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Pedo-environmental determination of olive oil quality. A case study

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Abstract. This paper reports the preliminary results of a study regarding the influence of different pedo-environments of the Benevento province on the composition of olive oil from the 'Ortice' cultivar and the specific relationships among individual soil properties and olive oil compounds. Multivariate statistical analyses (Principal Component Analysis, PCA and Partial Least Squares Regression PLSR) were used for the investigation. Results from PCA showed a clear tendency of olive oil samples from the different pedo-environment to cluster, although the distance among clusters was not relevant. Results from PLSR showed some interesting relationships among several soil properties and olive oil compounds. These relationships were relevant when PLSR was applied separately to samples from individual pedo-environments, while it was less relevant when applied to the data set as a whole. Further investigations will enlarge the data set, also including other cultivars.

Keywords. Olive oil composition – Pedo-environment – Benevento province – CISIA project.

Détermination pédo-environnementale de la qualité de l'huile d'olive. Un cas d'étude

Résumé. *Cet article présente les résultats préliminaires d'une étude de l'influence des différents pédo-environnements de la province de Benevento sur la composition de l'huile d'olive de la variété 'Ortice' et les relations spécifiques entre les propriétés des sols et les composés individuels de l'huile d'olive. L'analyse statistique multivariée (Analyse en Composantes Principales, ACP et régression PLS, PLSR) a été utilisée pour l'enquête. Les résultats de l'ACP montraient une nette tendance de cluster pour les échantillons d'huile d'olive provenant des différents pédo-environnements, bien que la distance entre les clusters n'était pas pertinente. Les résultats de la PLSR ont montré certaines relations intéressantes entre les propriétés du sol et plusieurs composés de l'huile d'olive. Ces relations sont pertinentes lorsque la PLSR est appliquée séparément à des échantillons des différents pédo-environnements, mais elles sont moins importantes lorsqu'elle est appliquée aux données dans leur ensemble. D'autres enquêtes, déjà en cours, sont nécessaires pour évaluer plus en détail la détermination pédo-environnemental sur la composition de l'huile d'olive du cultivar 'Ortice' et d'autres cultivars importants de la province de Benevento.*

Mots-clés. *Composition de l'huile d'olive – Pédo-environnement – Province de Benevento – Projet CISIA.*

I – Introduction

It is well known that the quality of any agricultural product results from the combined effects of a number of factors, such as genetic, anthropogenic and physical-environmental. While the former factors widely vary, and can be modified too, the physical-environmental ones are substantially stable and poorly adjustable, so that they represent the crucial features, determining the specific characteristics and distinctiveness of crops.

It has long been agreed that soil and underlying geology, landform and climate are the main environmental factors governing the characteristics of agricultural production. All these factors establish the modern concept of agricultural “zonation”. Such concept has largely and particularly been used in viticulture while it has so far been little applied to olive growing, despite the acknowledged influence of the nature and properties of soils, relief and climate on the physiology, growth and productivity of olive (Gucci, 2003; Rotundo *et al*., 2003; Saavedra, 2007).

In Italy, studies on olive growing zonation in the province of Siena have successfully been made by Franchini e Cimato (2006). More recently (2011), a study on this topic was started in the province of Benevento. In this province, the lack of any objective knowledge regarding the influence of pedo-environmental features on the quality of olive oil has long been one of the main causes that hampered the recognition of the Protected Designation of Origin (PDO).

The present paper reports some relevant preliminary results of the first year activity of the above mentioned activities. Specifically, it focuses on the discriminating effect of different pedo-environments on the characteristics of olive oil from the cultivar 'Ortice', the most important in the Benevento province, along with the cultivars 'Racioppella' and 'Ortolana'. Moreover, it explores the influence of specific soil properties on the 'Ortice' olive oil compostion.

II – Material and methods

1. Study area

The study area encompasses the province of Benevento (Fig. 1) NE of Campania region (southern Italy). The climate shows typical characteristics of the sub-umid Mediterranean environment, with a mean annual rainfall of 722 mm and a daily mean temperature generally increasing from 10-12 °C in April to 24-25 °C at the end of July, and decreasing to 18-20 °C in September. The yearly mean reference evaporation is about 1240 mm and values increase from about 3 mm day^{-1} in April to about 8 mm day^{-1} in July, starting to decrease in August. Agricultural land use is dominated by cereal crops, vineyards, olive orchards and woodlands (Regione Campania, 2009). Olive orchards cover about 18.000 ha (*i.e.* 38% of the study area), distributed on different pedo-environments (Fig. 2) (Fusco *et al*., 2006).

