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ORIGINAL RESEARCH ARTICLE

Exploring the aromatic typicity of blended red wines from geographically close sub-regions in AOC Corbières: a sensory and chemical approach

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ABSTRACT

Several studies have reported a terroir effect on monovarietal wines originating from geographically close areas, using both aromatic and sensory analyses. However, few studies have evaluated this effect on blended wines, a widespread practice that is recognised as adding great complexity to wines. This study aimed to discriminate blended wines produced in five sub-regions of the Corbières AOC according to their aromatic and sensory profiles and across two vintages: 2018 and 2019. The wines' aromatic profiles were semi-quantified using HS-SPME-GC-MS, and the sensory descriptors enabling the differentiation of the wines were identified by QDA analysis. Although blending is a frequently used process adapted for the production of homogeneous wines within an appellation, the sensory and chemical profiles enabled us to differentiate wines of the Lagrasse and Lézignan sub-regions from those of the Maritime and Durban sub-regions. The variation in intensity of red fruit jam notes may be linked to terroir factors relating to the micro-climatic conditions. Wines from vineyards in coastal regions or at higher elevations were discriminated by lower intensities of this descriptor. However, other discriminating descriptors, such as amyl, earthy or cooked vegetables, could be related to the winemaking process. Correlations were found between the tendencies observed regarding the sensory markers (such as red fruit jam, butter/lactic, amylic, cooked vegetable) and those regarding the chemical families of aroma or specific aroma compounds (such as ethyl esters, higher alcohols and sulphur compounds), whose production is particularly affected by the winemaking processes. Finally, this study shows that it is possible to discriminate blended wines from different geographically close regions, and that the terroir factor with the greatest influence on this discrimination seems to be linked to winemaking processes, including the type of blending carried out.

KEYWORDS: Red-blended-wines, typicity, *terroir*, aroma compounds, sensorial descriptors

INTRODUCTION

The production of wines that are easily identifiable by consumers and that possess unique sensory properties and composition is of high importance for wine producers. For this purpose, the products must express their *terroir*, a concept comprising the interactions between a place (topography, climate and soil), the people (tradition, winemaking and viticultural practices) and the resulting product (grape varieties and wines). For the "Old-World" European wine producing countries, provenance and regional typicity play a key role in the trading of high quality wines (Maitre *et al.*, 2010). Terroir-linked typicity (or typicality) can be preserved through the regulation of human intervention by regional appellations stipulating, for example, the authorised grape varieties, minimum alcohol levels and viticultural and oenological practices.

Aromatic compounds can significantly contribute to defining a wine's "typicity" depending on their concentration and interactions with other molecules. These compounds have different origins, being either i) present in the grapes and later released during the winemaking process (primary aromas), ii) produced by yeast metabolism during fermentation (secondary aromas), or (iii) revealed during wine ageing (tertiary aromas). The concentrations of primary aroma compounds in grapes depends on environmental vine conditions, such as soil, climate and grape variety; these parameters all influence the aromatic signature of the resulting wine. However, in the current climate change context, there is a growing need for the integration of human know-how and skills in order to achieve optimal terroir's expression. The application of certain viticultural practices, such as irrigation or nitrogen fertilisation, can ensure optimal vegetative and aromatic ripeness. Vinification processes involving alcohol-tolerant yeasts, temperature regulation during fermentation and blending operation can also help producers achieve the wine's desired aromatic profile.

Characterising the typicity of wines and establishing a link between this typicity and the terroir is a major challenge for the wine sector. Indeed, while terroir may be a means of reinforcing the image, reputation and the overall consumer perception of wines and their production location, the scientific study of terroir is difficult mainly due to the multiple factors involved: from climate, soil, and cultivar to human factors, such as history and socio-economics along with viticultural and oenological techniques.

The terroir effect on the aromatic and sensory profiles of wines has been the subject of many studies, but few studies have focused on territories in close geographical proximity. Sabon *et al.* (2002) studied the volatile profile of Grenache wines from different terroirs of the Rhone Valley; focusing on soil type, they observed that Grenache wines originating from dry gravel soils contained more β-damascenone and geraniol, while those originating from cooler soils, with higher water holding capacity tended to contain more β-ionone and cis hex-2-enol. In another study, Úbeda *et al.* (2017) analysed commercial wines originating from six sub-regions of Maule Valley (Chile) and were able to link differences in aromatic profile to the proximity of the sub-regions to the Andes Mountains or the Pacific Ocean. In a broader study, Kustos *et al.* (2020) carried out both aromatic and sensory analyses to evaluate the effects of two sub-regions on the typicality of Shiraz commercial wines. Similarities were found between the wines produced in the two regions, pointing to possible similarities in terms of climate and winemaking traditions between both regions. Finally, Leriche *et al.* (2020) studied the typicity of blended red wines from geographically close areas of Languedoc-Roussillon, using a sensory panel made up of wine sector professionals from inside and outside the study areas; they were able to identify the sensory typicity of five of the six studied terroirs.

In the South of France, the AOC Corbières is one of the most renowned appellations of the Languedoc region, with an area of over 8500 ha and the production of mostly red wines (> 85%) derived from blends of four main varieties: Syrah, Grenache, Carignan and Mourvèdre. The denomination is delimited by Mediterranean coastal and mid-mountain regions. It has a characteristic Mediterranean climate with very warm summers and mild winters, and the mid-mountain landscape modulates the climate throughout the area. In 2018, work was carried out by AOC Corbières to demarcate sub-regions within the appellation based on soil, geological, climatic and vegetation characteristics, resulting in five sub-regions being identified: Maritime, Durban, Lagrasse, Lézignan and Alaric. The aim of the present study was to understand whether the blended wines from these five regions could be discriminated by specific sensory and chemical profiles. Despite several studies on the impact of terroir on wine properties, there is a lack of knowledge about the extent of the terroir's influence on the sensory and aromatic profile of wines produced by blending, a widely used practice in winemaking. In addition, sensory analyses are generally carried out by non-professional panels, which can reduce the robustness of the results compared to a sensory expert panel. In light of this, a large sample of commercial wines were collected from different producers and the main aromatic compounds were analysed by SPME, besides being evaluated by a sensory-trained panel. In addition, the data were processed through statistical tests to highlight the specific sensory and chemical aspects that enabled the discrimination of the wines from different regions.

MATERIALS AND METHODS

1. Wine samples

Wine samples were provided by an average of 40 producers throughout the five sub-regions of the AOC Corbières appellation (Alaric, Durban, Lagrasse, Lézignan and Maritime). Detailed information on the five sub-regions is given in Table 1. Huglin climatic index and precipitations reported for each sub-region are based on *SAFRAN* climatic data retrieved through SICLIMA platform developed by AgroClim-INRAE. In general, for each *cuvée* two vintages (2018 and 2019) were selected. The wineries were selected

TABLE 1. Soil type and climate conditions of the five main sub-regions of the Corbières appellation.

Sub-region	Regional soil type[a]	Regional climate conditions (2018-2019)
Alaric (AL)	High terraces generated by the passage of the River Aude, deposited on a parent rock consisting of Carcassonne molasses and colluvium, and inclusions of hard limestone and red sandstone	Climate strict mediterranean type, semi-arid with temperate winters[a]. Huglin Index: 2388.4 (2018) -2242.4 (2019). Altitude: 85-180 meters above sea level. Average precipitations: 887.5 (2018)-501.2 (2019) mm.
Durban (DU)	Two different soils: 1) Schist and calcoshist, produced by the compression of clays from marine deposits of very ancient formation (when Pyrenees were formed). These soils are very filtering, not very fertile and acidic. 2) Hard limestone from the Tertiary era with a very shallow soil, red in colour due to its decalcification clay content and usually covered with very white stone.	Climate strict mediterranean type, semi-arid with temperate winters[a]. Huglin Index: 2152.6 (2018) -2014.6 (2019). Altitude: 100-250 meters above sea level. Average precipitations: 1044.5 (2018)-568.5 (2019) mm
Lagrasse (LA)	High clay-limestone terraces generated by the passage of Orbieu, preserved in erosion mounds or perched at high altitudes; deposited on Miocene molassic deposits, with conglomeratic facies, or on Carcassonne molasses (conglomerates and more or less coarse sandstones, fine clayey and sandy silts)	Climate strict mediterranean type, semi-arid with temperate winters[a]. Huglin Index: 2335.3 (2018) - 2190.6 (2019) Altitude: 80-250 meters above sea level. Average precipitations: 1108.5 (2018)-664.1 (2019) mm
Lézignan (LE)	Medium/high terraces with a low useful water reserve; Lutecian molasses and their colluvium (a mixture of sandstone, conglomerate and sandy marl)	Climate strict mediterranean type, semi-arid with mild winters[a]. Huglin Index: 2435.4 (2018) - 2288.9 (2019) Altitude: 34-80 meters above sea level. Average precipitations: 860 (2018)-503 (2019) mm
Maritime (MA)	Quaternary molasses and terraces, with: Calcareous marl, on very shallow, silty soils with chalky fragments, with low water reserves, sensitive to erosion; Hard limestone, with shallow, ruby clay soils, well drained and susceptible to erosion; Sandstone colluvium, with soils that are more or less deep, filtering, susceptible to erosion.	Climate strict mediterranean type, semi-arid with mild winters[a]. Huglin Index: 2454 (2018) - 2284.7 (2019) Altitude: 1-100 meters above sea level. Average precipitations varied from: 875 (2018)-510 (2019) mm.

[a]This information was taken from Rousseau and Roux (2021).

TABLE 2. Number of bottles analysed for each sub-region and each vintage (2018 and 2019).

