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Effect of Soil Type on Wines Produced from *Vitis vinifera* L. Cv. Grenache in Commercial Vineyards

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In recent years, the wine industry has become increasingly interested in the influence of the *terroir* characteristics on the features of a wine and, in particular, the mechanisms by which a soil influences wine quality. Among published papers on this topic, most merely describe the effect of the soil; few explain it. In this study were conducted a sensory evaluation and phenolic composition and stilbene concentration tests in order to analyze the effects of soil on wine. Significant differences were found in the results of the tests conducted on two vineyards during two consecutive harvests in 2004 and 2005. The results, in line with previous reports, show that the more fertile of the two vineyards, which was also the one with the greatest water-holding capacity, produced wines that presented significantly lower color intensity and shade, as well as lower total phenolic composition and a smaller quantity of hydroxycinnamic compounds. In 2004, these wines presented significantly higher *trans*-resveratrol content, due to a fungal attack that was favored by the vineyard's soil characteristics. Extreme drought conditions in 2005 had a marked impact on the characteristics of the wines, increasing wavelength measurements significantly and reducing stilbene concentrations. Finally, sensory evaluations revealed significant differences between the wines produced on the two vineyards in both years for five of the seven attributes evaluated. No significant differences were found from one year to the next between the wines produced from the same vineyard, indicating that the attributes of these wines were maintained despite markedly different vintage conditions.

KEYWORDS: Soil; terroir; polyphenols; stilbenes; resveratrol; sensory

INTRODUCTION

Red Grenache (Garnacha Tinta) is one of the world's main grape cultivars. It is the most widely planted red variety in the world and the second most widely planted of all varieties, occupying some 378 000 ha, of which 72% is planted in Spain (where it represents 13.5% of all planted vines), 23% in France, and 2% in the United States (*1*). Red Grenache is a typical Mediterranean grape variety, native to Aragón (Spain). It is vigorous, productive, and resistant to drought. Its wines are full-bodied and alcoholic, with a tendency to oxidize (*2*). β-Damascenone (floral and honey flavors), β-ionone (violet note), and geraniol are considered to be the varietal volatile compounds (*3*). Grenache wines are characterized by berry fruit aromas and by their tendency to resemble esters such as ethyl caproate. They can have a relatively unique fruitiness sometimes described as raspberry and almost candy-like (*1*).

The enology and viticulture of the 1980s and 1990s were characterized by the measures adopted throughout the world to improve technological know-how in the sector. Thanks to these efforts, the sector's sanitary cleanliness, the means of production, and process controls were all improved. As a result, many parameters in the vine growth cycle, juice fermentation, wine aging, and bottling were modified and improved. All of these viticultural and winemaking practices have had a direct influence on wine quality, but the latter remains heavily dependent on other factors, such as the environmental conditions. More recently, the wine industry has turned its attention to these others factors, the so-called *terroir* effect (*4*). This effect is an amalgamation of influences that include climate, landscape (slope, exposure, and the biological and physical environment), soil, and geology (*5*). Many studies have focused on the effects of climate (*6*−*8*), because it is considered to be the main constraining effect. The effects of altitude (*9*), water availability (*10*−*13*), slope (*14*), and exposure (*15*−*18*) on wine have also been evaluated. However, the influence of soil (regarding its texture, depth, chemical composition, fertility, and water availability) on the characteristics of a wine has not been studied so

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Table 1. Meteorological Data from L'Espluga de Francolí Weather Station

	av temp (°C)	rel humidity (%)	av wind speed at 10 m height (m/s)	net solar radiation (MJ/m^2)	rainfall (L/m^2)	ETO (L/m^2)	water balance (L/m^2)
1996–2005	14.4	70.5	3.1	43703.9	3889.2	6762.8	–2874
2004 season	13.1	71	3.5	5092.9	495.4	743.4	–248
vegetative period 2004	17.7	68	3.1	3801.9	283.2	606.6	–323
2005 season	13.5	69	3.4	5020.4	366.2	738.3	–372
vegetative period 2005	19	66	3.1	3702.5	192.6	600.4	–408

widely (*19*, *20*), although, recently, winemakers have shown a growing concern for the effects of soil composition and texture on wine quality (*21*−*23*). A soil provides the vine with nutrients and water, and any chemical composition imbalance will affect vine growth; in addition, the soil texture has a major influence on vine development and consequently on the characteristics of the wine. Factors such as water availability depend heavily on the soil (*11*−*14*), and in turn this can influence vine growing and wine quality. In fact, soil characteristics can help to explain differences in wine quality even within the same region or climate classification.

This paper presents the results of a quite thorough and up-to-date approach to assessing the properties of wine and attempting to relate these to the soil influence. We conducted sensory evaluation, phenolic composition, and stilbene concentration tests to analyze the effects of soil on wines. The first two tests, sensory evaluation and phenolic composition, are indicators of wine quality, whereas the importance of stilbene activity has been widely reported as having beneficial effects for human health (*24*−*26*). The tests were conducted on two commercial vineyards. The vineyards presented almost identical climatic, topographic, and viticultural characteristics and employed the same cultivation techniques and winemaking procedures, but were planted on different soils. Given these circumstances, we assumed that any differences between the wines could be attributed to the soil quality.

MATERIALS AND METHODS

Selection of Experimental Area. We selected two vineyards that could be considered homogeneous in terms of their topographic and climatic (altitude, slope, temperatures, sunshine hours, rainfall) as well as viticultural (plant density, rootstock, pruning, vine training) parameters along with their cultivation techniques, but which were planted on different soils. Given the obvious difficulties involved here, experiments were repeated over 2 years with three samples being tested for each vineyard. Both vineyards are used commercially for winemaking.

The vineyards were chosen according to their soil criteria from the Miguel Torres vineyards in Conca del Barberá Appellation (DO) at Lérida (Spain) near the town of Poblet, at GPS coordinates $X = 339588$ and $Y = 4582949$. The vineyards at each location are separated by a distance of 500 m. The first vineyard, Genovés (hereinafter, Gen) is located at GPS coordinates $X = 339383$ and $Y = 4583080$ and occupies an area of 3.8 ha; the second, Peu del Bosc (hereinafter, PdB), is located at GPS coordinates $X = 339763$ and $Y = 4582579$ and occupies 2.6 ha.