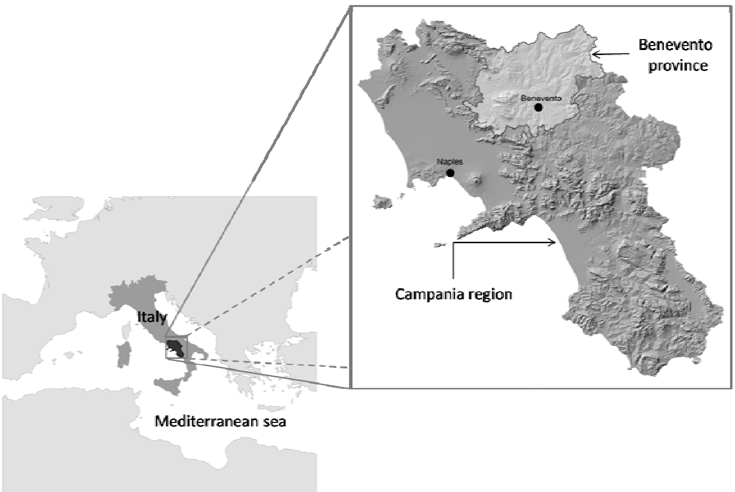


Fig. 1. Location of the study area (province of Benevento) within the regional (Campania), national (Italy) and Mediterranean context.

Fig. 2. Olive-growing area (in black) and limits of the landscape map units of the Benevento province over a Digital Elevation Models (DEM). Labels (S1 ÷ S27) refer to the landscape map units.

2. Olive and soil sampling and analyses

About 100 sampling sites were selected, in such a way to represent as much as possible the pedo-environments where the cultivar 'Ortice' is mostly cultivated (Fig. 3), namely: clay-marl and arenaceous-molasses deposits hills of Tammaro (S4), Fortore (S5) and Calore (S7); clay-marl hills of Titerno (S2); calcareous mountains of Taburno-Camposauro (S16); arenaceous-molasses deposits hills of Taburno-Camposauro (S1); clay-marl and calcareous hills of Calore (S13); alluvial plains (S19, S22, S24); sand-clayey hills of Benevento (S12). Soils associated with the above pedo-environmental units (di Gennaro, 2002) range from the weakly developed *Calcaric Regosols*, to the relatively better developed *Calcaric-Vertic* and *Calcaric Cambisols*, *Eutric* and *Calcic Vertisols*, to the well developed *Vitric* and *Molli-Vitric Andosols* and *Andic Luvisols*. Insights on the soil classification of olive orchards pedo-environments are in progress.

At each site, a sample of olive drupes was collected at the maturity stage of veraison, which varied largely from the beginning to the second decades of November forward, depending on the area microclimate. Drupes were frozen within a few hours after harvesting. Subsequently, they were carefully defrost, their pulp was separated from the core and gently minced for the extraction of oil. The latter was analyzed for the determination of total lipids, according to the method of Folch *et al*. (1957), fatty acids composition, by gas chromatography, polyphenols, according to Savarese *et al*. (2007), and antioxidant activity, according to Benzie and Strain (1996).

At each sampling site, a top-soil sample was also collected. Soil samples were air dried, grounded to pass a < 2 mm sieve, and then analysed in duplicate according to the Italian Official Methods for Soil Analysis (MIPAF, 2000). Samples were analysed for sand, silt and clay content, pH, electrical conductivity (EC), carbonates (as $CaCO_3$), organic carbon (OC), cation exchange capacity (CEC), exchangeable potassium (K^+), sodium (Na^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}).

Fig. 3. Olive and soil sampling site (filled circles) and limits of the landscape map units of the Benevento province area over a Digital Elevation Models (DEM). Labels (S1 ÷ S27) refer to the landscape map units.

3. Statistical data analysis

Olive drupes and soil variables were described as minimum, maximum, mean and coefficient of variation % (CV). According to Ameyan (1984), a variable shows small, moderate, or large variability when CV is below 20%, between 20 and 50%, or above 50%, respectively. *Skewness* was then calculated as the cube root of the deviation from the mean.