	N° bottles					
Vintage	Alaric	Durban	Lagrasse	Lézignan	Maritime	Total
2018	10	11	8	10	14	53
2019	8	7	8	8	7	38

to cover the entire area, with the aim of ensuring a good representation of each sub-zone. In line with the AOC specifications, the selected wines contained different percentages of at least two of the four main grape varieties: Syrah, Grenache, Mourvèdre and Carignan. The average percentages of each variety in 2018 and 2019 cuvées for each sub-region are reported in Table S1. All the selected wines were produced by wineries whose vineyards are located within the sub-regions considered. Of these wines, 97 % were post-alcoholic fermentation blending wines, while the remaining 3 % were co-fermentation wines. Finally, the selected wines had been produced without applying wood-based vinification processes to avoid the generation of woody aromas, which can mask the wine's typical aroma of the sub-region. In total, 53 (2018) and 39 (2019) AOC Corbières red wines were selected for the study (Table 2). The number of samples provided by the producers per sub-region decreased from one vintage to the next due to *cuvée* availability (stock clearance or non-production of the label for this specific vintage). The wines collected from both vintages had already been bottled by the producers and were stored at 12 °C until the analyses were performed.

2. Œnological Parameters

The following œnological parameters were analysed by the "Natoli & Associés" laboratory (Montpellier, France), using the International Organisation of Vine and Wine (OIV) reference methods: ethanol % (v/v), pH, total acidity (g/L H_2SO_4), lactic acid (g/L), volatile acidity (g/L H_2SO_4), active sulphur dioxide (mg/L), free and total sulphur dioxide (mg/L), colour intensity, total polyphenols index, carbon dioxide and acetaldehyde concentrations (mg/L).

3. Sensory analysis

3.1. Panel training and selection

The sensory analysis was performed by a sensory panel of expert judges unrelated to the wine industry, who had been selected for their sensory performance and further trained to perform wine descriptive analyses (Norm *ISO 8586 2023*). Twelve judges (three men and nine women, average age of 55 years old) were selected in the first year and twenty judges (seven men and thirteen women, average age of 51 years old) in the second year.

3.2. Quantitative Descriptive Analysis

The wines were analysed by Quantitative Descriptive Analysis (QDA) for their similarities and differences (Norm *ISO 13299 2003*). During the first session, the panelists generated a consensual list of descriptors. Then three training sessions were held. The panel came to a consensus on the selection of 16 attributes that differentiated the wine samples. These comprised eleven olfactory descriptors: amyl, boiled vegetables, jammy red fruits, empyreumatic, vanilla, spicy, wood, milky, humus, leather and vegetable (green); and five gustatory descriptors: alcohol, acidity, bitterness, fat and astringency. In order to ensure the homogeneity of the panel, the judges were trained to understand and consistently apply the attributes, and to familiarise themselves with the product space. Olfactory and gustatory reference standards were used to help the judges identify and memorise the sensory attributes (Table S2).

Finally, seven scoring sessions were organised: five were dedicated to the assessment of all the wines (each judge assessing between eight and ten wines per session), and two in which the analysis of 50 % of the wines was repeated to test the panelists' performance. The analyses were conducted in individual testing booths. The samples (30 mL) were served at room temperature (21.7 ± 0.6 °C) in black glasses (to avoid any potential visual influence during evaluations), covered with a plastic cap and marked with random three-digit codes. The wines were presented in a monadic service, in a William's Latin square design, to balance the presentation order and carry-over effect. Wines were analysed in duplicate. Assessors scored each attribute on unstructured linear scales from "low" on the left to "high" on the right. Data acquisition was assisted by FIZZ software (FIZZ network, v.2.518; Biosystème, Courtenon, France).

4. Volatile aroma compounds analysis by HS-SPME-GC–MS

4.1. Chemicals

Sodium chloride (CAS: 7647-14-5, ≥ 99.5 %), 1-octanol (CAS: 111-87-5, ≥ 99 %) and the C8:C20 alkane solution were purchased from Sigma Aldrich, Saint-Quentin-quélavier Cedex, France. Ultra-Pure water was produced in the lab by Milli-Q® IQ 7 003/05/10/15, Merck, Saint-Quentin-Fallavier Cedex, France.

4.2. Solid-phase microextraction (SPME)

The SPME analysis method used was taken from Yang *et al.* (2019) with some modifications. Each sample (20 mL vial) contained 1 mL of wine diluted in 9 mL of Ultra-Pure water, 1 g of NaCl and 10 µL of a 0.04 g/L 1-octanol used as internal standard solution. Wine dilution in water aimed at reducing the ethanol effect on volatility and adsorption of aroma compounds on the fibre to improve the method sensibility (Davis and Qian, 2019). Each vial was tightly capped with a PTFE-silicon septum. Sample preparation and analysis were performed in triplicate. SPME was performed using a Triplus autosampler (Thermo Fisher Scientific, Waltham, MA, USA). A 2cm-long fibre made of divinylbenzene/Carboxen/polydimethylsiloxane (DVB/CAR/PDMS), 50/30 µm (Supelco, Bellefonte, PA., USA) was used for volatile compounds adsorption. Sample equilibration was carried out at 40 °C for 15 min, with agitation at 250 rpm. Volatile extraction was performed under the same conditions for 30 min. Compounds were desorbed by inserting the fibre directly into the GC injection port in splitless mode and at 250 °C for 3 min. The SPME fiber was then reconditioned in a fibre conditioner at 270 °C for 30 min after each sample analysis.

4.3. Gas Chromatography-mass spectrometry (GC-MS) analyses

GC-MS analyses were carried out using a GC Trace Ultra gas chromatograph (Thermo Fisher, Waltham, MA, USA) coupled to an ISQ Series mass spectrometer (Thermo Fisher, Waltham, MA, USA), equipped with a DBWAX capillary column (30 m, 0.25 mm i.d., 0.25 µm film thickness, Agilent Technologies, Santa Clara, CA, USA). Helium was used as carrier gas, at a constant flow rate of 1.2 mL/min. GC oven temperature was set at 40 °C for 3 min, then increased to 210 °C at 3 °C/min, and to 245 °C at 5 °C/min, and maintained at this temperature for 5 min. The temperature of both the transfer line and ion source was set at 250 °C. Mass spectrometry was performed in the Electron Impact (EI) mode with an ionisation voltage of 70 eV. Spectrum data were acquired in the full scan mode (47 - 400 *m/z*).

A mixture of aliphatic hydrocarbons (C8:C20) was loaded onto the SPME fibre and injected following the same oven temperature programme to calculate the Kovats' Retention Index (RI) of each identified compound. The volatile compounds in the wines were identified by matching the mass spectra and retention indices to NIST 2.0 and Wiley libraries, and further confirmed using the Retention Index. Spectrums were interpreted with Xcalibur V. 3.0 mass spectrometry software (Thermo Fisher Scientific, Waltham, MA, USA). The relative amount of each compound was obtained by dividing its GC peak area by the one of the internal standard (1-octanol). Results were expressed as per microgram/L equivalents of internal standard added to the wine. The list of the volatile compounds identified, their retention indexes and average relative amount calculated for each wine are reported in Table 3 and 4.

5. Statistical Analysis

An ANOVA analysis was performed on all the oenological parameters. Regarding aroma compounds, ANOVA analysis was performed on the relative amount of each volatile compound, and on the relative amount of each family compound, in relation to the five regions (mean of the wines values). When significant differences were revealed ($p < 0.05$), mean values were compared using the Tukey (HSD) multiple comparison test. Moreover, a Discriminant Analysis (DA) was performed to study the influence of each chemical family on the discrimination of the five sub-regions.

The data from the sensory analysis were converted by the FIZZ software into marks from 0 to 10.

The panel performance (discrimination, repeatability and consensus) was first checked with a three-way ANOVA (wine x judge x repeat) and interactions analysis. Then, a two-way ANOVA (wine x judge) was run on all the descriptors in relation to the five sub-regions (mean of the wines intensities). The level of dissimilarity between the five sub-regions was calculated using an Agglomerative Hierarchical Clustering (AHC) and displayed in Euclidean distances. In particular, Ward's method was used to identify the clusters. AHC analysis was done on both all the sensory descriptors (olfactory and gustatory) and the olfactory descriptors only, to explore the link between sensory analysis and volatile composition. All data analyses were performed using XLSTAT software (version 2022, Addinsoft Paris).

RESULTS

1. Oenological parameters

The results of the analyses of the wine oenological parameters are reported in Table S3. The parameters that showed significant differences ($p < 0.10$) between the five sub-regions were ethanol % (v/v), pH and volatile acidity

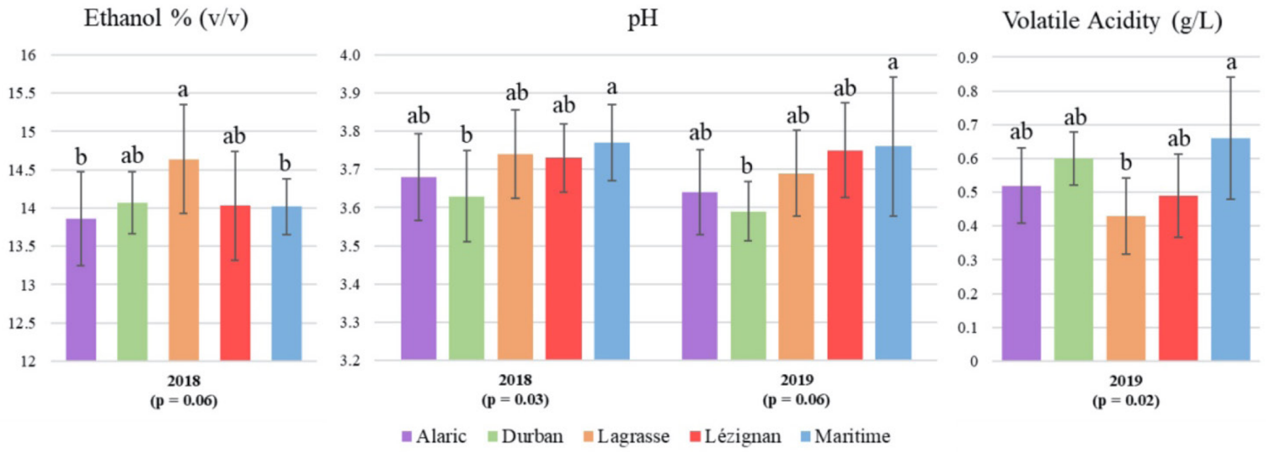

FIGURE 1. Significant differences in ethanol %, pH and Volatile Acidity (VA) between the five AOC Corbières sub-regions for the 2018 and 2019 vintages.

