud'. Nevertheless, the idea was to check if it is possible to group the samples according to the cultivars and the growing regions (origins) of the olive oils, in order to verify if such a statistical approach could have (or not) a discriminant effect on their distribution. It is important to highlight that the number of samples available in this investigation (and also the design of this study) is probably not fully adequate to perform discrimination between cultivar or regions of origins and the comparison between PDO and non-PDO quality of EVOO. For this aim, we would need a higher number of samples that has to be representative of the innate biodiversity of such variables. Nevertheless, looking at the cultivar first, one could see that the samples obtained by more than 50% olives from the cultivar Picudo were located in the first quadrant of the two-dimensional map (Fig. 4A), confirming their tendency to be very bitter and pungent oils and not so appreciated by the consumers. A similar situation was also found for samples obtained from Hojiblanca olives (considering the mono-cultivar and the blends with more than 50% from olives belonging to this cultivar), confirming that they shared basically similar sensory profiles and consumers' overall liking perception, except of two of them (27 and 68). Similar grouping effects were also found for Tonda Iblea (Fig. 4B), Viduna and Cerasuola mono-cultivar EVOOs. Checking whether the samples can be grouped according to the growing region (origin) of olives, good results were found for the samples from Crete (Greece), since they were all grouped in the same region of the two-dimensional map (Fig. 4D). It was also interesting to observe the results for EVOOs coming from Catalonia, since they all shared the same region of the two-dimensional map (Fig. 4C). The efficiency of such a grouping effect could be due to the similarity of the varieties, found for samples coming respectively from Crete and Catalunia (Table S1, in the supporting information). Interesting, but not too surprising, was the finding that samples coming from Andalusia (Spain) could not be grouped so well (graph not shown), maybe because of a very broad harvest period. Additionally, a large variety of different quality EVOOs exist in Andalusia, leading to a wide range of products with different sensory characteristics. Moreover, it was evaluated if the samples could be grouped in the PCA on the basis of the presence or absence of a Denomination of Origin (PDO), the type of applied farming system (organic vs. conventional), or the use of one or more cultivar of olives for obtaining the EVOOs (mono-cultivar vs. blends). For this purpose,