Principal Component Analysis (PCA) (Webster and Oliver, 1990) was applied to explore the relationships among the olive oil samples from the different pedo-environments, in relation to the oil composition. Partial Least Squares Regression (PLSR) analysis (Tenenhaus, 1998) was used to explore relationships among the selected olive oil compounds and soil properties.

III – Results and discussion

Table 1 shows descriptive statistics for the selected olive oil characteristics. According to the current scientific literature (Poiana and Romeo, 2006; Rial and Falqué, 2003; Ünal and Nergiz, 2003; European Union Commission, 1991), all the compositional characteristics of the 'Ortice' olive oil samples fall within the range of reference values. The CV varied from low (pH, total lipids, palmitic, stearic, oleic, linoleic, α-linolenic acids and total polyphenols), to moderate (palmitoleic, arachidic, eicosenoic, behenic acids and antioxidant activity), to high (nervonic acid). Skewness exhibited always small values, thus indicating that the distribution of olive oil variables was close to the normal.

Table 2 shows the descriptive statistics for the selected soil properties. Looking at mean values, it is apparent that sand and silt were present in a comparable proportion (336.8 and 375.3 g kg^{-1}, respectively), while clay content was present in a slightly lower percentage (287,9 g kg^{-1}). As a consequence, the majority of soils under investigation was classified as clay loam and loam textured.

Table 1. Descriptive statistics of compositional characteristics of olive oil samples

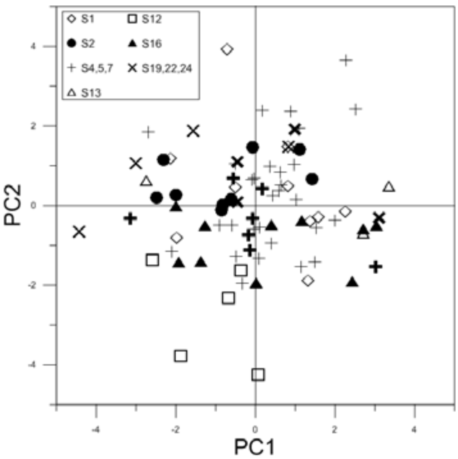
Variable	Min	Max	Mean	CV (%)	Skewness
pH	4.7	5.2	5.0	2.3	-0.3
Total lipids (g/100 g w.w.)	16.6	29.9	23.5	14.5	-0.3
Palmitic ac. C16:0 (%)	10.5	14.8	12.9	7.2	-0.3
Palmitoleic ac.C16:1 (%)	0.5	1.1	0.8	21.4	0.0
Stearic ac. C18:0 (%)	2.0	4.0	2.9	15.8	0.1
Oleic ac. C18:1 (%)	54.7	65.7	59.4	4.2	0.0
Linoleic ac. C18:2 (%)	9.3	12.6	10.8	6.9	0.0
α linolenic ac. C18:3 (%)	0.9	1.9	1.3	16.3	0.7
Arachidic ac. C20:0 (%)	0.1	0.4	0.3	29.1	-0.4
Eicosenoic ac. C20:1 (%)	0.0	0.3	0.1	36.8	-0.1
Behenic ac. C22:0 (%)	0.0	0.2	0.1	37.4	-0.1
Nervonic ac. C24:1 (%)	0.0	0.2	0.1	63.4	-0.6
Total Polyphenols (g GAE/100 w.w.)	0.3	1.7	1.0	18.9	-0.2
Antioxidant activity (mmol Fe(II) (kg w.w.)	27.5	146.8	89.0	23.7	0.1