Grape Cultivation. This experiment was conducted during 2004 and 2005 in a large vineyard planted between 1990 and 1993. Vines are R-110 rootstock grafted with *Vitis vinifera* cv. Grenache. All of the vines of each cultivar belonged to the same clone (Clone 70). The Gen vineyard was planted in 1990, whereas the PdB vineyard was planted in 1993. Rows were oriented east/west. The planting density was 4000 vines/ha. The planting distance was 2.2 m × 1 m. The vines were grown using the espalier system and trained with the royat bilateral pruning system, with three renewal spurs per branch. The foliage reached a height of 1.3 m.

For each vineyard, the average yield (estimated according to 10 years of previous experience) is about 17−18 clusters/vine and 0.12−0.14 kg/cluster, which represents 2−2.5 kg/vine. No fertilizers or manures were added, and there was no cover crop. No irrigation or herbicides were used. Grape ripeness in the vineyards was monitored from veraison to harvest, using a refractometer (refractometer Zuzi, 300) for degrees Brix (sugar content in grams per kilogram of grape juice), and standard must analyses were carried out for total acidity (TA) and pH.

Soil Analyses. These two vineyards belong to a network of vineyards established by Miguel Torres S.A. (public corporation). The soils were studied in line with official practices (*27*), using the terminology established by the FAO (*28*) and SSS (*29*) regulations. In addition, all color descriptions listed in this study correspond to those used in the Munsell code (*30*). Soil sampling was conducted according to the *National Soil Survey Handbook* published by the U.S. Department of Agriculture (*31*).

Meteorological Data. Meteorological data (temperature, hours of sunshine, and precipitation) were provided by the Meteocat weather station (*32*) in L'Espluga de Francolí, placed at GPS coordinates $X = 341693$ and $Y = 4584588$. Both vineyards have the same climatic classification, a Mediterranean climate, with hot summers, temperate winters, and low precipitation rates (*32*). Because the vineyards were located less than 500 m apart, the vineyard climates and their altitude, slope, temperatures, sunshine hours, and rainfall amounts were considered to be homogeneous. **Table 1** shows the results observed for average temperature, accumulate precipitation, average humidity, net solar radiation, evapotranspiration, water balance, as an accounting of the inputs and outputs of water, and average wind speed at 10 m height for different periods: from 1996 to 2005, for the seasons 2004 and 2005, and for the 2004 and 2005 vegetative periods (from April to October). The year 2005 was the driest year since 1947 when accumulated rainfall totals were first measured (*33*).

Winemaking (Figure 1). When values of 23−24 °Brix were recorded, the grapes were harvested in accordance with the Torres protocols (ISO 9001 and ISO 14000), based on 10 years of previous vinifications. Grapes were harvested (on October 13, 2004, and on September 19, 2005, at both vineyards) by removing the fruit from one of every five vines until 20 kg had been collected (*11*). Visual inspection of grapes for percentage of *Botrytis* was conducted in accordance with Torres protocols (ISO 9001 and ISO 14000). Grapes were destemmed and crushed, using an AMOS (type AS-511) crusher−destemmer. The paste was then pressed with a pneumatic vertical press, with the press wine recording up to 2 atm. Must from each vineyard was divided into three equal lots (by volume) into 4-L glass jars. Proportional parts of skins and seeds were added to each jar of must in the same proportions as they are found in the grapes (in 2004, 0.75 kg/L for PdB and 0.66 kg/L for Gen; in 2005, 1 kg/L for PdB and 1 kg/L for Gen, indicating that grapes were smaller in 2005). Then 35 mg/L of sulfur dioxide was added. All procedures and analyses were performed separately for each repetition.

At this juncture, the must and the skins were inoculated using *Lalvin* yeast (Fepsa: Rhône L2056) at a rate of 0.3 g/L. Diammonium phosphate was added as a nutrient at 0.2 g/L. Jars were punched once per day. Fermentation in glass jars was conducted at 28 °C, and controls of density and temperature were performed daily. When alcoholic fermentation had been achieved, skins were separated and pressed. Press wine was added to the devatted wine. Wines were transferred to 4-L jars and were then inoculated with 2% v/v active malolactic culture and stored at 20 °C. When the malic acid concentration was <0.1 g/L, the wines were racked and aerated and SO_2 was adjusted at 30−40

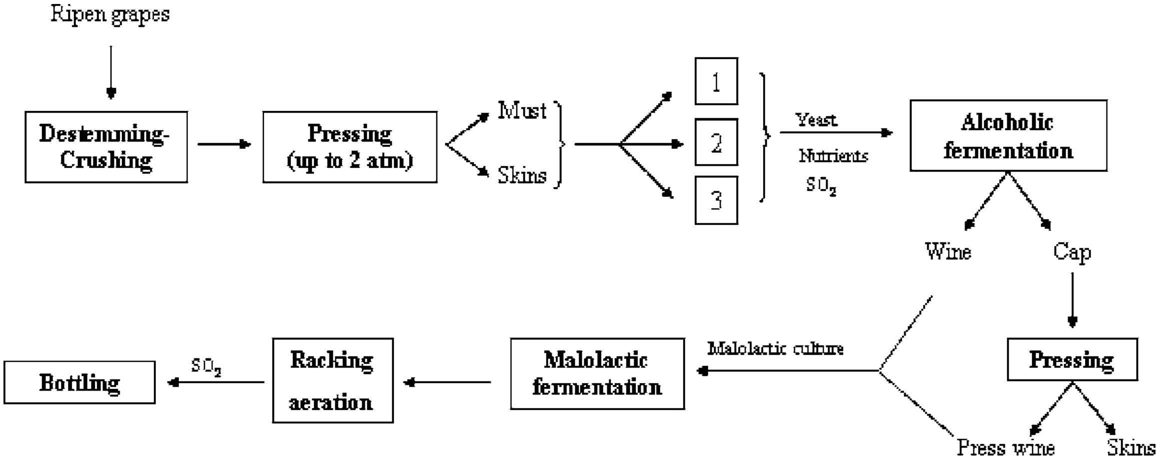

Figure 1. Flow chart for winemaking.

mg/L. Wines were transferred into 0.75-L bottles equipped with caps and stored at 10 °C.

