Research Article

Received: 24 May 2012 Revised: 20 July 2012 Accepted: 21 July 2012 Published online in Wiley Online Library: 30 August 2012

(wileyonlinelibrary.com) DOI 10.1002/jsfa.5863

Influence of some environmental factors on drupe maturation and olive oil composition

Claudio Di Vaio,[a] Sabrina Nocerino,[a*] Antonello Paduano[b] and Raffaele Sacchi[b]

Abstract

BACKGROUND: Understanding the relationships between olive cultivars and the cultivation environment as well as optimising cultivation choices can lead to maximum expression of oil production in terms of both quantity and quality. For this purpose, samples of the Ortice olive cultivar grown in two different environments in southern Italy at altitudes of 500 and 50 m above sea level (a.s.l.) were harvested on various dates to monitor drupe maturation and determine the nutritional and chemical characteristics of the oils.

RESULTS: Fruits grown at 50 m a.s.l. ripened about 10–15 days earlier than those grown at 500 m a.s.l. The oil obtained at 500 m a.s.l. was characterised by a higher content of total polyphenols and a higher content of oleic and stearic acids.

CONCLUSION: The different heat accumulation related to the environment affected drupe development as well as the colouring trend and oil content. Consequently, the growth environment changed the content of Ortice oil fatty acids and polyphenols, while the flavour profile remained fairly stable in both environments, with the cultivar effect prevailing over the environment factor.

Keywords: olive; phenolic composition; fatty acids; aromatic profile

INTRODUCTION

In-depth knowledge of the relationships between olive cultivars and the cultivation environment not only optimises cultivation choices but also favours maximum expression of oil production in terms of both quantity and quality. Oil quality is influenced by genetic, environmental and agronomic factors.[1,2] For olives, little is known regarding soil/climatic parameters and production, unlike other crops such as grapes.[3] Undoubtedly, environmental variables affect productive efficiency and oil quality. The cultivar is one of the main agronomic factors responsible for the chemical and organoleptic 'footprint' of the oil, strongly contributing in its qualitative and nutritional characteristics. However, cultivars have different resistance to stress conditions or thermal regimes during development and fruit ripening.[4] The temperature of an environment or a cropping year may affect the oil composition, increasing or decreasing the phenotypic stability.[5–7] Rain and/or irrigation can change the oil content of phenolic compounds, higher water availability tending to reduce their content.[8–10] Altitude has an effect on the quality characteristics of oils, in particular their fatty acid content. Oils obtained from plants grown at higher altitudes have greater stability to oxidation.[11–13] Temperature is also important for both drupe development and oil composition. In very hot sites, olives show early pigmentation, which causes rapid degradation of chlorophyll.[12] In sites with low temperatures, however, oils have a higher content of unsaturated fatty acids.[14] Temperature can also influence the aromatic component of the oil, reducing the content of volatile substances.[15,16] Tura *et al*.[17] report that aromatic olive oil quality depends firstly on the year and secondly on the cultivar. In the region of Campania there are many varieties of olives.[5,18,19] Ortice is the most common cultivar in the province of Benevento and is used both to produce oil and for direct consumption as green table olives. The plant has medium vigour, with ascending branches, and is a self-sterile and late-ripening cultivar. Its olives are medium or large, ellipsoidal in shape, with an average oil yield.[19] Although it is difficult to discriminate between the many factors that affect production, i.e. to distinguish the effect of cultivation techniques from that of the environment, our goal was to study the effect of environmental factors such as climate (temperature and rainfall) on fruit ripening, the chemical composition of the oils obtained, as well as their sensory profile, in the Ortice olive cultivar when grown in two different environments.