Table 2. Descriptive statistics of soil samples

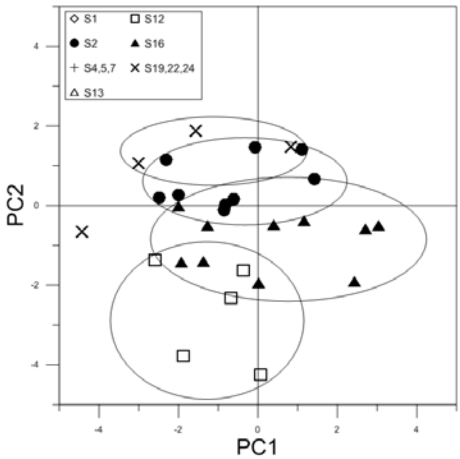
Variable	Min	Max	Mean	CV (%)	Skewness
pH	6.8	8.5	8.0	4.5	-1.4
EC (dS m^{-1})	0.3	2.5	0.5	53.8	5.5
P (mg kg^{-1})	3.1	358.3	43.8	140.5	3.2
Sand (g kg^{-1})	42.2	772.6	336.8	41.7	0.5
Silt (g kg^{-1})	130.7	621.8	375.3	23.3	0.1
Clay (g kg^{-1})	64.0	646.9	287.9	38.7	0.2
$CaCO_3$ (g kg^{-1})	14.0	681.0	155.6	80.1	1.5
OC (g kg^{-1})	5.6	51.8	17.0	40.9	1.6
CEC (cmol[+] kg^{-1})	10.9	42.7	24.9	28.5	0.3
Exch. Ca^{2+} (cmol[+] kg^{-1})	0.9	32.4	15.8	38.9	-0.3
Exch Mg^{2+} (cmol[+] kg^{-1})	0.3	4.9	1.9	48.6	1.1
Exch Na^{+} (cmol[+] kg^{-1})	2.3	11.6	3.0	40.3	5.4
Exch K^{+} (cmol[+] kg^{-1})	0.3	5.8	1.2	51.3	5.4

The OC content, averaging 17.0 g kg^{-1}, was moderately high. Soil reaction was on average slightly alkaline (pH = 8.0), ranging from pH = 6.8 to pH = 8.5. Mean value of cation exchange capacity (CEC) (24.9 cmol(+) kg^{-1}) was high. Mean value of $CaCO_3$ was very high (155.6 g kg^{-1}). According to carbonate content, exchangeable Ca^{2+} dominated the base exchangeable complex, showing a mean value (15.8 cmol(+) kg^{-1}) larger than Mg^{2+} (1.9 cmol(+) kg^{-1}), K^{+} (1.2 cmol(+) kg^{-1}), and Na^{+} (3.0 cmol(+) kg^{-1}). The EC was on average moderate, as 0.5 dS m^{-1}. The CV of the investigated soil properties varied mainly from moderate (sand, silt, clay, OC, CEC, and exchangeable Ca^{2+}, Mg^{2+} and Na^{+}) to high (EC, P, CaCO3, and exchangeable K^{+}). Only for pH the CV was low (4.5). Skewness exhibited relatively small values for sand, silt, clay, CEC, and exchangeable Ca^{2+}, thus indicating that also the distribution of such soil variables was close to the normal. Contrastingly, the skewness of the remaining soil variables exhibited larger values, thus denoting a significant deviation from the normal distribution, likely expressing a larger variability of factors depending on pedological features.

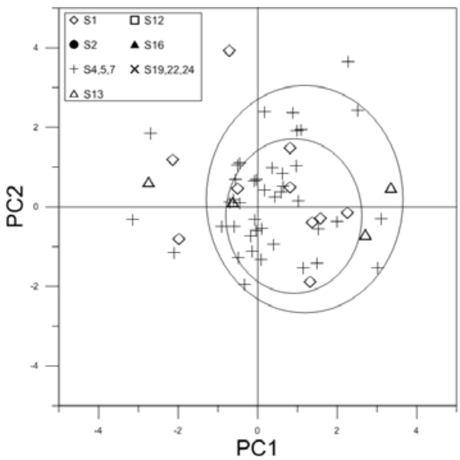
The results of PCA applied to olive oil characteristics revealed that the first two principal components account for more than half of the total variance in the original data set. Figure 4 reports the projection of the samples on the plane defined by the first two principal axes, providing substantial information on the relationships among the olive oil samples from the different pedo-environments.



(a)



(b)



(c)

Fig. 4. Scatterplot of the olive oil sampling sites projected on the plane of the first two Principal Components (PC): (a) all samples projected; (b) only samples from the S19,22,24, S2, S16 and S12 landscape units; (c) only samples from the S1, S4,5,7 and S13 landscape units. ***Legend: S19,22,24 = alluvial plains; S2 = clay-marl hills of Titerno; S16 = Calcareous mountains of Taburno-Camposauro; S12 = sand-clayey hills of Benevento; S1 = arenaceous-molasses deposits hills of Taburno-Camposauro; S4,5,7 = clay-marl and arenaceous-molasses deposits hills of Tammaro, Fortore and Calore; S13 = clay-marl and calcareous hills of Calore.***

Considering the distribution of all samples as a whole (Fig. 4.a), it would seem that there is no a relevant discrimination among samples from the different pedo-environments. However, if we split the samples into two clusters (Figs. 4.b and 4.c) in relation to their pedo-environmental origin, a trend of samples to group in relation to the specificity of pedo-environment appears.