Yeast Determination. Yeast mitochondrial mDNA restriction analyses were also performed to compare and identify individual yeast strains for each must sample when at a density of 1.010 g/L (*34*, *35*).

General Parameters. All must and wine analyses were carefully duplicated for each repetition.

The degrees Brix level in the must samples was monitored using a refractometer (Zuzi, 300); gluconic acid in musts was quantified using an enzymatic method with a cisa 200-Hycel; the alcoholic degree in wines was determined with an Anton-Paar Wine Alcoholyzer; a Basic 20 Crison pH-meter was used to measure pH; in wines, malic acid during malolactic fermentation was measured by using an enzymatic method with a cisa 200-Hycel (*36*); volatile acidity and residuals sugars were determined by IR-NIR.

Measurement of Absorbance. Color in all samples was analyzed by a Helios B Spectronic Unicam spectrophotometer diode array coupled to a Pentium II computer (Millennium software). Absorbance was measured at wavelengths of 280, 320, and 520 nm in 1 mm path length cells and at 420 nm in 10 mm path length cells, using distilled water as the reference blank. In wineries, wine color (*39*) is analyzed using chromatic indexes based on measurements at different wavelengths. Absorbance at 420 nm is related to browning, whereas browning at 520 nm is associated with anthocyanin content; conventionally, and for the sake of convenience, the chromatic characteristics of red and rosé wines are described by the intensity of their color and shade. Color intensity ($A_{420} + A_{520}$) refers to color importance, whereas shade (A_{420}/A_{520}) represents the trend toward orange. Given their significance, absorbances at 280 nm, related to total phenolic content, and absorbance at 320 nm, which corresponds to the maximum absorbance for the hydroxycinnamate group, were also measured.

Stilbene Analysis by HPLC. Stilbene analysis was carried out using an Alliance Waters 2496 instrument equipped with an automatic injection valve, a Waters 996 diode array detector, and a Waters 474 fluorometer. The column used was a Lichrospher 250-4 RP 18 (250 mm × 4.6 mm), 5 μm particle size with a precolumn Lichrocart 4-4 Lichrospher 100 RP 18. Injection was performed by automatic injector, and the volume injected was 20 μL.

The HPLC conditions were set according to those previously described by Poussier et al. (*37*), who used a constant flow rate of 1 mL/min with two solvents: solvent A, water, and solvent B, acetonitrile. All solvents were of HPLC grade, and the elution profile was as follows: 0 min, 90% A, 10% B; 18 min, 15% A, 85% B; 23 min, 15% A, 85% B; 30 min, 90% A, 10% B; 35 min, 90% A, 10% B.

Stilbene Standards. trans-Resveratrol was purchased from Sigma Chemical Co., and *trans*-piceid was purchased from Aldrich. The *cis* forms of the aglycon and glycoside standards were obtained by exposure of the *trans* isomers to sunlight (*38*).

Sample Preparation. All samples were protected from light to avoid light-induced isomerization during sample treatment (using filtration in darkness and an opaque injection valve). Wines were analyzed by direct HPLC injection after filtration through 0.45 μm.

Quantification. The concentration of *trans*-stilbene forms was measured by fluorometry using the external standard method by calibration curves (standard area versus concentration in mg/L: 0.0025−20). *cis*-Resveratrol quantification was assumed as *trans*-resveratrol, and *cis*-piceid was assumed as *trans*-piceid.

Sensory Analyses. A descriptive sensory analysis was conducted by the sensory panel at Bodegas Miguel Torres. The panel, selected on the basis of their availability (*1*), comprised 10 trained wine tasters (ages ranging between 26 and 50 years), all of whom were staff of Bodegas Miguel Torres S.A. During the past 5 years, this tasting panel has met once a week.

The panel was trained in three 1-h sessions held over a month to describe the aromas and mouthfeel properties of these wines. For each wine, the judges were asked to choose the descriptive terms independently. Then, in consultation with the panel members, the list of descriptive terms was reduced by combining related terms. By panel consensus, five aroma and two mouthfeel terms describing sensations were chosen to define the wines. Reference standards were prepared to represent these descriptors and were used during training to calibrate the panel.

Each test session consisted of two wine samples coded with random three-digit numbers, with the order of samples randomized. Judges were trained to rate these attributes on a scale from 0 (not present) to 5 (more intense). Wines from both vineyards were tasted after bottling and were served as 20 mL samples in ISO glasses covered with plastic covers to allow volatiles to equilibrate with the headspaces at 20 °C. Judges were also encouraged to expectorate and to rinse their mouths with water between samples. Sessions lasted approximately 25 min.

Statistics. Statistical analyses were performed using the Statistica (Statsoft, 2001) software package on various wine analyses, including absorbance measurements, stilbene concentrations, and sensory results.

RESULTS AND DISCUSSION

Soil Description. The vineyards were very similar in terms of their geomorphology and temperature regimes (**Table 2**). The soil chemical composition of the vineyards (**Table 3**) makes them both suitable for vine growing (*10*). Both vineyards presented alkaline pH values. The active limestone percentage was considered to be inappreciable for the PdB vineyard and low for the Gen vineyard and, therefore, as having no impact on vine growing. However, organic matter, organic carbon, and potassium contents were considerably higher for the Gen vineyard, increasing soil fertility; consequently, vine nutrition may be improved. The organic matter percentage, a measure closely related to fertility, was 2 times higher in the Gen soil. Consequently, the PdB soil was considered to be poor, whereas the Gen soil was considered to be a rich soil. Potassium