MATERIALS AND METHODS

The study was conducted in 2009 at two farms located in two very different areas of cultivation in southern Italy. The first was in

* Correspondence to: Sabrina Nocerino, Dipartimento di Arboricoltura, Botanica e Patologia Vegetale, Università di Napoli Federico II, Via Università 100, I-80055 Portici, Naples, Italy. E-mail: sabrinanocerino@libero.it

a Dipartimento di Arboricoltura, Botanica e Patologia Vegetale, Università di Napoli Federico II, Via Università 100, 80055 Portici, Naples, Italy

b Dipartimento di Scienze degli Alimenti, Università di Napoli Federico II, Via Università 100, 80055 Portici, Naples, Italy

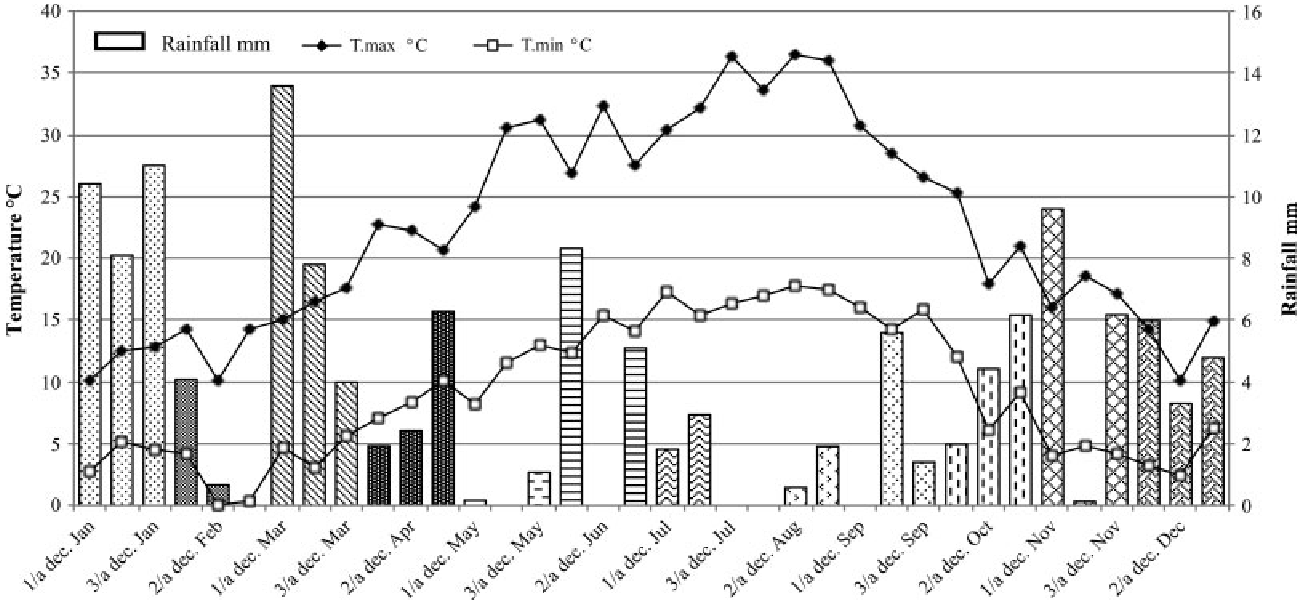

Figure 1. Temperature and rainfall in 2009 at San Lupo (500 m a.s.l.).

San Lupo (41°07′00″ N, 14°46′00″ E) in the province of Benevento (BN), where the cultivar Ortice is traditionally grown. The farm lies at an altitude of 500 m above sea level (a.s.l.). The trees are in full production, with plants trained around the central axis. The cultivation is rainfed and the soil has a clayey texture. The second farm, the Improsta experimental farm run by Campania Regione, was in Eboli (40°37′01″ N, 15°03′23″ E) in the province of Salerno (SA), close to sea level (50 m). Here too the orchard is in full production, with rainfed plants trained around the central axis on clayey/silty soil. Within these two fields, eight plants of the variety Ortice with homogeneous vegetative and productive characteristics were selected, from which 100 drupes were collected twice weekly from the beginning of October, giving a total of seven samplings. The following measurements were taken on these samples: fruit weight, flesh firmness using a 1 mm tip, fruit colour using the Jaén index (0–7), and fruit oil content by the Soxhlet method. In each field at harvest, which was executed at the full ripening stage, 50 kg of olives were picked, from which monovarietal oils were obtained using a micro-mill (Oliomio, type Mini 50, Italy). These oils were analysed for quality indices (acidity, peroxide and spectrophotometric indices), sensory profile by panel test,[20] phenolic composition by high-performance liquid chromatography, and fatty acid profile.[21] The relationship between ripening and the effect of temperature, integrated over time, was expressed by the method of the accumulation of growing degree-days (GDD),[22,23] which includes the calculation of the thermal sum

$$S = \sum (T - T_0)$$

where S is the thermal sum of the differences between the daily mean air temperature T and the threshold temperature T_0 (10 °C).