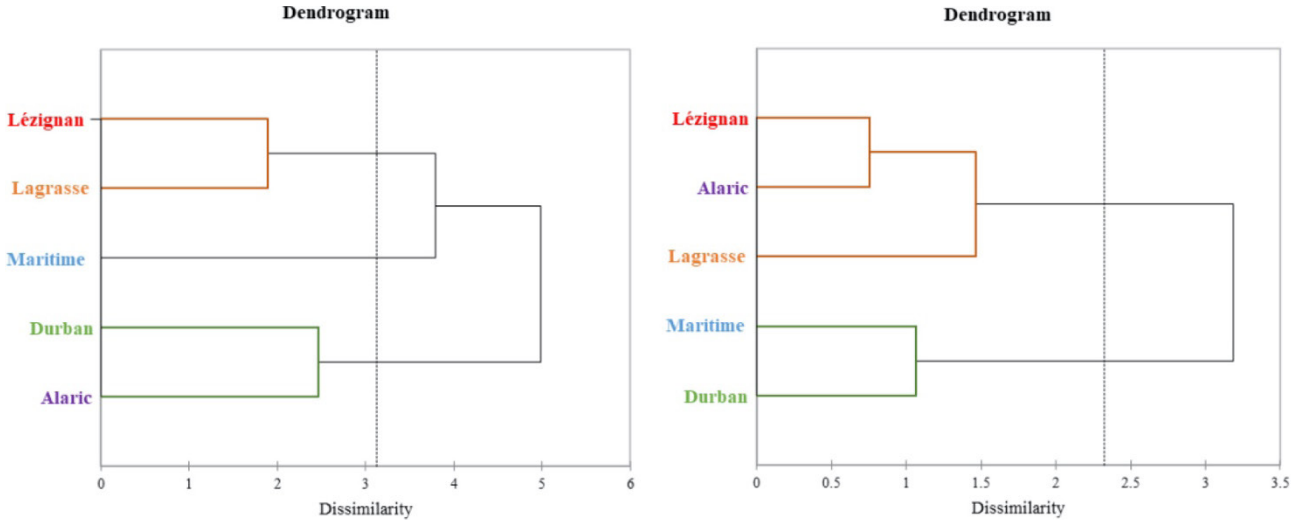

FIGURE 2. AHC analysis of the five AOC Corbières sub-regions in terms of the gustatory and olfactory descriptors of wines from 2018 (a) and 2019 (b).

(g/L) (Figure 1). A high variability of ethanol content between the samples in each region was observed, with a difference of 1.2-2.5 % vol between the minimum and maximum values. Significant differences in ethanol content between the regions were observed in the 2018 vintage only: Lagrasse wines had a higher mean alcohol degree (% vol) than the Maritime and Alaric wines. Concerning pH, significant differences were observed in both the 2018 and 2019 vintages: in particular, the wines from the Maritime region had the highest mean pH, which was significantly different to the Durban wines, with the lowest pH in both vintages. Finally, in 2019, the average volatile acidity (g/L) of the Maritime wines were significantly higher than the wines from the Lagrasse sub-region.

2. Sensory analysis of AOC Corbières wines

2.1. Classification of the five sub-regions

The sensory panel defined sixteen sensory attributes for differentiating the wines of both vintages. However, the vegetable (or green) character was only found in wines from the 2019 vintage. The interactions between the wine and repetitions and between the wine and subject were found to have few significant effects on the sensory parameters for both vintages, indicating high repeatability and strong panel consensus. An AHC analysis was carried out on the olfactory and gustatory sensory descriptors (Figure 2). In 2018, three clusters were observed containing i) Lézignan and Lagrasse wines, ii) Durban and Alaric wines, and

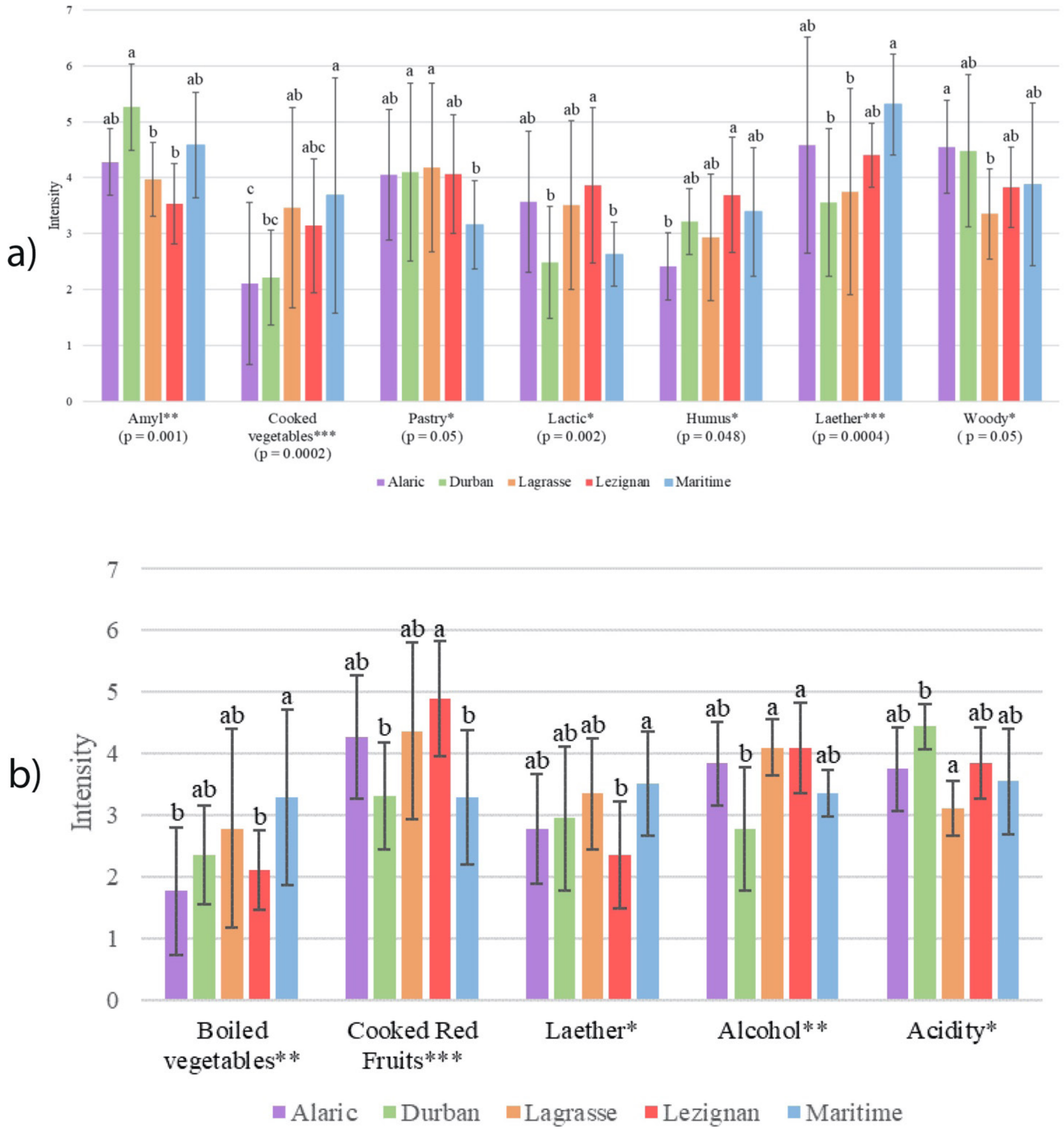

FIGURE 3. Significant sensorial descriptors of 2018 and 2019 AOC Corbières wines ($p < 0.05$). Barplots show the mean values for each significant sensorial descriptor for each studied sub-region for 2018 (a) and 2019 (b). Scores are reported on an intensity scale of 1-7 for readability. For the ANOVA results: * = p-value < 0.05; ** = p-value < 0.01; *** = p-value < 0.001.

iii) Maritime wines in a separate group between the other two, but closer to the Lézignan and Lagrasse cluster. In 2019, two clusters were identified containing i) wines from the Lézignan, Lagrasse and Alaric sub-regions, and ii) wines from the Maritime and Durban sub-regions. Interestingly, the wines from the Lagrasse and Lézignan sub-regions were separate from the wines from Durban and Maritime for both vintages (Figure 2). The differences found between the sub-regions for both vintages is presented below in the ANOVA analysis description.

2.2. Sensorial characterisation of the five sub-regions

Of all the descriptors, seven were found to be significant for the 2018 vintage wines: amyl, cooked vegetables, pastry, lactic, humus, leather and woody; meanwhile, five were significant for 2019: cooked vegetables, jammy red fruits, leather, alcohol and acidity. The differences between the five regions are reported in Figure 3. The average intensity scores and the standard deviations of each descriptor per sub-region are reported in Tables S4/S5.

For 2018, only the olfactory descriptors showed significant differences between the five studied sub-regions. In particular, the Alaric wines displayed lower humus and cooked vegetable notes than Lézignan and Maritime wines respectively, and higher woody notes than Lagrasse's wines. The wines from the Durban sub-region had a cooked vegetable and woody character, which was similar to the wines from the Alaric region; however, Durban wines were also perceived with weaker lactic/buttery and leather notes and more intense amylic and pastry notes. In between, the Maritime wines were distinguished from the two latter regions by their more intense cooked vegetable and leather notes, and weaker lactic/buttery and pastry notes. Less intense leather and amylic notes characterised the wines from the Lagrasse sub-region compared to Maritime and Durban wines respectively, and a more intense pastry character than the Maritime wines only. Finally, the Lézignan wines were characterised by less intense amylic notes, similar to the Lagrasse wines, but more intense lactic notes than the Durban and Maritime wines.