Table 2. Geomorphology and Temperature Regimes of Soil

	PdB	Gen
cartography		
scale	1:5000	1:5000
GPS coordinates	*X*, 339383; *Y*, 4583080	*X*, 339383; *Y*, 4583080
altitude (m)	531	491
temperature and water		
soil humidity regime	Xeric	Xeric
water table	inaccessible	inaccessible
drainage type	good	good
temperature regime	Mesic	Mesic
geomorphology		
relief shape	hillside (slope)	Ejecta cone
slope long	300 m	>500 m
general slope	10%	5%
local slope	10%	5%
orientation	north	north
surface pebbles	abundant pebbles (60–70%), not stony, slates (90%), quartz (10%)	frequent pebbles (10%), not stony, limestone, slates, and conglomerates
AWC (m^3/ha) to 120 m depth	1500	1600
vegetation	natural, removed	natural, removed
use	agricultural, vineyard	agricultural, vineyard
technology	dry	dry, without drainage
classification		
SSS 1999	Haploxerept fluventic, thick loam, mixed active, mesic	Haploxerept fluventic, thick loamy, mixed, active, mesic
FAO/ISSS/ISRIC 1998	Cambisol fluvic eutric	Cambisol fluvic eutric

concentration, which has a positive influence on yield, plant vigor, and drought resistance (*10*), was notably higher for the Gen soil. As shown in **Table 4**, a further difference was the surface pebbles. PdB soil was richer in coarse fraction, and its slate fraction was notably higher, favoring water drainage and reducing its water-holding capacity. By contrast, the clayey-loam texture of the Gen soil increased its water-holding capacity and favored vine development, as was confirmed by the frequent root system even in deep horizons.

Although water and fertile elements are necessary for good vine development, excessive quantities can be detrimental for grape composition, increasing vine vigor and production, promoting rot development, and reducing harvest quality (*2*). By contrast, more restricted water availability combined with low fertility levels has been shown to benefit grape quality (*12*, *40*, *41*). Therefore, given that the PdB soil has less water and is less fertile, we should expect to obtain better quality but a smaller production size from this vineyard.

Grape Maturation. From veraison to harvest, grapes were controlled each week. Considering degrees Brix, pH, and total acidity as maturity indicators, grapes in both vineyards ripened simultaneously (**Table 5**). In 2004, harvesting was undertaken on October 13; degrees Brix (23.9 for vineyard Gen and 23.6 for vineyard PdB), total acidity (6.26 g/L for Gen and 5.9 g/L for PdB), and pH (3.29 for Gen and 2.99 for PdB) values were similar for both vineyards, and therefore wine differences could not be attributed to the state of maturity. Visual inspection confirmed that Gen grapes were 10% affected by gray mold and that PdB grapes appeared to be visually healthy. According to the Torres protocol for the equivalence between gluconic acid concentration (an indicator of *Botrytis cinerea* attack) and percentage *Botrytis* infection, gluconic acid concentration (0.22 g/L for Gen and 0 g/L for PdB) analysis confirmed the visual analyses. In 2005, harvesting was undertaken on September 19; degrees Brix (24.5 for vineyard Gen and 24.5 for vineyard PdB), total acidity (4.95 g/L for Gen and 5.78 g/L for PdB), and pH (3.13 for Gen and 2.97 for PdB) were very similar for both vineyards, and as such wine differences could not be attributed to the state of maturity. After visual inspection, Gen and PdB grapes were found to be healthy. This was confirmed by the gluconic acid concentration (0.05 g/L for both vineyards).

General Parameters. All values obtained from the wine analyses were within the legal intervals established by the European Union (**Table 5**). A comparison of the 2004 wines, alcohol degree (Gen, 14.05 ± 0.63, and PdB, 13.31 ± 0.24), total acidity (Gen, 5.01 ± 0.55 g/L, and PdB, 5.98 ± 0.09 g/L), and pH (Gen, 3.85 ± 0.01, and PdB, 3.41 ± 0.02), showed them to be similar, as was expected following the maturation analyses. Likewise, a comparison of the 2005 wines, alcohol degree (for Gen, 13.05.±0.15, and for PdB, 12.31 ± 0.85), total acidity (for Gen, 5.24 ± 0.22 g/L, and for PdB, 5.51 ± 0.55 g/L), and pH (for Gen, 3.49 ± 0.03, and for PdB, 3.42 ± 0.05) showed them to be similar, as was also expected following the maturation analyses.

Yeast Strain. m-DNA was analyzed by UV for both fermentations; the fermenting yeast was the same (data not shown). Moreover, following a comparison of patterns, it could be deduced that the fermenting yeast was Rhône L2056, which was the inoculated yeast. Thus, the differences found between both wines could not be attributed to the yeast.

Total Phenolic Content and Absorbance Measurements. In 2004, when the PdB and Gen vineyards were compared, all absorbance measurements (**Table 5**) were found to be significantly different ($p \leq 0.01$). Wine chromatic characteristics and color intensity were significantly higher for PdB wines, whereas shade was significantly lower for these wines. Absorbances at 280 and 320 nm were also significantly higher for PdB wines, indicating the higher concentration of total polyphenols and hydroxycinnamates in PdB wines. These differences could be attributed to the influence of soil. PdB horizons presented an important coarse fraction, 99% of which are slates. These coarse elements, including slates, are unable to retain water, resulting in less water-holding capacity of soil (AWC in **Table 2**), which may affect vine development. These conditions have been shown to increase phenolic content and to favor anthocyanin synthesis (*12*, *40*, *41*). Moreover, Gen soil was more fertile. Fertility has been described (*10*) as a factor that increases vine vigor and vegetative development, increasing production size but decreasing color matter and phenolic content. As alcohol degree, total acidity, and pH were quite similar for both wines, aging could be estimated according to phenol content and chromatic indexes (*42*, *43*). It seems then that PdB wines may age longer while their color may remain stable for a longer period of time. PdB wines recorded significantly higher levels in all wavelength measurements, so it can be concluded that PdB soil is more suitable for producing wines for aging (*42*, *43*). Likewise, in 2005, a similar tendency as in 2004 was observed when results for PdB and Gen vineyards were compared; however, the differences were not so pronounced. Absorbance measurements at 280, 320, 420, and 520 nm and color intensity were significantly higher ($p \leq 0.01$) for PdB wines, whereas their shade value was significantly lower ($p \leq 0.01$). However, in this harvest, these differences were not so pronounced because of the extreme drought in 2005 (*33*). The water-holding capacity of a soil is constant, but in 2005 the water-supply buffer effect of soil diminished because no water was accumulated. Even though the Gen soil had a greater water-holding capacity (AWC in **Table 2**), precipitation levels were so low in 2005 that Gen vines could not obtain as much water from the soil's reserve water supply as they had in 2004.