To study the seasonal temperatures and rainfall in the two environments, reference was made to data from the agricultural weather stations of San Lupo (BN) and Eboli (SA), using maximum and minimum temperatures and daily rainfall. All data were subjected to analysis of variance, and the standard error of means was calculated using the statistical program XL-Stat PRO-2009, (Addinsoft). Means followed by different letters are statistically different at $P \leq 0.05$.

RESULTS AND DISCUSSION

From the pattern of minimum and maximum temperatures recorded at the hill farm in San Lupo and the rainfall pattern for the same area in 2009 (Fig. 1), it was observed that minimum temperatures were very cold during the second decade of February (even below 0 °C) and that at no time did they exceed 5 °C. Peak maximum temperatures were recorded during August (35 °C). By contrast, temperatures and rainfall measured in the same year at Eboli (Fig. 2) show that minimum temperatures in this area were higher, at times exceeding 20 °C, while maximum temperatures seemed to remain quite similar to those at San Lupo (34 °C, once again during August). From a comparison of the two environments, it was noted that at the higher-altitude site of San Lupo there was a high temperature excursion throughout the year, with maximum values of 24.7 °C between July and August. By contrast, at Eboli the temperature excursion was much lower, with a maximum of 17 °C. As regards rainfall during 2009, at San Lupo there was a total rainfall of 1445.8 mm, with 152 rainy days, which was over twice that recorded at Eboli during the same period (713.6 mm, with 126 rainy days). The relationship between drupe ripening and the integrated effect of temperature over time was determined by cumulative GDD calculated according to the heat sum, reaching a value of 2212.6 at San Lupo *versus* 2684.7 at Eboli. From the comparison of cumulative GDD between the two environments throughout the year (Fig. 3), cumulative GDD were higher at Eboli, gradually increasing from the spring.

The development of average fruit weight in the two environments is shown in Table 1. The growth pattern of drupes was very similar, although it remained slightly lower at San Lupo. At the end of the observations, i.e. the 10 December sampling, Eboli recorded a drupe weight of 5.55 g, while the corresponding weight at San Lupo was 4.75 g.

Regarding pulp firmness, Ortice generally showed high resistance to penetration. The trend for this parameter was very similar in the two environments: it showed a constant reduction during maturation (Table 1), attaining by the end of the observations a value of 259.6 kg cm^{-2} at Eboli and a value of 227.1 kg cm^{-2} at San Lupo.