For 2019, both the olfactory and gustatory descriptors showed differences between the five studied sub-regions. The Durban wines were marked by less intense jammy red fruit notes and alcoholic mouthfeel, but a more intense acidic mouthfeel. Similarly, the wines from the Maritime sub-region were characterised by a less intense jammy red fruits character, as well as higher leather and cooked vegetables notes, as was the case for the 2018 vintage. The Lagrasse wines were perceived differently to the Durban wines, having a higher alcoholic and lower acidic mouthfeel. The Alaric wines had less intense cooked vegetables notes, as was the case for

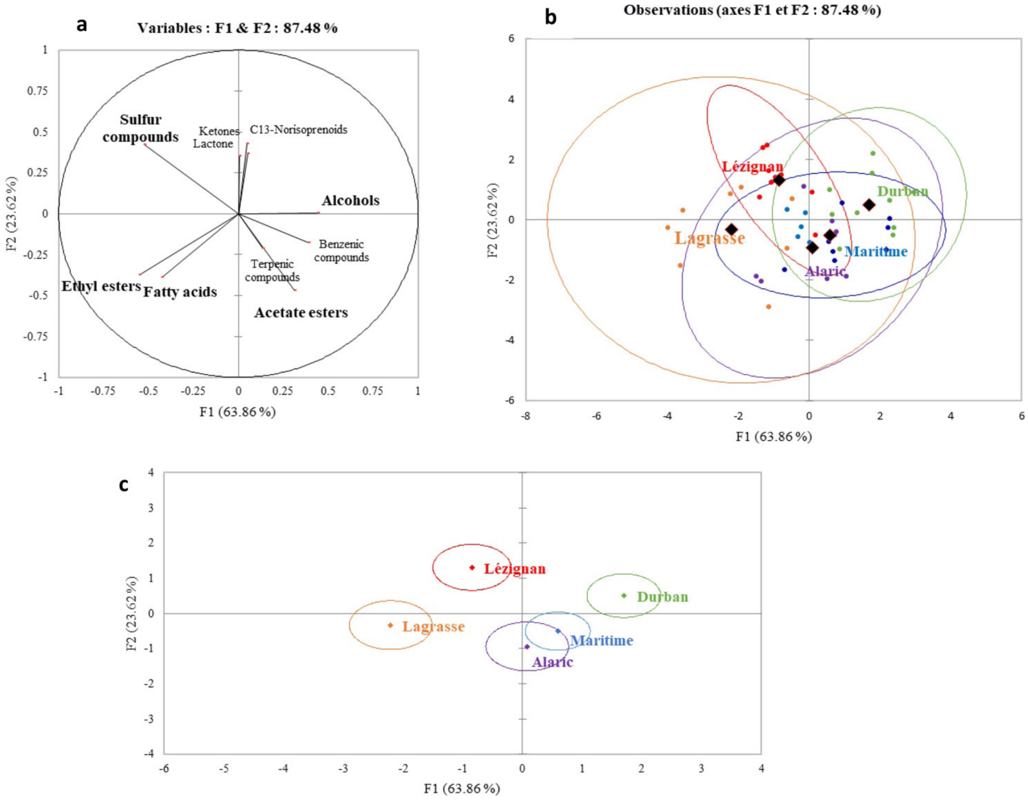

FIGURE 4. Results of the discriminant analysis of the family compounds for 2018. a) Projection of the variables on the two main axes. Significant families are reported in bold. b) Distribution of wine samples on the two main axes. Wine samples are grouped according to the five studied sub-regions. c) Projection of the barycenters of the five studied sub-regions. Regions are represented by the following colours: Lagrasse = orange; Alaric = purple; Lézignan = red; Maritime = light blue; Durban = green.

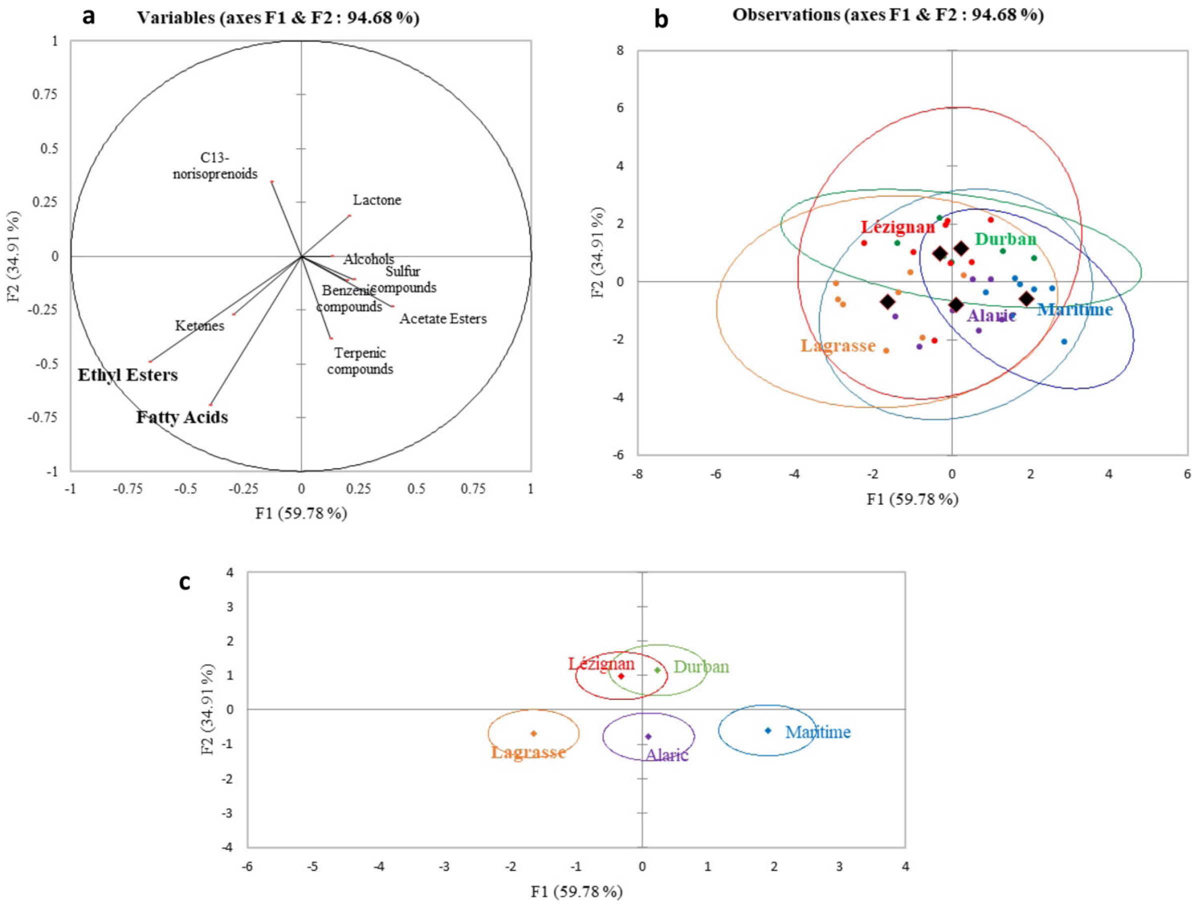

FIGURE 5. Results of the discriminant analysis of the family compounds for 2019. a) Projection of the variables on the two main axes. Significant families are reported in bold. b) Distribution of wine samples on the two main axes. Wine samples are grouped according to the five studied sub-regions. c) Projection of the barycenters of the five studied sub-regions. Regions are represented by the following colours: Lagrasse = orange; Alaric = purple; Lézignan = red; Maritime = light blue; Durban = green.

2018. Finally, The Lézignan wines were distinguished by their more intense jammy red fruit notes, less intense cooked vegetable, and leather notes. They were also perceived as having the same higher alcoholic mouthfeel as the Lagrasse wines.

3. Volatile composition of AOC Corbières wines

3.1. Discriminant Analysis of aroma compounds.

A discriminant statistical analysis was performed on the total relative amount of compounds for each of the ten identified chemical families, taking the five studied sub-regions as observations. Figure 4 shows the contribution of the chemical families of aroma compounds, in terms of relative quantities, to the FDA axes (4a), the projection on the axes of all wines analysed and their grouping by sub-regions (4b), and the position on the axes of the barycenters of the five sub-regions (4c). The families shown in bold were found to be significant through the ANOVA analysis.

For 2018, the first two axes account for 87.48 % of the total variance (63.86 % and 23.62 % respectively) (Figure 4a). The F1 axis is defined mainly by alcohols on the positive side and fatty acids, ethyl esters and sulphur compounds on the negative side. The F2 axis explains the vertical dimension by contrasting the C13-norisoprenoids with the acetate esters. In Figure 4b, the samples are considerably dispersed around the barycenter of the ellipses, and the ellipses of the five sub-regions overlap. However, in terms of the barycenters of the ellipses, we can observe that the five sub-regions are separated into two distinctive zones of the graph: the Lézignan and Lagrasse regions are on the left-hand side of the graph, and the Alaric, Maritime and Durban sub-regions on the right-hand side (Figure 4c). The position of the Lézignan wines on the graph is positively correlated with the sulphur compounds and C13-norisoprenoids and negatively correlated with the acetate esters. The Lagrasse wines are closer to the Lézignan wines, and they are positively correlated with the sulphur compounds, ethyl esters and fatty acids, and negatively correlated with the C13 norisoprenoids and alcohols. On the other side, the Durban, Alaric and Maritime wines are positively correlated with the alcohols and acetate esters, and negatively correlated with the ethyl esters, sulphur compounds and fatty acids.

For 2019, the discriminant analysis explains 94.68 % of the variance along the first two axes (59.78 % and 34.91 %

TABLE 3. Average relative amounts and standard deviations of the volatile compounds in AOC Corbières wines of 2018. All the compounds were quantified as µg/L 1-Octanol equivalents. For the ANOVA results: * = p-value < 0.05; ** = p-value < 0.01; *** = p-value < 0.001; ns = not significant (for a p-value > 0.05).