For the 2004 and 2005 seasons, results were significantly different ($p \leq 0.01$) for both wines. Absorbance measurements at 280, 320, 420, and 520 nm were significantly higher in 2005.

Table 3. Soil Horizon Sequence Properties

	horizon	depth (m)	pH (H_2O 1:2.5)	EC 1:5 (dS/m, 25 °C)	organic matter (%)	organic carbon (%)	N Kjeldahl (%)	C/N	active limestone (%)
PdB	Ap1	0–0.15/0.20	8.2	0.15	0.9	0.52	0.14	3.71	tr
	Ap2	0.15/0.20–0.45	7.9	0.18	0.7	0.41	0.10	4.10	tr
Gen	Ap1	0–0.17/0.25	8.3	0.20	1.8	1.05	0.22	4.77	3
	Ap2	0.17/0.25–0.4	8.2	0.22	1.7	0.99	0.18	5.5	2

	fertility					particle size analysis (%)		
	P Olsen (mg/kg)	K $AcONH_4$ (mg/kg)	$CaCO_3$ (%)	Mg^{2+} (cmol+/kg)	K^+ (cmol+/kg)	sand (2–0.05 mm)	silt (0.05–0.002 mm)	clay (<0.002 mm)
PdB	35	115	tr	1.0	0.3	44.8	30.9	24.3
	23	84	tr	1.0	0.2	37.7	36.3	26.0
Gen	31	377	14	0.9	1.0	49	34.1	16.9
	27	230	12	0.9	0.6	48.6	32.4	19.0

Table 4. Soil Description

	depth (cm)	horizon	color	mottling	coarse fraction[a]	slate (%)	texture	consistency	structure	root system
PdB	0–15/20	Ap1	10YR 3/2	no	very common	99	loam	little compact	fine, granular, weak	common, thin and thick
	15/20–45	Ap2	7.5 YR 3.5/3	no	very common	99	loam	compact, friable	strong, very thick	abundant, thin and thick
	45–75	Bw1	7.5 YR 3/4	no	very common	99	loam	compact, friable	1, airy strong, very thick 2, airy, moderate, thick	little, thin and very thin
	75–100	Bw2	7.5 YR 3/3	no	abundant	85	loam	compact, friable	weak	common, thin and medium
	100–130	Bk (gravel)	10 YR 4/3	no	very abundant	90	loam	very compact, friable	without	little, thin and very thin
Gen	0–17/25	Ap1	7.5 YR 3/4	no	common	80	loam	little compact, very friable	very weak	very little, thin and very thin
	17/25–40	Ap2	7.5 YR 3.5/4	no	very common	80	loam	very compact, friable	1, airy, strong, very thick 2, airy, moderate, thick	abundant, from very thin to thick[b]
	40–83	2Bw1	7.5 YR 4/4	no	very common	80	clayey-loam	very compact, firm	1, airy, very strong, thick 2, airy, weak, medium	common from very thin to medium[b]
	83–120	3Bw2 (gravel)	7.5 YR 4/6	no	abundant	80	clayey-loam	very compact, firm	1, airy, moderate, thick 2, airy weak, medium	common, from very thin to thick[b]

[a] Coarse fraction %: very few, <1%; few, 1–5%; common, 6–15%; very common, 16–35%; abundants, 36–70%; very abundant, >70%. [b] Root penetration is restricted by a compacted horizon.

This may be attributed to the drought conditions recorded in 2005 (*33*). Under such conditions, it has been reported that phenolic content will increase (*12*, *40*, *41*). In 2005 wine shade was significantly lower and color intensity significantly higher. These results indicate that 2004 wines presented less color and an orange tinge. As ripening degree was similar and the winemaking and agronomical factors were the same, evolution will be conditioned by polyphenol content and chromatic indexes (*42*, *43*). Thus, it can be estimated that the 2005 wines will age better than those of 2004. In addition, differences between 2004 and 2005 Gen wines were greater than differences between 2004 and 2005 PdB wines. Again, soil influence may explain it. On PdB, the higher coarse fraction of the soil favors water drainage and the soil accumulates less water; consequently, PdB wines are less affected by drought. Moreover, 2004 PdB results were not significantly different from 2005 Gen results, meaning that under drought conditions, Gen soil behaved as PdB soil, under normal conditions. This shows the relevance of a soil's water supply buffer effect, which depends on its coarse fraction.

Stilbene Concentration. When the two vineyards were compared, in 2004, *trans*-resveratrol level was significantly higher ($p < 0.01$) for Gen wines than for PdB wines. This result is consistent with previous reports (*44*, *45*) because Gen grapes

Table 5. Results Obtained from Grape and Wine Analysis

	2004		2005	
	Gen	PdB	Gen	PdB
grape analysis				
°Brix	23.6	23.9	24.7	24.9
TA (g/L)	5.9	6.26	4.81	5.78
pH	2.99	3.29	3.03	2.97
gluconic acid (g/L)	0	0.22	0.05	0.06
wine analysis				
alcohol degree (%)	14.05 ± 0.63	13.31 ± 0.24	13.05 ± 0.15	12.31 ± 0.85
TA (g/L)	5.01 ± 0.55	5.98 ± 0.09	5.24 ± 0.22	5.51 ± 0.55
pH	3.85 ± 0.01	3.41 ± 0.02	3.49 ± 0.03	3.42 ± 0.05
absorbances				
A_{280}	20.2 ± 2.3	43.1 ± 3	37.0 ± 1.1	50.1 ± 0.4
A_{420}	0.9 ± 0.2	2.9 ± 0.2	2.3 ± 0.2	3.6 ± 0.3
A_{520}	0.6 ± 0.0	2.0 ± 0.0	2.2 ± 0.3	4.2 ± 0.2
A_{320}	9.1 ± 0.7	16.2 ± 1.4	15.5 ± 0.5	19.3 ± 0.5
color intensity	1.5 ± 0.2	4.8 ± 0.3	4.6 ± 0.4	7.9 ± 0.5
shade	1.7 ± 0.3	0.7 ± 0.0	1.0 ± 0.1	0.8 ± 0.0
stilbene (mg/L)				
trans-piceid	3.89 ± 0.60	2.45 ± 0.17	1.05 ± 0.08	1.25 ± 0.27
cis-piceid	11.56 ± 2.33	10.69 ± 1.68	1.08 ± 0.04	1.21 ± 0.03
trans-resveratrol	1.06 ± 0.04	0.37 ± 0.02	0.24 ± 0.05	0.01 ± 0.00
cis-resveratrol	0.36 ± 0.05	0.30 ± 0.00	0.10 ± 0.03	0.00 ± 0.00
total amount	16.86 ± 3.03	13.81 ± 1.53	2.47 ± 0.15	2.47 ± 0.31