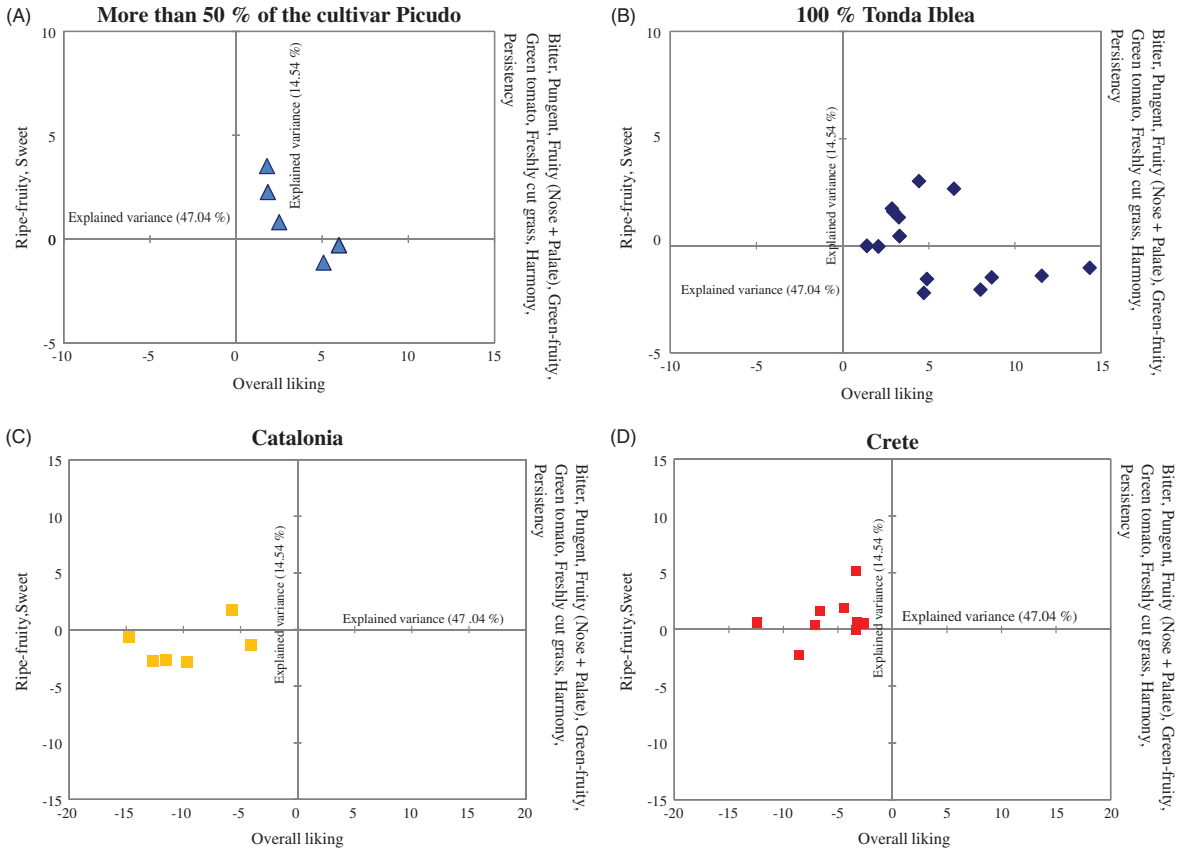


Figure 4. Principal component analysis: projection of the samples in the factors plane. PCA was elaborated considering all the sensory attributes as explained in the paper and each graph reported here show only the samples characterised by features reported above each one. Overall liking was evaluated by consumers.