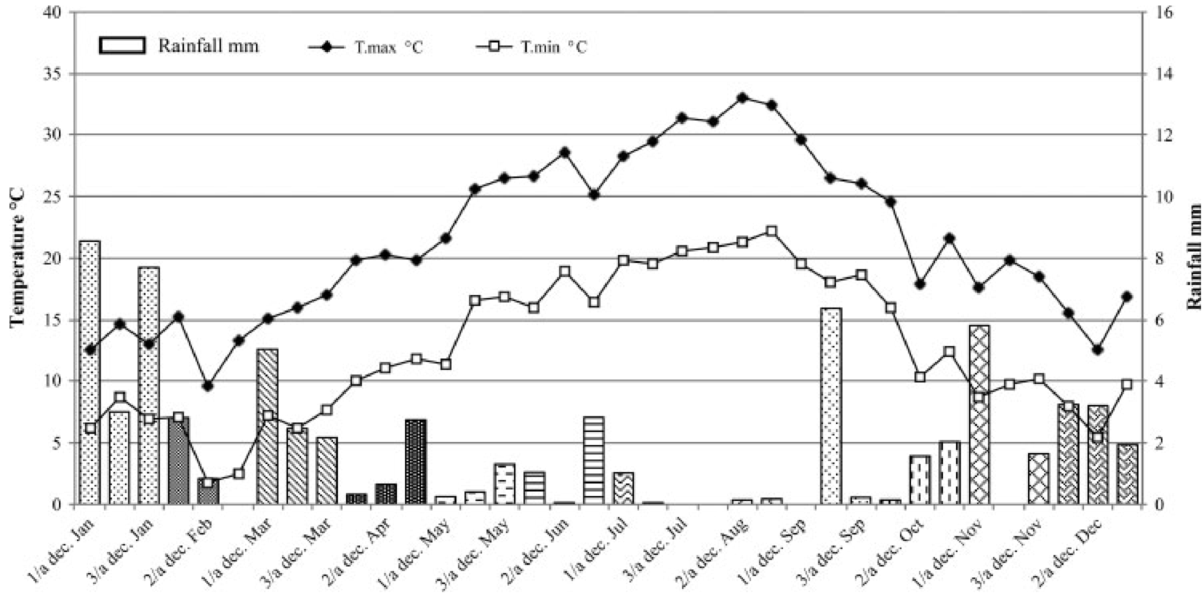

Figure 2. Temperature and rainfall in 2009 at Eboli (50 m a.s.l.).

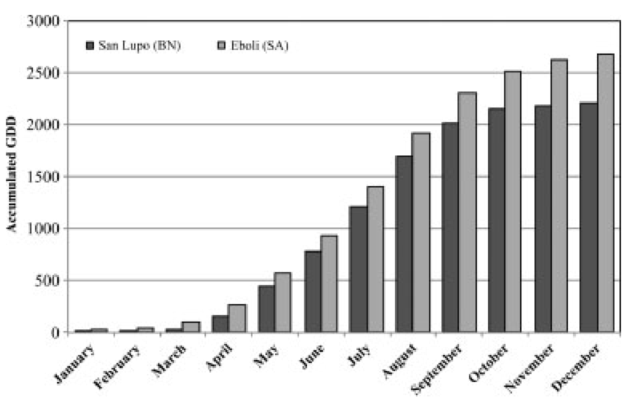

Figure 3. Heat sum comparison of sites at San Lupo and Eboli.

Fruit colour was determined by the Jaén index, according to which the optimal harvest time is when the value lies between 3 and 4. As shown in Table 1, Ortice grown at Eboli reached this optimal range around 5 November, when the Jaén index amounted to 3.65, while at the same sampling date the index at San Lupo was 2.66; only between 16 and 25 November was the optimal range attained at San Lupo, indicating a delay in maturation. Consequently, Ortice grown at Eboli ripened earlier than the same cultivar grown at San Lupo, where maturation was delayed and more gradual.

Fruit oil content increased to 27.9% on the last sampling date (10 December) at San Lupo, compared with 21.7% at Eboli.

Regarding the biomorphological observations, our data are confirmed by reports in the literature. Clearly, fruit development was greater at Eboli, which is almost at sea level, than at San Lupo, which is at a higher altitude: the average weight of olives at Eboli was always higher than that of olives at San Lupo. This is in line with the findings of Mohamed Mousa *et al.*[12] on an olive cultivar grown at two different altitudes, which showed a greater increase in weight of fruits grown at lower altitude compared with fruits grown at higher altitude. Moreover, according to our data from the penetrometer index, we noted greater pulp firmness at the low-altitude site. It was also clear that there was earlier ripening

Table 1. Changes in drupe characteristics during ripening of Ortice olives grown at Eboli and San Lupo