Table 6. Reference Standards for Panels[a]

fresh fruit	fresh fruity wine
ripe fruit	Mistela wine
apple peel	2 mL/L of ethanal, 0.2%
vegetal	0.4 mL/L of *trans*-2-hexenol, 0.1%
raisin	mellow wine from 1996
density	5 g/L of carboxymethylcellulose (Sigma-Aldrich)
astringency	1.5 g/L of tannin

[a] Unless otherwise indicated, materials were added to 100 mL of neutral base red wine. References were prepared 1 h before evaluation and presented in ISO glasses.

were slightly affected by *B. cinerea*, and the infection with this mold increases resveratrol synthesis. As the environmental factors, with the exception of soil characteristics, and the agronomical and winemaking practices were constant for both wines, it can be concluded that the significant differences in *trans*-resveratrol concentrations are due, therefore, to the soils. Gen soil is more fertile, and its water-holding capacity is higher, which favors rot development (*1*). In 2005, *trans*-resveratrol is again significantly higher ($p < 0.001$) in Gen wines than in PdB wines, but both are lower than in 2004, due to the drought conditions of 2005. Previous reports (*46*−*49*) suggest that lower resveratrol contents are typical of warm, dry climatic conditions and related to higher temperatures, which occurred in 2005.

From a comparison of Gen results, 2004 wines presented significantly ($p \leq 0.01$) higher *trans*- and *cis*-piceid, *trans*-resveratrol, and total stilbene concentration than 2005 wines. As commented previously, in 2004, Gen grapes were slightly affected by *B. cinerea*, which has been shown to increase resveratrol concentration. As well, 2005 PdB wines had significantly ($p \leq 0.01$) lower levels than 2004 for *cis*-piceid, *trans*-resveratrol, and total stilbene. The relationship between low *trans*-resveratrol levels and higher temperatures or dry climate has been reported (*46*−*49*). Differences between 2004 and 2005 were greater for Gen wines than for PdB wines, meaning that there is a stronger influence of soil in a season with moderate precipitation compared to a season with low precipitation. Again, this may be explained by the different characteristics of the soils. Due to its loam-clayey texture and its less coarse fraction, the water-supply buffer effect of Gen soil diminishes notably during a drought season. This soil is not able to retain as much water as in the previous year. Moreover, *trans*-resveratrol in 2005 Gen wine was not significantly different from the 2004 PdB result, so under drought conditions, as observed for total phenolic results, Gen soil may behave as PdB soil, under normal conditions.

Interestingly, for the 2005 harvest, when the weather was so dry (*33*), the stilbene concentrations were extremely low for both vineyards. Equally low *trans*-resveratrol concentrations have been mentioned in Japanese wines (*50*).

Sensory Analyses. ANOVA was performed to characterize sensory differences between wines in terms of color, taste, and aroma analyses. Visual color inspection was consistent with chromatic indexes and absorbance results. We observed that in 2004 and 2005, Gen wines presented significantly less color and with the shade tending to orange, whereas PdB wine colors were defined by the panel as red-purple and more intense. For both years, five of the seven attributes (**Table 6**) were found to be significantly different ($p < 0.01$), and their mean scores are shown as a cobweb plot in **Figure 2**. Gen wines were characterized by higher intensities of raisin and ripe fruit aromas and greater density of mouthfeel. By contrast, PdB wines were described as presenting a higher apple peel aroma and astringency. Considering its color characteristics and higher astringency, the sensory panel estimated that PdB wines were more suitable for aging. This is consistent with results of absorbance measurements. The sensory differences may be attributed to the soil influence because all of the other factors, climatic, agronomical, and winemaking, were the same.

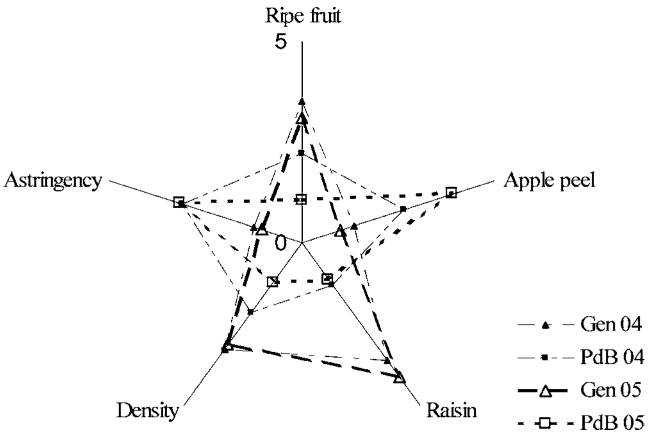

Figure 2. Cobweb vineyard for 2004 and 2005.

If we compare 2004 and 2005 results for each vineyard, the values were not significantly different. This indicates that the wines' sensory attributes were similar and remained constant from one year to the next.

Several authors (*51*, *52*), using gas chromatography−olfactometry, have tried to establish a hierarchy of the contributions made by compounds to wine aroma and conclude that fruity, phenolic, flowery, and balsamic notes are the main aromas in a Grenache wine. Sabon et al. have shown the influence of terroir features on some varietal volatile compounds of Grenache wines from the Rhone Valley (*3*). However, these studies do not show if these compounds are significant contributors to the flavor of Grenache wines, because there were no sensory analyses.