Part 1/2

Compounds	RI	RI ref	Alaric		Durban		Lagrasse		Lezignan		Maritime		ANOVA
			mean*	SD	mean*	SD	mean*	SD	mean*	SD	mean*	SD	
Sulfur compounds													
Dimethyl sulfide (DMS)	847	844	1.47 ab	0,842762	1.09 b	0,51	1.94 a	0,89	1.73 ab	0,80	1.12 ab	0,54	0.045 (*)
Methionol	1703	1702	0.27 b	0,374357	0.66 a	0,13	0.52 ab	0,17	0.67 a	0,18	0.35 ab	0,40	0.010 (*)
Total			1.74 ab	0,77	1.76 ab	0,42	2.46 a	0,84	2.40 a	0,75	1.47 b	0,54	0.007 (**)
Acetate Esters													
Isoamyl acetate	1114	1118	497.87 a	152,80	409.56 ab	100,80	411.44 ab	202,13	285.76 b	130,78	422.05 ab	149,56	0.042 (*)
2-Phenylethyl acetate	1797	1803	4.15 a	2,07	3.92 a	1,39	3.30 a	1,29	3.07 a	0,80	3.82 a	0,99	ns
Ethyl Acetate	888	889	384.81 ab	60,53	448.89 a	75,60	346.84 b	76,87	343.58 b	92,11	353.09 b	88,30	0.031 (*)
Hexyl Acetate	1259	1261	2.43 a	2,13	1.75 a	0,95	3.59 a	2,92	2.11 a	0,88	2.11 a	1,01	ns
Total			889.25 a	194,16	864.11 a	120,99	765.17 ab	221,48	634.52 b	182,22	781.07 ab	146,35	0.031 (*)
Ethyl Esters													
Ethyl 2-methylpropanoate	974	971	8.27 a	4,80	9.21 a	3,29	6.46 a	1,64	7.01 a	2,29	7.15 a	1,88	ns
Ethyl Butanoate	1037	1035	20.13 a	10,25	15.05 a	4,24	18.20 a	6,69	13.60 a	4,98	13.15 a	3,125	ns
Ethyl 2-methylbutanoate	1053	1053	19.66 a	8,37	33.11 a	18,11	16.73 a	9,40	20.69 a	11,35	21.90 a	17,77	ns
Ethyl 3-methylbutanoate	1068	1070	39.35 a	16,52	48.81 a	21,04	37.12 a	26,04	42.15 a	24,83	33.73 a	8,98	ns
Ethyl Hexanoate	1223	1224	19.86 ab	4,89	17.80 b	5,99	29.02 a	15,35	15.79 b	3,40	19.35 ab	6,04	0.015 (*)
Ethyl Heptanoate	1330	1331	1.90 a	1,17	3.13 a	1,60	2.19 a	0,71	1.85 a	0,66	2.29 a	1,33	ns
Ethyl 2-hexenoate	1350	1357	1.17 a	1,01	0.95 ab	0,64	1.72 a	1,43	0.00 b	0,00	1.13 ab	0,83	0.005 (**)
Ethyl L-lactate	1350	1347	20.97 a	7,11	18.47 a	6,17	20.73 a	5,09	20.92 a	10,59	17.68 a	2,87	ns
Ethyl Octanoate	1433	1435	953.11 ab	371,34	653.43 b	230,73	1313.15 a	702,88	661.27 b	207,28	845.19 ab	246,03	0.004 (**)
Ethyl 2-hydroxy-4-methylpentanoate	1533	1538	4.68 a	1,27	6.49 a	2,07	5.87 a	1,98	4.84 a	2,15	7.01 a	2,19	ns
Ethyl Decanoate	1633	1630	155.82 ab	24,72	124.27 b	37,40	204.56 a	92,17	115.59 b	28,31	118.50 b	31,06	0.001 (**)
Diethyl Succinate	1666	1668	255.64 a	58,35	402.21 a	128,80	399.07 a	175,55	391.64 a	122,07	423.03 a	175,42	ns
Ethyl 9-Decenoate	1680	1694	1.87 a	2,62	0.53 ab	0,31	1.81 a	1,65	0.33 ab	0,34	0.12 b	0,23	0.007 (**)
Total			1502.40 ab	416,56	1333.49 b	251,28	2056.63 a	897,07	1295.67 b	245,56	1510.24 ab	363,50	0.017 (*)
Terpenic compounds													
β-Linalool	1541	1541	7.77 a	4,20	7.09 a	2,22	11.07 a	7,47	7.58 a	2,07	8.09 a	1,36	ns
Terpinen-4-ol	1587	1593	0.03 a	0,08	ND	0,00	ND	0,00	ND	0,00	0.09 a	0,22	ns
α-Terpineol	1682	1688	1.86 a	0,37	2.82 a	1,85	2.33 a	0,78	2.56 a	0,89	2.16 a	0,72	ns
β-Citronellol	1752	1764	1.96 a	1,03	2.28 a	1,26	2.31 a	1,14	2.09 a	0,68	2.81 a	0,82	ns
Nerolidol	2060	2054	1.86 a	1,81	1.61 a	0,76	1.24 a	0,20	1.29 a	0,59	1.33 a	0,48	ns
Fenchone	1377	1402	7.44 a	20,38	5.66 a	12,89	0.18 a	0,52	2.48 a	5,10	15.15 a	35,79	ns
Total			20.93 a	18,03	19.47 a	16,30	17.12 a	7,98	15.99 a	4,87	29.62 a	35,73	ns
C13-norisoprenoids													
Vitispirane	1513	1515	19.90 a	11,64	27.75 a	19,81	21.42 a	10,68	29.39 a	21,20	20.97 a	9,51	ns
β-Damascenone	1799	1790	0.30 ab	0,10	0.37 a	0,14	0.32 a	0,23	0.35 a	0,14	0.13 b	0,09	0.001 (**)
1,1,6-trimethyl-1,2-dihydronaphthalene (TDN)	1718	1714	0.36 b	0,59	0.61 ab	0,83	0.47 ab	0,84	1.53 a	1,35	0.40 b	0,69	0.041 (*)
Total			20.57 a	11,66	28.73 a	19,83	22.21 a	10,79	31.26 a	21,62	21.49 a	9,49	ns

Part 2/2

Compounds	RI	RI ref	Alaric		Durban		Lagrasse		Lezignan		Maritime		ANOVA
			mean*	SD	mean*	SD	mean*	SD	mean*	SD	mean*	SD	
						Benzenic compounds							
Estragole	1682	1688	2.39 a	6,75	2.89 a	7,65	0.53 a	1,04	0.82 a	1,51	4.20 a	9,97	ns
4-Ethylphenol	2210	2205	2.19 a	3,02	5.41 a	6,10	0.75 a	1,73	0.52 a	0,95	4.81 a	11,65	ns
Total			4.57 a	6,26	8.30 a	8,24	1.28 a	1,71	1.34 a	1,45	9.01 a	14,35	ns
						Alcohols							
1-pentanol isomers**	1217	1215	2413.52 a	544,06	2486.54 a	660,37	1992.26 a	392,68	1984.59 a	378,92	2049.92 a	407,25	ns
2-methylpropan-1-ol	1104	1105	6.28 a	1,86	5.39 ab	1,17	4.07 bc	0,90	2.87 c	1,83	5.03 b	1,30	< 0.0001 (***)
4-Methyl-1-pentanol	1339	1347	1.06 a	1,54	1.68 a	1,41	2.78 a	2,33	0.89 a	1,17	1.29 a	1,51	ns
3-Methyl-1-pentanol	1350	1353	4.48 a	3,52	4.35 a	2,95	4.81 a	3,38	2.65 a	1,73	3.49 a	2,30	ns
1-Hexanol	1351	1353	127.71 a	62,25	132.86 a	36,72	134.58 a	48,45	130.91 a	32,47	103.49 a	28,52	ns
1-Octen-3-ol	1446	1460	0.79 a	0,36	0.83 a	0,25	0.58 a	0,20	0.64 a	0,45	0.67 a	0,52	ns
1-Heptanol	1450	1452	6.04 ab	1,46	7.71 a	2,07	5.28 ab	1,10	4.92 b	1,80	4.79 b	2,51	0.009 (**)
2-Ethyl-1-hexanol	1584	1515	5.29 a	3,61	4.93 a	3,03	5.41 a	1,83	6.35 a	4,55	4.90 a	3,11	ns
Benzyl alcohol	1862	1862	3.23 a	1,43	4.08 a	4,49	3.10 a	1,99	3.54 a	1,62	3.93 a	1,87	ns
2-Phenylethanol	1894	1890	433.72 b	126,9213	614.75 a	81,29	438.94 b	128,89	542.47 ab	46,46	604.14 a	133,70	0.001 (***)
Total			3002.13 ab	777,6341	3263.13 a	713,84	2591.81 b	479,39	2679.82 ab	460,27	2781.65 ab	557,43	0.04 (*)
						Lactone							
γ-Butyrolactone	1612	1640	2.13 a	1,258804	2.59 a	0,94	2.35 a	0,32	2.82 a	0,65	2.36 a	1,35	ns
Total			2.13 a	1,224754	2.59 a	0,92	2.35 a	0,34	2.82 a	0,72	2.36 a	1,33	ns
						Ketones							
3-Heptanone	1150	1163	8.21 a	10,32	14.04 a	7,05	11.90 a	4,78	12.21 a	8,44	11.34 a	5,51	ns
3-Octanone	1245	1240	4.41 b	5,89	10.62 a	3,53	8.98 ab	2,89	8.22 ab	4,38	8.00 ab	4,22	0.030 (*)
3-Nonanone	1270	1357	2.24 a	2,20	0.45 a	0,17	0.40 a	0,13	0.38 a	0,21	1.21 a	2,98	ns
5-Nonanone	1313	1325	4.16 b	3,36	12.25 a	1,94	12.54 a	2,54	12.01 a	4,68	10.88 a	4,79	< 0.001 (***)
Total			19.03 a	19,96	37.36 a	11,80	33.82 a	9,76	32.83 a	16,75	31.43 a	12,82	ns
						Fatty acids							
Hexanoic Acid	1847	1857	1.42 ab	1,19	0.47 ab	0,63	2.00 a	1,79	0.88 ab	1,09	0.43 b	1,06	0.028 (*)
Octanoic Acid	2053	2070	4.29 ab	3,04	2.55 b	2,01	5.81 a	3,05	2.97 ab	1,31	3.48 ab	1,48	0.030 (*)
Decanoic Acid	2260	2250	0.64 ab	0,41	0.51 b	0,44	1.04 a	0,44	0.70 ab	0,20	0.65 ab	0,38	0.030 (*)
Total			6.35 ab	4,13	3.53 b	2,77	8.85 a	4,45	4.56 b	2,07	4.56 b	2,33	0.006 (**)

* expressed in µg/L of equivalents of 1-Octanol.