Parameter	Location	7 October	15 October	26 October	5 November	16 November	25 November	10 December
Drupe weight (g)	Eboli (SA)	3.97a ± 0.08	4.11a ± 0.08	4.81a ± 0.11	4.57a ± 0.10	5.13a ± 0.11	5.04a ± 0.12	5.55a ± 0.11
	San Lupo (BN)	3.86a ± 0.07	3.59b ± 0.09	4.26b ± 0.08	4.53a ± 0.07	4.41b ± 0.09	4.60b ± 0.09	4.75b ± 0.09
Pulp firmness ($kg\ cm^{-2}$)	Eboli (SA)	487.00a ± 3.96	505.20a ± 8.60	448.40a ± 5.88	399.30a ± 5.38	349.90a ± 3.54	339.00a ± 3.31	259.60a ± 3.70
	San Lupo (BN)	473.30a ± 4.28	448.23b ± 7.40	407.30b ± 4.04	402.40a ± 2.85	324.40a ± 2.61	339.80a ± 2.88	227.10a ± 2.02
Jaén index (0–7)	Eboli (SA)	0.59a ± 0.09	0.73a ± 0.10	2.90a ± 0.10	3.65a ± 0.09	3.93a ± 0.09	3.94a ± 0.09	4.16a ± 0.10
	San Lupo (BN)	0.15a ± 0.04	1.05a ± 0.14	1.52b ± 0.10	2.66b ± 0.07	3.05b ± 0.08	4.51b ± 0.09	4.72b ± 0.12
Oil content (% FW)	Eboli (SA)	20.84a ± 0.16	19.49a ± 0.48	25.07a ± 0.40	23.58a ± 0.63	22.66a ± 0.21	21.87a ± 0.27	21.70a ± 0.20
	San Lupo (BN)	23.01a ± 0.00	21.40a ± 0.11	28.27b ± 0.39	25.07a ± 0.61	28.65b ± 0.10	25.56b ± 0.23	27.88b ± 0.36

Values are mean ± standard error. For each parameter and date, statistically significant differences are indicated by different letters ($P \leq 0.05$).

Table 2. Quality indices of oils obtained from Ortice olives grown at Eboli and San Lupo

			UV		
Location	Acidity (% oleic acid)	Peroxide value (meq O_2 kg^{-1})	K_{232}	K_{270}	ΔK
Eboli (SA)	0.70a ± 0.05	4.3a ± 0.11	1.942a ± 0.076	0.161a ± 0.011	−0.006a ± 0.000
San Lupo (BN)	0.63a ± 0.01	3.6a ± 0.11	1.573a ± 0.031	0.105a ± 0.035	−0.004a ± 0.000

Values are mean ± standard error. For each index, statistically significant differences are indicated by different letters ($P \leq 0.05$).

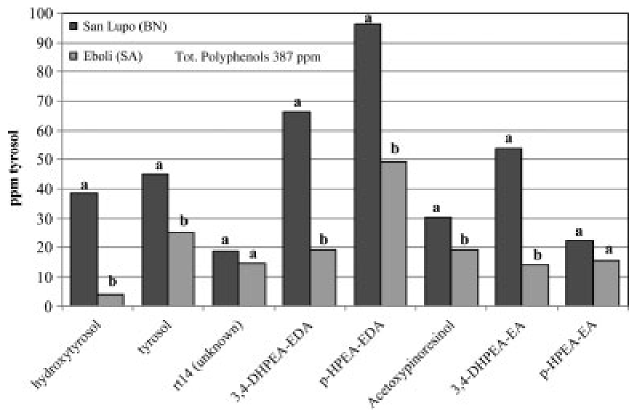

Figure 4. Comparison of phenolic composition of Ortice olive oils from San Lupo and Eboli. Statistically significant differences are indicated by different letters ($P \leq 0.05$).

Table 3. Fatty acid composition of oils obtained from Ortice olives grown at Eboli and San Lupo

	Content (% of total fatty acids)	
Fatty acid	Eboli (SA)	San Lupo (BN)
Palmitic acid	16.328a	13.934b
cis-7-Hexadecenoic acid	0.081a	0.096a
Palmitoleic acid	1.302a	0.890b
Heptadecanoic acid	0.061a	0.054a
Heptadecenoic acid	0.081a	0.074a
Stearic acid	2.881a	3.163b
Oleic acid	56.696a	65.288b
Vaccenic acid	3.085a	2.595b
Linoleic acid	17.104a	11.603b
Arachidic acid	0.407a	0.349b
Linolenic acid	0.886a	0.736b
Eicosenoic acid	0.183a	0.188a
Behenic acid	0.092a	0.094a
Squalene	0.765a	0.895b
Lignoceric acid	0.048a	0.040a
Ratios		
Oleic/linoleic	3.314a	5.626b
Saturated/unsaturated	0.249a	0.216a