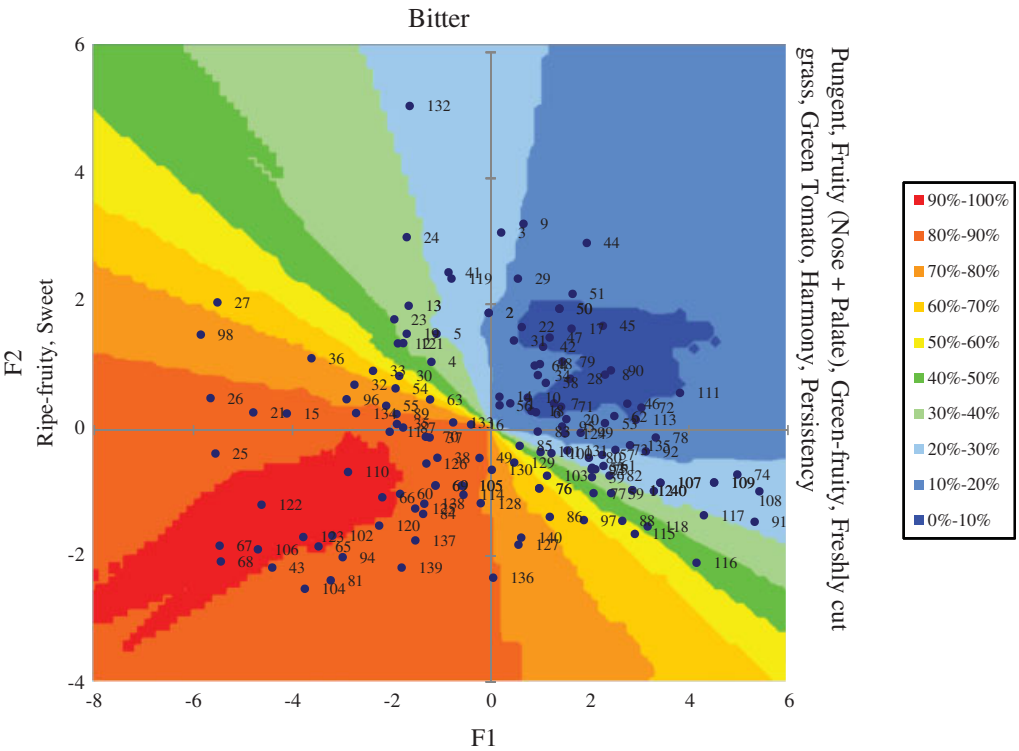


Figure 5. Preference map, showing all the samples, built as described in the paper. The attributes reported in the axes are highly correlated with the factors 1 and 2. Overall liking was evaluated by consumers.

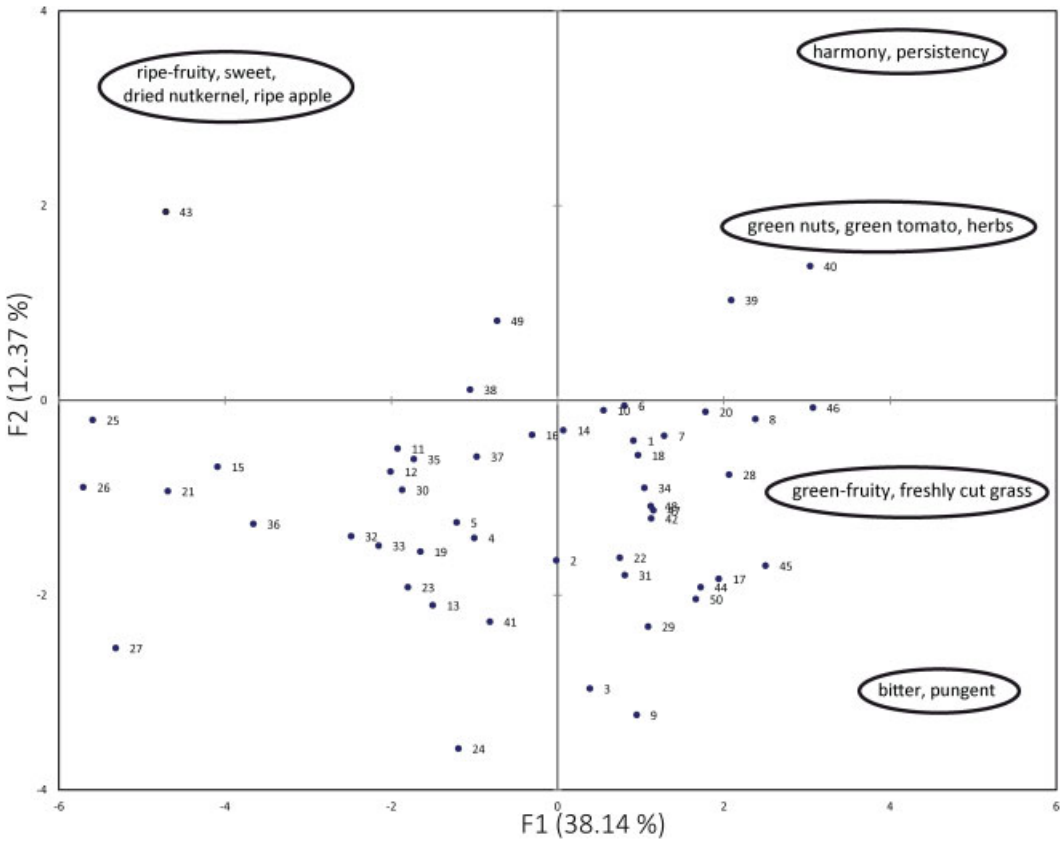


Figure 6. Principal component analysis, showing a selection of samples. The attributes reported are highly correlated with the factors 1 and 2.

it was decided to carry out two different approaches in terms of statistical evaluation, corresponding to two different approaches in building a PCA: (1) considering the attributes: fruity (ortho- and retronasally perceived), bitter, pungent, aromatic notes, harmony, persistency, overall liking, as variables; and (2) considering only the attributes: harmony, persistency and overall liking. For both elaborations, no discrimination in groups were found between mono-cultivar vs. blends, PDO vs. not PDO, and organic vs. conventional EVOOs. This can be due to the fact that olive oils registered within the IOOA competition normally all show very high sensorial quality, regardless of the presence of a Designation of Origin or the fact whether the oil was obtained by mono-cultivar olives and as well independently of the applied agronomic system (conventional vs. organic).