** 1-pentanol, 3-methylbutanol and 2-methylbutanol.

ND = not detected.

RI: Retention Index based on a series of n-hydrocarbons reported according to their elution order on DBWAX 30M.

respectively) (Figure 5a). The F1 axis is mainly defined by acetate esters on the positive side and F2 by ethyl esters and fatty acids on the negative side. Similar to 2018, the samples are scattered around the barycenters and the ellipses of the five groups overlap (Figure 5b). For this vintage, the sub-regions stand out in different ways to 2018, except for the Lagrasse wines, which are again positively correlated with ethyl esters and fatty acids, and the wines from the Alaric and Maritime sub-regions with acetate esters. However, both these latter zones are further apart for 2019 than for 2018. Lastly, the 2019 wines from the Durban and Lézignan sub-regions are closer together and negatively correlated with ethyl esters, fatty acids and acetate esters (Figure 5c).

3.2. Average aromatic profile of AOC Corbières wines

Forty-eight compounds were identified and their amounts relative to the internal standard calculated in the 53 (2018) and 39 (2019) AOC Corbières wines. The statistical analysis highlighted significant differences between 19 aroma compounds for 2018 and 9 compounds for 2019. Those aroma compounds belong to eight out of the ten identified chemical families: alcohols, esters (ethyl and acetate), fatty acids, terpenic compounds, C13-norisoprenoids, ketones and sulphur compounds. The average amounts of volatile compounds from the ten chemical families and over the two vintages are reported in Tables 3 and 4. It should be

TABLE 4. Average relative amounts and standard deviations of the volatile compounds in AOC Corbières wines of 2019. All the compounds were quantified as µg/L 1-Octanol equivalents. For the ANOVA results: * = p-value < 0.05; ** = p-value < 0.01; *** = p-value < 0.001; ns = not significant (for a p-value > 0.05).

Part 1/2

Compounds	RI	RI ref	Alaric		Durban		Lagrasse		Lezignan		Maritime		ANOVA
			mean*	SD	mean*	SD	mean*	SD	mean*	SD	mean*	SD	
			Sulfur compound										
Methionol	1703	1702	0.50 a	0,21	0.44 a	0,17	0.43 a	0,11	0.53 a	0,13	0.53 a	0,16	ns
Total			0.50 a	0,21	0.44 a	0,18	0.43 a	0,11	0.53 a	0,17	0.53 a	0,16	ns
			Acetate Esters										
Isoamyl acetate	1114	1118	116.87 a	37,973	76.67 a	18,339	103.84 a	55,084	91.93 a	34,914	145.41 a	73,353	ns
2-Phenylethyl acetate	1797	1803	1.81 a	0,586	1.35 a	0,18	1.61 a	0,42	1.42 a	0,463	3.00 a	2,753	ns
Ethyl Acetate	888	889	166.04 a	59,152	189.11 a	108,447	134.18 a	27,141	149.91 a	46,632	170.05 a	28,073	ns
Hexyl Acetate	1259	1261	1.52 a	1,285	0.75 b	0,251	1.53 a	0,771	1.15 ab	0,384	1.37 ab	0,902	ns
Total			286.25 a	89,948	267.88 a	120,964	241.16 a	66,391	244.41 a	74,876	319.83 a	60,184	ns
			Ethyl Esters										
Ethyl Butanoate	1037	1035	21.84 a	9,197	15.15 a	6,08	22.30 a	8,96	20.68 a	7,88	18.46 a	5,46	ns
Ethyl 2-Methylbutanoate	1053	1053	13.00 a	8,556	15.14 a	6,48	11.84 a	3,53	11.31 a	5,88	10.76 a	2,80	ns
Ethyl 3-Methylbutanoate	1068	1070	10.75 a	6,341	12.62 a	7,88	10.22 a	3,65	10.57 a	5,61	9.73 a	2,18	ns
Ethyl Hexanoate	1223	1224	156.78 ab	28,885	124.24 b	14,19	218.90 a	64,33	140.60 b	30,73	148.51 b	59,04	0.002 (**)
Ethyl Heptanoate	1330	1331	0.89 a	0,281	1.43 a	0,82	1.01 a	0,55	0.77 a	0,25	0.95 a	0,38	ns
Ethyl 2-Hexenoate	1350	1357	0.72 a	0,695	0.43 a	0,34	0.65 a	0,42	0.61 a	0,89	0.48 a	0,62	ns
Ethyl L-Lactate	1350	1347	7.73 a	3,978	7.09 a	2,95	6.10 a	1,32	7.26 a	2,94	7.44 a	0,72	ns
Ethyl Octanoate	1433	1435	171.09 a	61,795	121.70 a	62,07	195.31 a	92,11	141.27 a	70,29	123.11 a	45,39	ns
Ethyl 2-hydroxy-4-methylpentanoate	1533	1538	2.40 b	1,764	3.88 ab	1,87	3.54 ab	1,12	3.09 ab	2,59	5.22 a	1,42	0.04 (*)
Ethyl Decanoate	1633	1630	23.74 a	13,442	13.85 a	11,79	24.27 a	17,61	18.59 a	11,92	16.06 a	9,44	ns
Diethyl Succinate	1666	1668	103.54 a	54,443	87.11 a	24,67	131.1 a	43,73	87.46 a	32,05	94.15 a	28,14	ns
Ethyl 9-Decenoate	1680	1694	0.36 a	0,61	0.16 a	0,21	0.33 a	0,33	0.11 a	0,09	0.11 a	0,12	ns
Total			512.83 ab	139,44	402.80 b	84,40	625.59 a	153,95	443.62 b	135,44	433.17 b	92,60	0.003 (**)
			Terpenic compounds										
β-Linalool	1541	1541	1.31 a	0,98	1.22 a	1,02	2.32 a	1,30	1.30 a	1,12	2.10 a	0,49	ns
Terpinen-4-ol	1587	1593	0.256 a	0,40	0.33 a	0,42	0.29 a	0,28	0.42 a	0,54	0.14 a	0,08	ns
α-Terpineol	1682	1688	0.23 a	0,13	0.49 a	0,43	0.42 a	0,13	0.53 a	0,64	0.40 a	0,04	ns
β-Citronellol	1752	1764	0.10 b	0,10	0.12 ab	0,11	0.16 ab	0,09	0.11 ab	0,10	0.23 a	0,08	0.04 (*)
Nerolidol	2060	2054	0.82 a	0,53	0.68 a	0,74	0.68 a	0,33	0.74 a	0,48	1.13 a	0,69	ns
Fenchone	1377	1402	3.49 a	9,43	0.30 a	0,68	1.32 a	3,53	1.21 a	3,21	4.45 a	9,47	ns
α- Limonene	1128	1056	2.34 a	1,85	1.31 a	1,13	2.99 a	1,38	1.39 a	1,35	3.27 a	1,43	ns
Total			8.55 a	9,44	4.44 a	2,63	8.17 a	3,83	5.69 a	4,64	11.72 a	10,11	ns
			C13-norisoprenoids										
Vitispirane	1513	1515	3.99 a	2,09	9.17 a	13,14	5.72 a	2,56	5.51 a	4,68	4.02 a	2,93	ns
β-Damascenone	1799	1790	0.34 a	0,28	0.27 a	0,19	0.36 a	0,13	0.32 a	0,28	0.31 a	0,18	ns
Total			4.32 a	2,15	9.44 a	13,11	6.08 a	2,53	5.83 a	4,81	4.33 a	3,37	ns