For each fatty acid or ratio, statistically significant differences are indicated by different letters ($P \leq 0.05$).

of fruits grown at the lower-altitude site, which can be harvested about 10–15 days earlier than those grown at San Lupo. The data on oil accumulation in olive fruits also agreed with those reported elsewhere: according to Mohamed Mousa *et al.*,[12] oil content was higher in high-altitude olives, as our results also showed for olives from the higher-altitude province of Benevento (27.9% at San Lupo *versus* 20.7% at Eboli).

In both environments, at full ripening, 50 kg of olives were collected and then micro-milled to obtain two samples of monovarietal oil, on which chemical and sensory analyses were carried out. Analysis of oil quality indices (acidity, peroxide and spectrophotometric indices), reported in Table 2, showed that all analytical parameters fell within the limits set by law[20] for the category of extra virgin olive oils. The data did not show substantial differences between the two sites.

Analysis of the phenolic composition of the two oils showed that the Ortice cultivar had a medium–high total phenol content (Fig. 4). Greater accumulation of biophenols was observed in San Lupo oil (387 ppm) than in Eboli oil (177 ppm). The San Lupo oil showed much higher contents of 3,4-DHPEA-EDA (dialdehydic form of elenolic acid esterified with hydroxytyrosol), which has a high antioxidant activity, and *p*-HPEA-EDA (dialdehydic form of elenolic acid esterified with tyrosol), which is responsible for spicy notes, than the Eboli oil. In general, it may be noted that all other phenolic compounds presented a higher content in San Lupo oil. As regards the fatty acid composition (Table 3), there were significant differences between the two oils. The oil obtained from olives grown at Eboli had a higher content of linolenic and palmitic acids and was less rich in oleic and stearic acids. This is in agreement with several other studies[11,12,24] showing an increase in monounsaturated fatty acids at higher altitudes.

Sensory analysis of the two oils (Fig. 5) showed the typical sensory attributes of the Ortice cultivar,[25] with a profile characterised, regardless of environment, by clear notes of fruity olive and green tomato. On tasting, both oils presented good fluidity and a balance of bitter and spicy notes, though the San Lupo oil had more marked bitter and spicy perceptions.

As reported in other papers,[5,19,26] the fatty acid composition in the present study was strongly influenced by the growing environment. As temperatures rose, there was an increase in palmitic and linoleic acids and a decrease in oleic acid. Studies on fatty acid composition in relation to altitude have shown that oils produced at higher altitude have a higher proportion of unsaturated fatty acids[14] and greater oxidative stability,[11] as evidenced by the results of our work. However, opinion is divided as to the influence of the environment on phenolic composition. The work carried out by Farinelli *et al.*[27] showed an increase in polyphenol content in dry summers and autumns, while Tous and Romero[28] found a higher accumulation of phenolic compounds at low temperatures. Our results appear to confirm the findings of the latter study, showing a higher total phenol content in San Lupo oil. The phenolic composition was reflected in the sensory analysis: the higher temperatures at Eboli led to a reduction in the