In conclusion, at the same grape ripening degree, soil may affect wine characteristics. Wines issued from the richer soil and with the less coarse fraction presented less total phenolic content and color intensity, but higher stilbene concentration. Drought seems to have a remarkable effect on more fertile soil with less coarse fraction (particularly slate content). The infuence of soil is stronger in a season with moderate rainfall (2004), compared to a season with low rainfall (2005). Under heavy drought conditions, Gen soil (more fertile and with higher water-holding capacity) may behave as PdB soil (less fertile and with lower water-holding capacity) under normal conditions. With regard to sensory analyses, significant differences between the wines produced from the two vineyards were observed. Wines could be described using five attributes: apple peel, ripe fruit, astringency, density, and raisin. Interestingly, for both years, the climatic conditions being very different, the same attributes were used to describe the wines.

Future studies will be needed using other red and white varieties and soils with different characteristics; however, there are some difficulties in finding vineyards that have the same agronomical characteristics and differ only in soil.

LITERATURE CITED

(1) Boulton, R.; Singleton, V. L.; Bisson, L. F.; Kunkee, R. E. V. *Principles and Practices of Winemaking*, 1st ed.; Springer, Chapman and Hall: New York, 1996.

(2) Hidalgo, L. El suelo vitícola. In *Tratado de Viticultura General*, 2nd ed.; Mundi-Prensa Ediciones: Madrid, Spain, 1999; pp 229−250.

(3) Sabon, I.; de Revel, G.; Kotseridis, Y.; Bertrand, A. Determination of volatile compounds in Grenache wines in relation with different terroirs in the Rhone Valley. *J. Agric. Food Chem.* **2002**, *50*, 6341−6345.

(4) Lila, M. A. Perspective. The nature-versus-nurture debate on bioactive phytochemicals: the genome versus terroir. *J. Sci. Food Agric.* **2006**, *86*, 2510−2515.

(5) Falcetti, M. The 'terroir'. What is the 'terroir'? Why study it? Why teach it? *Bull. O. I. V.* **1994**, *67*, 246−275.

(6) Jackson, D. I.; Lombard, P. B. Environmental and management practices affecting grape composition and wine quality—a review. *Am. J. Enol. Vitic.* **1993**, *44*, 409−430.

(7) Shaw, A. B. The emerging cool climate wine regions of Eastern Canada. *J. Wine Res.* **1999**, *10*, 79−94.

(8) Due, G. Climate and wine: effects on quality and style. *Aust. N. Z. Wine Ind. J.* **1995**, *10*, 70−71.

(9) Mateus, N.; Marques, S.; Goncalves, A. C.; Machado, J. M.; Freitas, V. Proanthocyanidin composition of red *Vitis vinifera* varieties from the Douro Valley during ripening: influence of cultivation altitude. *Am. J. Enol. Vitic.* **2001**, *52*, 115−121.

(10) Chone, X.; Leeuwen, C.; Chery, P.; Ribereau-Gayon, P. Terroir influence on water status and nitrogen status of non-irrigated Cabernet Sauvignon (*Vitis vinifera*). Vegetative development, must and wine composition (example of a Medoc top estate vineyard, Saint Julien area, Bordeaux, 1997). *S. Afr. J. Enol. Vitic.* **2001**, *22*, 8−15.

(11) Kennedy, J. A.; Matthews, M. A.; Waterhouse, A. L. Effect of maturity and vine water status on grape skin and wine flavonoids. *Am. J. Enol. Vitic.* **2002**, *53*, 268−274.

(12) Roby, G.; Harbertson, J. F.; Adams, D. A.; Matthews, M. A. Berry size and vine water deficits as factors in wine grape composition: anthocyanins and tannins. *Aust. J. Grape Wine Res.* **2004**, *10*, 100−107.

(13) Reynolds, A. G.; Naylor, A. P. Pinot noir and Riesling grape vines respond to water stress duration and soil water-holding capacity. *HortScience* **1994**, *29*, 1505−1510.

(14) Mazza, G.; Fukumoto, L.; Delaquis, P.; Girard, B.; Ewert, B. Anthocyanins, phenolics and color of Cabernet Franc, Merlot, and Pinot Noir wines from British Columbia. *J. Agric. Food Chem.* **1999**, *47*, 4009−4017.

(15) Price, S. F.; Breen, P. J.; Valladao, M.; Watson, B. T. Cluster sun exposure and quercetin in Pinot noir grapes and wine. *Am. J. Enol. Vitic.* **1995**, *46*, 187−194.

(16) Tsanova-Savova, S.; Ribarova, F. Free and conjugated myricetin, quercetin, and kaempferol in Bulgarian red wines. *J. Food Compos. Anal.* **2002**, *15*, 639−645.

(17) Spayd, S. E.; Tarara, J. M.; Mee, D. L.; Ferguson, J. C. Separation of sunlight and temperature effects on the composition of *Vitis vinifera* cv. Merlot berries. *Am. J. Enol. Vitic.* **2002**, *53*, 171−182.

(18) Bergqvist, J.; Dokoozlian, N.; Ebisuda, N. Sunlight exposure and temperature effects on berry growth and composition of Cabernet Sauvignon and Grenache in the central San Joaquin Valley of California. *Am. J. Enol. Vitic.* **2001**, *52*, 1−7.

(19) Seguin, G. Terroirs and pedology of wine growing. *Experientia* **1986**, *42*, 861−873.

(20) van Leeuwen, C.; Friant, P.; Chone, X.; Tregoat, O.; Koundouras, S.; Dubourdieu, D. Influence of climate, soil, and cultivar on terroir. *Am. J. Enol. Vitic.* **2004**, *55*, 207−217.

(21) Turner, P.; Creasy, G. Terroir. Competing definitions and applications. *Wine Ind. J.* **2003**, *18*, 48−55.

(22) Smart, R. Terroir reconsidered. The new New World approach to wine quality. *Wine Ind. J.* **2003**, *18*, 42−43.

(23) Tinney, M. C. Is terroir more than just a place?; 2005; http://www.winebusiness.com/ReferenceLibrary/webarticle.cfm?dataId=34053.