Part 2/2

Compounds	RI	RI ref	Alaric		Durban		Lagrasse		Lezignan		Maritime		ANOVA
			mean*	SD	mean*	SD	mean*	SD	mean*	SD	mean*	SD	
Benzenic compounds													
Estragole	1682	1688	0.46 a	1,31	0.21 a	0,37	0.14 a	0,30	0.16 a	0,45	0.43 a	0,82	ns
4-Ethylphenol	2210	2205	1.44 a	3,33	2.39 a	4,74	1.61 a	4,51	0.46 a	0,80	2.97 a	5,39	ns
Total			1.90 a	3,40	2.59 a	4,71	1.75 a	4,46	0.61 a	0,85	3.40 a	5,31	ns
Alcohols													
1-pentanol isomers**	1217	1215	1010.57 a	364,54	929.83 a	379,08	835.30 a	130,59	1009.51 a	399,56	834.05 a	180,58	ns
Isobutanol	1104	1105	1.63 a	0,94	1.76 a	0,79	1.03 a	0,32	1.61 a	0,71	1.40 a	0,37	ns
3-Methyl-1-pentanol	1339	1347	1.37 a	1,36	1.83 a	3,06	1.47 a	1,15	0.67 a	0,79	1.02 a	0,80	ns
4-Methyl-1-pentanol	1350	1353	0.36 a	0,20	0.59 a	1,09	0.26 a	0,12	0.13 a	0,14	0.27 a	0,07	ns
1-Hexanol	1351	1353	37.04 a	12,85	41.60 a	21,26	42.08 a	15,35	49.50 a	18,72	36.73 a	7,73	ns
1-Octen-3-ol	1446	1460	0.85 a	0,60	1.17 a	0,67	1.14 a	0,23	0.91 a	0,62	1.60 a	0,58	ns
1-Heptanol	1450	1452	2.03 b	0,43	3.47 a	0,90	2.29 b	0,63	2.21 b	0,54	2.56 ab	0,73	0.002 (**)
2-Ethyl-1-hexanol	1584	1515	2.31 b	0,92	1.68 b	1,01	5.39 a	3,60	2.99 ab	1,41	3.23 ab	2,15	0.018 (*)
Benzyl alcohol	1862	1862	0.47 b	0,14	0.46 b	0,29	0.57 ab	0,33	0.57 ab	0,16	0.83 a	0,29	0.04 (*)
2-Phenylethanol	1894	1890	105.70 a	25,64	110.91 a	34,15	93.55 a	25,17	116.35 a	40,08	11.24 ab	16,11	ns
Total			1162.32 a	360,30	1093.31 a	410,52	983.09 a	152,02	1184.45 a	368,45	992.93 a	349,53	ns
Lactone													
γ-Butyrolactone	1612	1640	0.62 a	0,19	0.70 a	0,35	0.55 a	0,10	0.70 a	0,42	0.64 a	0,09	ns
Total			0.62 a	0,19	0.70 a	0,35	0.54 a	0,10	0.70 a	0,43	0.64 a	0,11	ns
Ketone													
3-Nonanone	1270	1357	1.13 a	0,73	0.92 a	0,65	1.47 a	0,43	0.93 a	0,85	1.19 a	0,15	ns
Total			1.13 a	0,75	0.92 a	0,67	1.46 a	0,42	0.93 a	0,77	1.19 a	0,47	ns
Fatty acids													
Hexanoic Acid	1847	1857	1.92 b	1,26	1.55 b	1,14	3.77 a	0,97	1.82 b	1,57	2.64 ab	0,58	0.004 (**)
Octanoic Acid	2053	2070	8.08 ab	0,69	4.99 b	2,71	9.53 a	3,49	5.43 b	3,39	6.46 ab	2,48	0.014 (*)
Decanoic Acid	2260	2250	2.28 a	1,56	1.05 a	0,75	1.81 a	0,97	1.58 a	0,94	1.79 a	1,75	ns
Total			12.28 ab	1,44	7.59 b	3,77	15.12 a	4,77	8.83 b	5,22	10.90 ab	4,68	0.01 (*)

* expressed in µg/L of equivalents of 1-Octanol.

** 1-pentanol, 3-methylbutanol and 2-methylbutanol.

ND = not detected.

RI: Retention Index based on a series of n-hydrocarbons reported according to their elution order on DBWAX 30M.

noted that the 1-hexanol, that was the only C_6-compound found in this study, was included in the alcohol's chemical family. In addition, because the GC peaks of 1-pentanol, 3-methylbutanol and 2-methylbutanol compounds were co-eluted, they are reported in Tables 2 and 3 as an added amount under the name of 1-pentanol isomers.

For the 2018 vintage, aromatic compounds belonging to seven of the ten identified chemical families were found at significantly different concentrations in blended wines from the different sub-regions. In particular, the Durban wines contained the highest relative amount of total alcohols (3.26 mg/L eq. 1-octanol), while the lowest amounts were found in Lagrasse wines (2.60 mg/L eq. 1-octanol). The same behaviour was observed for the level of 2-phenylethanol (614.7 µg/L eq. 1-octanol) in Durban and in Lagrasse (439 µg/L eq. 1-octanol). In addition, the Durban and Alaric wines contained 1.5 to 2 times higher relative amounts of ethyl acetate and isoamyl acetate (448.9 and 497.9 µg/L eq. 1-octanol respectively) than the Lézignan wines (343.6 and 285.8 µg/L eq. 1-octanol). In the Lagrasse wines, the relative amounts of ethyl esters, in particular ethyl hexanoate (29.02 µg/L eq. 1-octanol), ethyl octanoate (1310 µg/L eq. 1-octanol) and ethyl decanoate (204.6 µg/L eq. 1-octanol) were double those of the Durban and Lézignan's wines (15.8-661.3 µg/L eq. 1-octanol). The differences in fatty acid concentrations between the different sub-regions followed the same trend as those observed for the ethyl esters family. Together with the Lagrasse wines, the Lézignan wines contained higher amounts of sulphur compounds (2.4 µg/L eq. 1-octanol) than the wines from the Maritime sub-region (1.5 µg/L eq. 1-octanol). In particular, the Lagrasse and Lézignan wines showed an average relative amount of DMS and methionol double that of the wines from Durban, Maritime (DMS only) and Alaric (methionol only) sub-regions. Regarding varietal compounds, no differences between the five studied sub-regions were detected for the terpenic compounds. However, the relative amounts of TDN was four times higher (1.5 µg/L eq. 1-octanol) in the Lézignan wines than in the wines from the Maritime and Alaric sub-regions (0.4 µg/L eq. 1-octanol). In addition, the relative amounts of the norisoprenoids compound β-damascenone was three times lower in wines from the Maritime sub-region (0.1 µg/L eq. 1-octanol) than all the other wines (0.3 µg/L eq. 1-octanol). Finally, although no significant differences were found in total relative amounts of ketones, the wines from the Alaric sub-region contained lower relative amounts of 3-octanone (4.4. µg/L eq. 1-octanol) than Durban wines (10.6 µg/L eq. 1-octanol), as well as the lowest relative amounts of 5-nonanone (4.2 µg/L eq. 1-octanol) of all the sub-regions (10.9-12.5 µg/L eq. 1-octanol).

Regarding the 2019 vintage, no significant differences were found between the wines from all five regions in terms of the relative amounts of the higher alcohols, acetate esters and sulphur compounds. However, Maritime wines contained higher relative amounts of benzyl alcohol (0.8 µg/L eq. 1-octanol) than the Alaric and Durban wines (0.5 µg/L eq. 1-octanol), and the relative amounts of 2-ethyl-1-hexanol (5.4 µg/L eq. 1-octanol) in the Lagrasse wines were three-fold those in the Durban and Alaric wines (1.7-2.3 µg/L eq. 1-octanol). In addition, the Lagrasse wines showed the same trend for 2019 as for 2018, with relative amounts of ethyl hexanoate, ethyl octanoate (and their respective fatty acids) and ethyl decanoate twice those of the Durban and Lézignan wines. Once again, no significant differences were found in total amounts of terpenic compounds in wines from the 2019 vintage. However, the relative amount of β-citronellol (0.2 µg/L eq. 1-octanol) in the Maritime wines was double that of the wines from the Alaric region (0.1 µg/L eq. 1-octanol).

DISCUSSION

1. Discrimination of wines based on oenological parameters

The results show that of all the oenological parameters only ethanol, pH and volatile acidity discriminated the wines. The AOC Corbières wines had an average alcohol degree of 14%vol and a pH of 3.6; these values are in agreement with other studies carried out in wines made from red grape varieties at similar latitudes (Bonada *et al.*, 2015; Gómez-Plaza *et al.*, 2016). Many factors can affect the alcohol content of a wine, including climate, growing conditions, grape variety and even fermentation temperatures (van Leeuwen *et al*., 2018). In particular, since ethanol production during fermentation is directly related to must sugar concentration, the choice of time of harvest is a crucial decision. Ethanol content was significantly higher in Lagrasse's wines, compared to Maritime and Alaric's ones. However, this difference was only significant for the 2018 vintage, indicating that the variation in ethanol content is a result of changing weather conditions from one year to the next.

However, the differences in wine pH between zones were similar for both vintages. Wines from the Maritime sub-region had, on average, the highest pH and the Durban wines the lowest. Wine pH has been reported to be first affected by climatic conditions, followed by cultivar then soil composition (van Leeuwen *et al.*, 2018). In the present study, the vintage had no impact on the ranking of the wines' pH, suggesting that differences between the zones may be linked to differences in soil composition. Several studies have shown wine pH to be positively correlated to yeast assimilable nitrogen in must, and YAN to be more influenced by soil than by climate (vintage) (Reynard *et al.*, 2011). In the present study, information regarding YAN in must had not been provided by the producers, but it was possible to hypothesise that vines from the Maritime region are grown on a soil with a better nutrient status than that of Durban vines, resulting in a higher pH of the former (3.77) compared to the latter (3.60).

2. Discrimination of wines based on sensorial analysis

The sensory analysis enabled us to group the wines into two or three clusters spanning multiple sub-regions and based on olfactory and gustatory similarities; however, it was not possible to discriminate between each of the regions in terms of the wines produced. In general, the wines were characterised according to descriptors in common that were perceived at similar intensities: this suggests a convergence of sensory profiles in these geographically close sub-regions. The descriptors that were perceived at the highest intensities in all the wines were astringent, jammy red fruits, leather, amylic, bitterness, alcohol and spicy. The shared descriptors, perceived at comparable intensities, suggests a homogeneity of sensory profiles in these close sub-regions. We noted that the classification of the wines was not the same for the 2018 vintage as the 2019 vintage, suggesting once again that there were variations in weather conditions during the two vintages and their impact on the sensory characteristics of the wines from the different geographical sub-regions. However, from one vintage to the next, we found similar groupings or distances between certain wines or similar significant sensory attributes.