In particular (Fig. 4.b), samples from the sand-clayey hills of Benevento, tend to cluster in the lower left quadrant, and are well separated from samples from the clay-marl hills of Titerno (S2) as well as from those coming from the alluvial plains (S19,22,24) (excluding the sample falling in the left size of the scatterplot, which should be considered as an outlier), which tend to cluster in the middle-upper part of the scatterplot. In turn samples from alluvial plains are well separated from those coming from the calcareous mountains of Taburno-Camposauro (S16). These latter, although evidently clustered in the middle-lower part of the scatterplot, partially overlap with samples from the S2 and S19,22,24 pedo-enviornment. It should be observed that the separation among the different clusters occurs mainly along the second PC axis. This axis is positively correlated (Fig. 5) with polyphenols and antioxidant activity and negatively with α-linolenic (C18:3) and palmitic (C16:0) acids, although the correlation with polyphenols and antioxidant activity is higher, in respect to that with α-linolenic and palmitic acids. In other words, all the above olive oil characteristics contribute to discriminate samples from the so-discussed pedo-environments. It should also be observed (Fig. 4.b) that samples from S19,22,24 are more or less equally distributed along the first and second principal axis. Contrastingly, samples from the remaining pedo-environments tend to be more distributed along the first principal axis which, in turn, is positively correlated (Fig. 5) with the palmitoleic (C16:1) acid and negatively with oleic acid (C18:1) and pH. Such a context, implies a quite relevant within-cluster variability of the above characteristics.

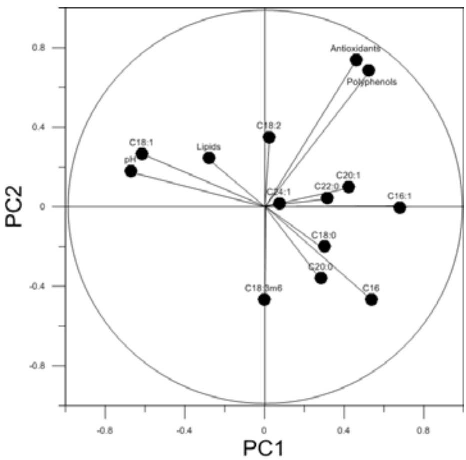


Fig. 5. Contribution of the olive oil components to the first two Principal Components.

Samples from the clay-marl and arenaceous-molasses deposits hills of Tammaro, Fortore and Calore (S4,5,7) (Fig. 4.c), excluding some outliers, tend to cluster mainly in the middle-right part of the PC1-PC2 scatterplot. Also samples from the arenaceous-molasses deposits hills of Taburno-Camposauro (S1) show a tendency to cluster, but within the previous cluster. Both clusters delimited in Fig. 4.c clearly overlap those previously delimited in Fig. 4.b. In other words, the composition of the 'Ortice' olive oil produced in the pedo-environments of the clay-marl and arenaceous-molasses deposits hills of Tammaro, Fortore and Calore and arenaceous-molasses deposits hills of Taburno-Camposauro, although relatively homogeneous, is not clearly distinguished from the composition of the 'Ortice' olive oil produced in the other pedo-environments (Fig. 4.b). Finally (Fig. 4.c) olive oil of samples from the clay-marl and calcareous hills of Calore (S16) shows no clear tendency to cluster. However, this statement must be made with caution, taking into account the small number of samples presently analysed.

Results of PLSR applied to olive oil and soil variables highlighted several significant relationships. In particular, we observed that the first two PLSR components explained together about 70% of the general variance on the initial data set. The first two components were then retained for further interpretation. This was done by plotting the correlation values among soil and olive variables on the factorial x,y planes defined by the first (t1) and second (t2) axes (Fig. 6.a).