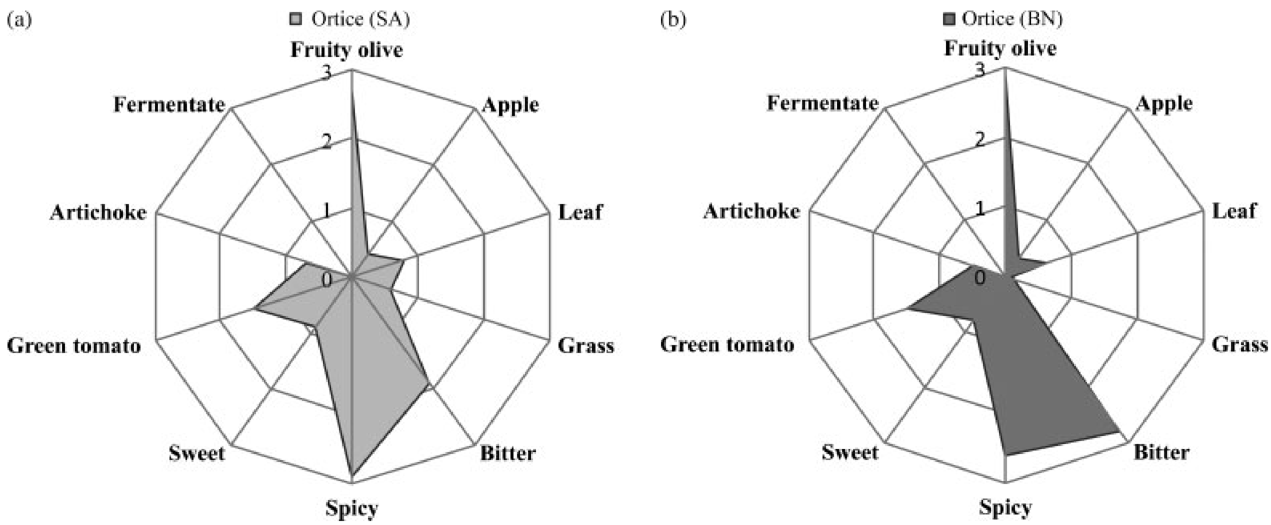

Figure 5. Sensory profiles of Ortice olive oils from (a) Eboli (SA) and (b) San Lupo (BN).

phenolic content and to a consequent reduction in the aromatic and organoleptic profile, with less marked bitter and spicy notes and a reduction in aromas, deviating from the typical oil profile obtained in the province of Benevento.[25]

CONCLUSION

The growing environment is crucial in expressing the typical characteristics and quality of olive cultivars. Although it is difficult to decompose the influence of environmental parameters on the various quantitative and qualitative aspects of production, the overall data obtained in this trial indicate a better expression of the autochthonous Ortice cultivar grown in its own environment. This adds further evidence to show that the typicality of extra virgin oil depends greatly upon the combination of variety and environment, a key requirement for recognition of Protected Designation of Origin.

ACKNOWLEDGEMENT

The authors wish to thank Dr Mark Walters for editing the manuscript.