Building a preference map

A prefmap (Fig. 5) was built with XLSTAT, taking into account the results of the objective evaluation (first elaborated with the PCA, see above) and the results of the consumer tests (overall liking). The prefmap was built using a quadratic complex model and the resulting 'heat-map' shows the areas in darker hues or warm colours (yellow, orange, red) where most of the consumers have a preference above average. Areas where only few consumers have a preference above average are shown in lighter hues or cold colours (blue). It was interesting to observe that the most appreciated samples (darker hues or warm / hot colours) were in the direction of the axis that explains especially the ripe fruity and the sweet attributes. Their position is opposite to the bitter axis, and to the attributes on the right hand side of the preference map, pungent, fruity (ortho- and retronasally perceived), green fruity, freshly cut grass, green tomato, harmony, persistency, suggesting that these attributes were not much accepted by the consumers, as previously reported.[20] For better understanding of the preference map (Fig. 5), a plot obtained by PCA including the projection of a selection of samples and the attributes highly correlated with the factors 1 and 2 is also shown (Fig. 6). Most – and at the same time equally appreciated (accepted) EVOO samples – came from different countries (mostly Spain, but also Greece and Italy) and they were both PDO and not PDO samples; moreover they were mono-cultivar EVOOs as well as blends of different olive varieties and they came from organic as well as conventional farming systems. Nevertheless it is important to underline that all the preference mapping methods do not provide a complete picture of the interaction between consumer liking and product specific characteristics, so the interpretation is only possible and has to be related to and reflected together with the results of the basic statistical analyses (e.g. product hedonic rating frequencies, mean scores, etc.).[33]

CONCLUSIONS

Sensory characteristics found in oils produced from good quality olives, obtained in different countries, from different harvest times and with different production technologies were not equally appreciated (accepted) by consumers in this study. Consumers mostly rejected the very bitter and very pungent oils by trend, so one can conclude that peculiar bitterness and pungency in EVOOs is not seen as pleasant (positive) by consumers. Taking this into account, it seems that consumers do not practice a 'well-informed' consumption of EVOOs, in terms of a holistic perception of the

overall quality of olive oils. This means that certain knowledge about health-related components and sensory characteristics in olive oils (e.g. high intensities of bitter and pungent aspects) does not lead to a higher acceptance of oils showing these aspects. If consumers could link cognitive information about certain oil components (e.g. phenols) and related health aspects to their sensorial interpretations and preferences, a somehow 'learned' higher acceptance due to cognitive reasons could result and lead to a different nutritional behaviour. To achieve this purpose, dissemination of the health impact of both pungency and bitterness of EVOOs should be intensified in order to give people the possibility to integrate this information about beneficial effects with their sensory experience and expectation. Nevertheless, the 'pure' sensory aspects of olive oils of course have to remain and build the main impact of any sensory acceptance by consumers. Discriminating effects according to the geographical origin of EVOOs, the presence/absence of a Designation of Origin (PDO), the different farming system (organic vs. conventional) and the aspect of mono-cultivar vs. blends of different cultivars could not be proved in this investigation; only grouping effects were observed, considering some geographical areas and different cultivars of olives. This leads to the conclusion that the degree of quality of premium EVOOs that were object of this investigation was not dependent on the presence of a Denomination of Origin or on different farming systems (organic vs. conventional) or on the presence of one or more cultivars of olives.

SUPPORTING INFORMATION

Supporting information may be found in the online version of this article.

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