(24) Lamuela-Raventos, R. M.; Waterhouse, A. L. Resveratrol and piceid in wine. *Oxid. Antioxid.* **1999**, *299*, 184−190.

(25) Meishiang, J.; Lining, C.; Udeani, G. O., et al. Cancer chemopreventive activity of resveratrol, a natural product derived from grapes. *Science* **1997**, *275*, 218−220.

(26) Frankel, E. N.; Waterhouse, A. L.; Teissedre, P. L. Principal phenolic phytochemicals in selected California wines and their antioxidant activity in inhibiting oxidation of human low-density lipoproteins. *J. Agric. Food Chem.* **1995**, *43*, 8940−8944.

(27) Klute, A. *Methods of Soil Analysis*; ASA and SSSA: Madison, WI, 1986.

(28) www.fao.org 2001.

(29) www.soils.org/index.html 2005.

(30) Munsell Color. *Munsell Soil Color Charts*; Macbeth Division of Kollmorgen Instruments Corp.: Baltimore, MD, 1990.

(31) U.S. Department of Agriculture, Natural Resources Conservation Service, 2005. *National Soil Survey Handbook, Title 430-VI*; http://soils.usda.gov/technical/handbook/.

(32) www.meteocat.org, Generalitat de Catalunya, 2005.

(33) www.inm.es/web/izq/noticias/archivo/20050401.html.

(34) Querol, A.; Barrio, E.; Huerta, T.; Ramon, D. Molecular monitoring of wine fermentations conducted by active dry yeast strains. *Appl. Environ. Microbiol.* **1992**, *58*, 2948−2952.

(35) Sambrook, J.; Fristch, E.; Maniatatis, T. *Molecular Cloning*; Cold Spring Harbor Laboratory Press: Cold Spring Harbor, NY, 1989.

(36) *Off. J. Eur. Communities* **1990** (Oct 3), 192 (Regulation CEE 26776/1990).

(37) Poussier, M.; Guilloux-Benatier, M.; Torres, M.; Heras, E.; Adrian, M. Influence of different maceration techniques and microbial enzymatic activities on wine stilbene content. *Am. J. Enol. Vitic.* **2003**, *54*, 261−266.

(38) Romero-Perez, A. I.; Lamuela-Raventos, R. M.; Waterhouse, A. L.; Torre-Boronat, M. C. Levels of *cis*- and *trans*-resveratrol and their glucosides in white and rose *Vitis vinifera* wines from Spain. *J. Agric. Food Chem.* **1996**, *44*, 2124−2128.

(39) Glories, Y. La couleur des vins rouges. *Connaiss. Vigne Vin* **1984**, *18* (4), 253−271.

(40) Salon, J. L.; Chirivella, C.; Castel, J. R. Response of cv. Bobal to timing of deficit irrigation in Requena, Spain: water relations, yield, and wine quality. *Am. J. Enol. Vitic.* **2005**, *56*, 1−8.

(41) Koundouras, S.; Marinos, V.; Gkoulioti, A.; Kotseridis, Y.; van Leeuwen, C. Influence of vineyard location and vine water status on fruit maturation of nonirrigated cv. Agiorgitiko (*Vitis vinifera* L.). Effects on wine phenolic and aroma components. *J. Agric. Food Chem.* **2006**, *54*, 5077−5086.

(42) Cheynier, V.; Dueñas-Paton, M.; Salas, E.; Maury, C.; Souquet, J.; Sarni-Manchado, P.; Fulcrand, H. Structure and properties of wine pigments and tannins. *Am. J. Enol. Vitic.* **2006**, *57*, 298−305.

(43) Waterhouse, A.; Laurie, V. F. Oxidation of wine phenolics: a critical evaluation and hypotheses. *Am. J. Enol. Vitic.*, **2006**, *57*, 306−313.

(44) Jeandet, P.; Bessis, B.; Maume, B. F.; Meunier, P.; Peyron, D.; Trollat, P. Effect of enological practices on the resveratrol isomer content of wine. *J. Agric. Food Chem.* **1995**, *43*, 316−319.

(45) Roldan, A.; Palacios, V.; Caro, I., et al. Resveratrol content of Palomino fino grapes: influence of vintage and fungal infection. *J. Agric. Food Chem.* **2003**, *51*, 1464−1468.

(46) Siemann, E. H.; Creasy, L. L. Concentration of the phytoalexin resveratrol in wine. *Am. J. Enol. Vitic.* **1992**, *43*, 49−52.

(47) Versari, A.; Parpinello, G. P.; Tornielli, G. B.; Ferrarini, R.; Giulivo, C. Stilbene compounds and stilbene synthase expression during ripening, wilting, and UV treatment in grape cv. Corvina. *J. Agric. Food Chem.* **2001**, *49*, 5531−5536.

(48) Nikfardjam, M. S. P.; Márk, L.; Avar, P.; Figler, M.; Ohmacht, R. Polyphenols, anthocyanins, and *trans*-resveratrol in red wines from the Hungarian Villány region. *Food Chem.* **2006**, *98*, 453−462.

(49) Yasui, Y.; Yunoki, K.; Naito, A.; Kawaguchi, M.; Ohnishi, M. Effects of weather conditions and aging on resveratrol concentration in red wines. *J. Jpn. Soc. Food Sci. Technol.* **2002**, *49*, 220−227.

(50) Okuda, T.; Yokotsuka, K. *Trans*-resveratrol concentrations in berry skins and wines from grapes grown in Japan. *Am. J. Enol. Vitic.* **1996**, *47*, 93−99.
(51) Ferreira, V.; Ortin, N.; Escudero, A.; Lopez, R.; Cacho, J. Chemical characterization of the aroma of Grenache rose wines: aroma extract dilution analysis, quantitative determination, and sensory reconstitution studies. *J. Agric. Food Chem.* **2002**, *50*, 4048−4054.
(52) Marti, M. P.; Mestres, M.; Sala, C.; Busto, O.; Guasch, J. Solid-phase microextraction and gas chromatography olfactrometry analysis of successively diluted samples. A new approach of the aroma extract dilution analysis applied to the characterization of wine aroma. *J. Agric. Food Chem.* **2003**, *51*, 7861−7865.

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