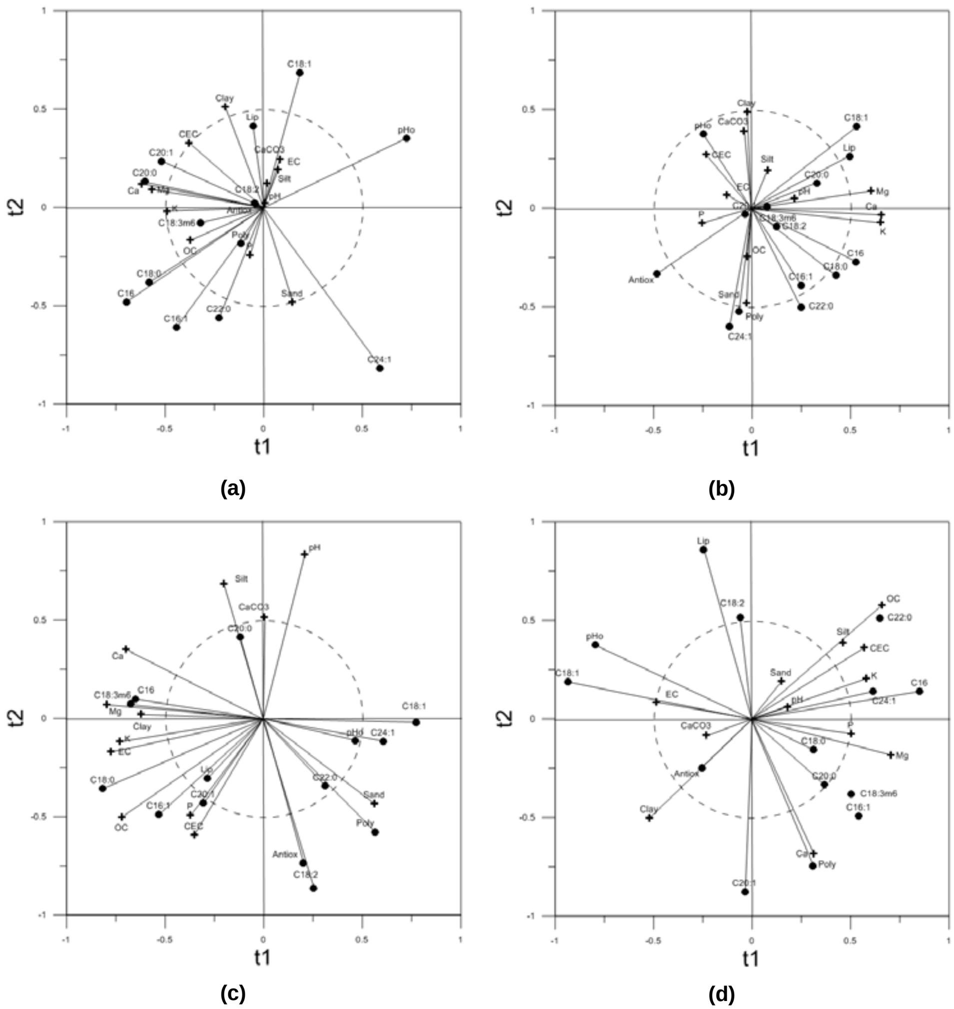


Fig. 6.1. Ordination of soil properties and olive oil components on the t1-t2 factorial plane resulting from the application of Partial Least Squares Regression (PLSR) analysis to: all olive oil and soil samples (a); only samples from landscape units S1 (b), S2 (c) and S3 (d). See captions to figure 4.

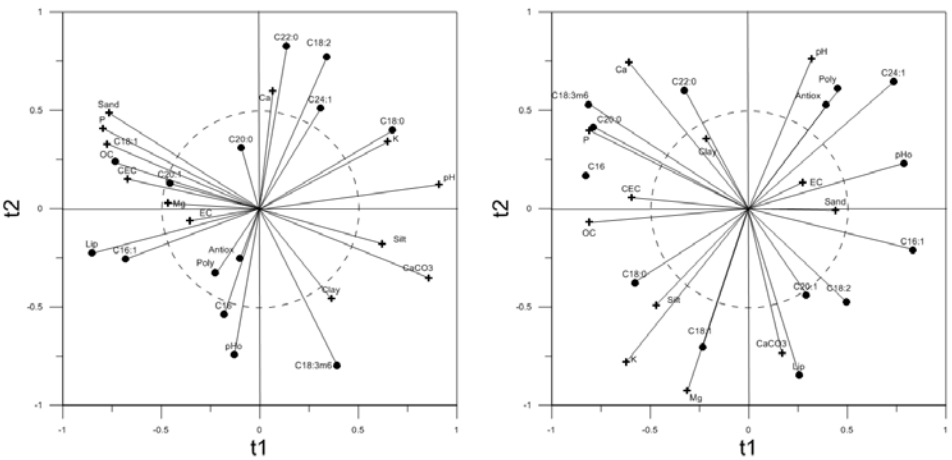
In the interpretation of the factorial plane, it was considered that when two variables are far from the centre, and concurrently close to each other, they are highly and positively correlated; if they are orthogonal, they are not correlated; if they are on the opposite side of the centre, they are highly and negatively correlated. When the variables are close to the centre, it means that some information is carried over on other axes, and that any interpretation might be hazardous. For the purposes of the present study only variables with a factorial value > 0.5 were considered for further interpretation.