REFERENCES

1 Cimato A, Effect of agronomic factors on virgin olive oil quality. *Olivae* **31**:20–31 (1990).
2 Kiritsakis A, *Olive Oil*. American Oil Chemists' Society, Champaign, IL (1991).
3 Amerine MA and Winkler AJ, Composition and quality of musts and wine of California grapes. *Hilgardia* **15**:493–673 (1944).
4 Inglese P, Famiani F, Servili M, Esposto S and Urbani S, Factors affecting extra-virgin olive oil composition. *Hort Rev* **38**:83–147 (2011).
5 Lombardo N, Marone E, Alessandrino M, Giodino G, Madeo A and Fiorino P, Influence of growing season temperatures on the fatty acids (FAs) of triacylglycerols (TAGs) composition in Italian cultivars of *Olea europaea*. *Adv Hort Sci* **22**:49–53 (2008).
6 Fiorino P and Ottanelli A, Crescita ed inflizione dei frutti di cultivar di olivo (*Olea europaea*) nella Toscana interna e possibili influenze dell'ambiente nella determinazione dei trigliceridi. *Atti del Convegno Nazionale 'Germoplasma Olivicolo e Tipicità dell'Olio'*, Perugia, pp. 158–164 (2004).
7 D'Imperio M, Dugo G, Alfa M, Mannina L and Segre A, Statistical analysis on Sicilian olive oils. *Food Chem* **102**:956–965 (2007).
8 Pannelli G, Servili M, Baldioli M, Selvaggini R and Montedoro GF, Effect of agronomic and seasonal factors on olive (*Olea europaea* L.) production and on the qualitative characterization of the oil. *Acta Hort* **356**:239–243 (1994).
9 Patumi M, d'Andria R, Marsilio V, Fontanazza G, Morelli G and Lanza B, Olive and olive oil quality after intensive monocone olive growing (*Olea europaea* L., cv. Kalamata) in different irrigation regimes. *Food Chem* **77**:27–34 (2002).
10 Tognetti R, d'Andria R, Sacchi R, Lavini A, Morelli G and Alvino A, Deficit irrigation affects seasonal changes in leaf physiology and oil quality of *Olea europaea* (cultivars Frantoio and Leccino). *Ann Appl Biol* **150**:169–186 (2007).
11 Osman M, Metzidakis I, Gerasopoulos D and Kiritsakis A, Qualitative changes in olive oil collected from trees grown at two altitudes. *Riv Ital Sost Grasse* **71**:187–190 (1994).
12 Mohamed Mousa Y, Gerasopoulos D, Metzidakis I and Kintsakis A, Effect of altitude on fruit and oil quality characteristics of 'Mastoides' olives. *J Sci Food Agric* **71**:345–350 (1996).
13 Montedoro GF, Servili M and Pannelli G, Le caratteristiche del prodotto e le relazioni con le variabili agronomiche, in *Olea – Trattato di Olivicultura*, ed. by. Edagricole, Bologna, pp. 263–289 (2003).
14 Kiritsakis A and Markakis P, Olive oil: a review. *Adv Food Res* **31**:453–482 (1987).
15 Lehninger AL, La biosintesi dei lipidi, in *Principi di Biochimica*, ed. by. Zanichelli Editore, pp. 561–574 (1983).
16 Ridolfi M, Terenziani S, Patumi M and Fontanazza G, Characterization of the lipoxygenases in some olive cultivars and determination of their role in volatile compounds formation. *J Agric Food Chem* **50**:835–839 (2002).
17 Tura D, Failla O, Bassi D, Pedò S and Serraiocco A, Environmental and seasonal influence on virgin olive (*Olea europaea* L.) oil volatiles in northern Italy. *Sci Hort* **122**:385–392 (2009).
18 Pugliano G, *La Risorsa Genetica dell'Olivo in Campania*. SeSIRCA Regione Campania, (2001).
19 Di Vaio C, Nocerino S, Paduano A and Sacchi R, Characterization and bio-agronomic evaluation of olive germplasm cultivars in Campania. *Acta Ital Hortus* **1**:99–104 (2011).
20 EC Regulation 2568/91 on the characteristics of olive oil and olive residue oil and on the relevant methods of analysis. *Off J Eur Commun* NL 248/1 (1991).
21 Christie WW, *Lipid Analysis* (2nd edn). Pergamon, Oxford (1982).
22 Baskerville GL and Emin P, Rapid estimation of heat accumulation from maximum and minimum temperatures. *Ecology* **50**:514–517 (1969).
23 Zalom FG, Goodell PB, Wilson LT, Barnett WW and Bentley WJ, Degree-days: the calculation and use of heat units in pest management. *University of California Division of Agriculture and Natural Resources Leaflet 21373* (1983).
24 Kiritsakis A and Markakis P, Effect of olive collection regime on olive oil quality. *J Sci Food Agric* **35**:677–681 (1984).

25 Ambrosino ML, Conte F, Paduano A, Sansone L, Terminiello R and Sacchi R, *Gli Oli di Oliva Monovarietali in Campania*. Università di Napoli Federico II, Naples (2003).
26 Ripa V, De Rose F, Caravita ML, Parise MR, Perri E, Rosati A, *et al*, Qualitative evaluation of olive oils from new olive selections and effects of genotype and environment on oil quality. *Adv Hort Sci* **22**:95–103 (2008).
27 Farinelli D, Ruffolo M, Scatolini G, Siena M and Tombesi A, Influence of fruit ripening on oil quality to establish the optimum harvesting time for olive cultivars in 'Umbria' DOP. *Acta Ital Hortus* **1**:159–163 (2011).
28 Tous J and Romero A, Cultivar and location effects on olive oil quality in Catalonia, Spain. *Acta Hort* **356**:323–326 (1994).