The projection of soil and olive variables on the factorial plan defined by the first (t1) and second (t2) axes (Fig. 6.1.a) revealed that a certain number of variables are far from the centre and linked with either one or another of the axes.

In particular, the horizontal axis (t1) ordinates soil CEC, exchangeable Ca^{2+} and Mg^{2+} and olive oil variables C16:0 (palmitic acid) C18:0 (stearic acid), C20:0 (arachidic acid) C20:1 (eicosenoic acid) and pHo (= olive oil pH, to be distinguished by soil pH). This latter is negatively correlated with the remaining olive oil and soil variables. Furthermore CEC, exchangeable Ca^{2+} and Mg^{2+}, C20:0 (arachidic acid) and C20:1 (eicosenoic acid) tend to group together, thus denoting a high correlation each other, compared with the other variables linked to t1.

The vertical axis (t2) ordinates clay, C18:1 (oleic acid), C16:1 (palmitoleic acid), C22:0 (behenic acid) and C24:1 (nervonic acid). Both soil clay content and, particularly, C18:1 are positively correlated with the second axis, then between themselves, although the position of clay in not very far from the origin of axis. The remaining variables are negatively correlated with the second axis, then with clay and C18:1 (oleic acid).

It is interesting to note that, when PLSR is applied to the subset of data defined on the basis of their pedo-environmental origin (Figs. 6.1.b, c, d and 6.2.e, f), the general relationships among soil and olive oil variables tend to be more discriminating and significant. In other words, a better understanding of the influence of soil properties on olive oil composition can be achieved working within individual pedo-environments. Of course, the low number of cases (samples) available for certain pedo-environments can affect the results, although PLSR is a reliable multivariate technique also when the number of variables in low, in respect to the number of cases.



(e) (f)

Fig. 6.2. Ordination of soil properties and olive oil components on the t1-t2 factorial plane resulting from the application of Partial Least Squares Regression (PLSR) analysis to: only samples from the S19,22,24, S2, S16 and S12 landscape units (e); only samples from S4,5,7 and S13 landscape units (f). See captions to Fig. 4.

IV – Conclusions

The preliminary results of the present case study, based on a pedo-environmental approach and supported by multivariate statistical analysis, suggest that the combined geo-pedo-climatic features can affect the olive oil characteristics more than one can expect, beyond the well-known, relevant influence of genetic factors, as well as of production technologies. This is true at least for the investigated area, as Benevento province and for the cultivar 'Ortice'. Therefore, it is possible to assert that:

(i) Different 'Ortice' olive oils, in terms of composition –and then organoleptic features– can be produced in the different pedo-environments of the Benevento province; this aspect can be advantageously considered by producers, to characterise their olive oils on the basis of their pedo-environmental origin;

(ii) A general specificity of the 'Ortice' olive oil of the Benevento province exists, despite slight local (i.e., pedo-environmental) differences; this is important in view of the recognition of the Protected Designation of Origin (PDO).

It must be observed that the number of investigated sites, as well as of olive samples, used in this preliminary paper is still incomplete. A more detailed study will be carried out soon when the whole data set will be available. This will allow to better explore the pedo-environmetal specific relationships among soil and olive oil variables.

On the whole, our results are encouraging enough to delve further into the presented research, foreseeing the chance to widen up the set of data, considering also other relevant olive oils cultivars characterizing the province of Benevento, in addition to 'Ortice'.

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