The sensory profile of the Lézignan wines was relatively distinct to those of the Durban and Maritime wines for both 2018 and 2019; however, the Lézignan wines were grouped with the Lagrasse wines for both vintages and the Alaric wines for 2019. The wines from Lézignan were described as having higher intensities of lactic/buttery and humus notes for 2018 and more intense jammy red fruit and alcohol notes for 2019. In particular, the butter/lactic aroma was more pronounced in wines from Lézignan than in the wines from the Maritime and Durban sub-regions. Previous studies have suggested that this character is related to specific winemaking techniques, having been found to be more accentuated in *Oenococcus oeni*-inoculated wines than in wines in which malo-lactic fermentation (MLF) occurs naturally or under aerobic conditions (Bartowsky and Henschke, 2004). However, little information about MLF had been provided by the producers, but the fact that inoculated MLF occurred more in Lézignan wines than in wine from the other sub-regions may be an explanation. Previous studies have attributed lactic notes to the presence of ethyl lactate, which can increase up to four-fold depending on the lactic bacteria involved (Zea *et al.*, 2010). In this study, the sensory analysis results are concomitant with the chemical analysis of the wines, for which the relative amount of ethyl lactate was much higher in the wines from 2018 than from 2019. Humus/damp cave/earthy descriptors are usually perceived as off-flavours in wines and are associated with the microbiological contamination of the grapes and the production of volatile compounds, such as geosmin, 1-octen-3-one and 1-octen-3-ol (Cravero, 2020; Lisanti *et al*., 2014). 1-octen-3-ol was detected in the wines, but with no significant differences between the sub-regions. Geosmin was not detected in any of the wines; however, this compound is odour active at very low concentrations (80-90 ng/L in red wines) and the analytical method used was likely not sensitive enough to detect it, even though it may have been present. The climate changes occurring in recent years are causing both an increase in the fungal contamination of grapes and a proliferation of winery contaminant microorganisms due to higher temperatures and changes in the chemical composition of the musts (i.e., high pH and sugar content) (Cravero, 2020; Lisanti *et al*., 2014). The humus/earthy notes that were perceived in the present study suggest that the vines growing in the Lézignan region experienced higher climate temperatures in 2018 than those grown in Alaric. Furthermore, the Lézignan wines of the 2019 vintage exhibited a more intense jammy red fruit character than the wines from the Maritime and Durban sub-regions. High temperatures during grape ripening is a terroir factor that contributes to jammy red fruit aromas in wines (Bonada *et al*., 2015). In particular, Bonada and colleagues reported that the jammy red fruit flavour in Syrah wines increased under high temperature and water deficit, but not under high temperature without a water deficit. The significant sensory descriptors of the Lézignan wines suggest that, in 2019, the vines in this region probably underwent higher temperatures and water deficit than those growing in the Maritime and Durban regions. The Lagrasse and Alaric wines were perceived as having similar jammy red fruits notes to the wines from Lézignan, suggesting that the vines growing in these regions underwent similar climate conditions of high temperature and water deficit in the 2019 vintage. However, it should be noted that the jammy red fruits descriptor was perceived at high intensities in all the wines of 2018; this might be linked to the climatic conditions of high temperatures and low precipitation typical of the Corbières appellation terroir. In summary, while the butter/lactic notes, as reported in previous studies, may be associated with the winemaking process, specifically MLF, the jammy red fruits and humus/earthy characters are more likely linked to climate conditions.

For both vintages, the results of the AHC analysis showed the Durban wines to be relatively far from the Lézignan and Lagrasse wines, but closer to the Maritime wines (Figure 2). Durban wines were judged as having less intense cooked vegetable, lactic/buttery, leather and jammy red fruits notes, but more intense amylic and pastry notes (Figure 3). The jammy red fruit aroma of both the Durban and Maritime wines from 2019 was perceived as being low in intensity, suggesting that the vines growing in these sub-regions, in this vintage, underwent milder temperatures and water stress. In this study, the fermentative/amylic descriptor was associated with a nail polish character. Previous studies have associated this olfactory descriptor to specific winemaking processes, as it is mainly imparted to the wine by fermentative aroma compounds present in it, such as higher alcohols (2-methylbutan-1-ol, 3-methylbutan-1ol, 2-methylpropan-1-ol, propan-1-ol, and butan-1-ol) (Cameleyre *et al*., 2015; Coulon-Leroy *et al*., 2018; Rapp, 1990; van Leeuwen *et al.*, 2022). Since the Durban wines, as well as the Alaric wines, contained higher relative amounts of 2-methyl-1-propanol, this trend possibly confirms the fermentative origin of the amylic notes. The low internal standard deviation for this attribute in the wines of the Durban sub-region confirms that it is typical for wines from this sub-region. The wines from the Maritime and Alaric sub-regions showed similar typicality. Regarding consumer acceptance of this attribute in wines, a study on Gamay wines reported that the preference for wines with amyl notes was very consumer dependent (Geffroy *et al.*, 2016). In previous studies, pastry notes perceived in wines from Durban were related to oxidation phenomena occurring during the fermentation of wine or during ageing (Geffroy *et al.*, 2016). Those notes have been found to increase in Syrah wines containing higher concentrations of acetaldehyde, which is fully consistent with the higher acetaldehyde levels found in Durban wines (Garcia *et al.*, 2022). In the present study, pastry notes were perceived in all the wines, with quite a high standard deviation in each sub-region, suggesting that this attribute is very much producer-dependent. Nonetheless, the Durban wines had higher (even if not significant) average concentrations of acetaldehyde (20.64 mg/L) than the Maritime wines (13.57 mg/L), thus possibly explaining the higher oxidation (Table S3).

The Maritime wines from both vintages were perceived as having more intense leather and cooked vegetable notes;

these wines formed a group apart for the 2018 vintage, while for 2019 they were grouped with wines from the Durban sub-region (Figure 2). Both leather and cooked vegetables are descriptors whose origin has been associated with the winemaking process in previous sudies, but whose final intensities in wine might also depend on the grapes' composition. Leather notes have previously been associated with several phenols (ethylphenols, phenol, cresols, guaiacols and syringols) that originate from the bioconversion by *Brettanomyces bruxellensis* yeast of the hydroxycinnamic acids present in grapes (Escudero *et al.*, 2007; Segurel *et al.*, 2009; Souza Gonzaga *et al.*, 2019). The reason why consumer perception of the leathery character can be either positive or negative is unclear, but it may depend on both consumer expectations and the matrix composition, such as polyphenol content (Frost *et al.*, 2018). In particular, Aznar *et al.* (2003) reported the role of 4-ethylphenol as a fruity aroma suppressor when added to wine, and this could explain the lower intensity of the jammy red fruit aroma perceived in wines from 2019 and their grouping with the wines from the Durban sub-region for this vintage (Figure 2). Nevertheless, the standard deviation for this attribute is lower than for the other attributes, meaning that leather notes were perceived as being more intense in most of the wines from the Maritime sub-region (Figure 3). Similar intensities of leather notes were perceived in the 2018 Lézignan wines, with a low standard deviation for the sub-region, which suggests that this aroma was recurrent in these wines. Finally, Souza Gonzaga *et al.* (2019) reported that leather notes were perceived either negatively, when very intense, or positively, when they contributed to the wine's character. The positive or negative character of this aroma could not be judged by the sensory analysis panel, since the acceptance of wine can only be assessed via a consumer survey and not by a sensory panel. The cooked vegetable notes perceived in red wines has been attributed to the presence of sulphur compounds whose production during fermentation may be caused by a low or moderate initial nitrogen content in the musts (between 110-250 mg/L) or by the higher pH of the wines. However, the standard deviation for this sensorial attribute is quite high, suggesting a high variability in intensity of this descriptor for the wines from Maritime sub-region (Figure 3). The cooked vegetable notes in Maritime wines may thus be related to individual producers, rather than to the whole sub-region. Nevertheless, for both vintages the cooked vegetable notes were perceived at lower intensities in the wines from the Alaric and Durban sub-regions (albeit with a significant difference for the 2018 vintage only); this may be due to the fact that the Durban wines had a lower pH.

3. Discrimination and particularities of wines based on aroma compounds in wines.

In all the wines, the ester chemical family was the most abundant, followed by the higher alcohols; this result is in agreement with the aroma profiles reported in similar studies on blended red wines made at similar latitudes and climate (Casassa *et al.*, 2022; Hjelmeland *et al.*, 2013; Hopfer *et al.*, 2012). Previous studies have suggested that a higher concentration of esters may have an influence on the jammy red fruit character of red wines (Cameleyre *et al.*, 2017; Lytra *et al.*, 2012). Therefore, the high relative amount of esters in the wines relates to the jammy red fruits descriptor that was perceived in the wines from all the sub-regions, albeit at varying degrees of intensities. In the discriminant analysis, the comparison of the relative amounts of aroma compounds by chemical class did not allow the wines to be clearly discriminated according to sub-region, but instead grouped certain wines that had similar aromatic profiles (Figure 4 and 5). Once again, the position of wines on the FDA graph was different depending on the vintage year, which is likely due to changing weather conditions from one year to the next. However, there are significant differences in certain families of aromas present in both vintages.

Both vintages of the Lagrasse wines were distinguished by higher relative amounts of ethyl esters and their corresponding saturated fatty acids. These compounds are formed during fermentation through yeast metabolism, and their concentration is primarily influenced by the type of yeast used, must composition (sugar content, lipids and yeast assimilable nitrogen YAN), and oxygen availability and temperature during fermentation (Antalick *et al.*, 2015; Ribéreau-Gayon *et al.*, 2006; Ugliano and Henschke, 2009). Regarding the ethyl esters, the mean relative amounts of ethyl hexanoate, ethyl octanoate and ethyl decanoate were very high compared to the other wines; however, the standard deviations internal to the sub-regions were also very high, suggesting high variability between the bottles. Therefore, the type of yeast used during the winemaking process is probably the terroir factor that governed this particular chemical characteristic of the wines from this region. Also, the 2018 Lagrasse wines had marked higher average relative amounts of DMS than the wines from the Durban sub-region. This can be explained by the fact that the Lagrasse wines were made from a blend of grapes containing a higher average percentage of Syrah grapes (60 %) than Durban wines (28 %), and the Syrah variety is known to be generally richer in DMS (Samaniego Solis *et al.*, 2023). The accumulation of DMS in wines increases during fermentation and ageing due to the degradation of precursor compounds, such as S-methylmethionine (SMM). DMS content in wines is related to the primary nitrogen content of the grapes, and thus to the nitrogen status of the vine, which is in turn mostly influenced by the vineyard of origin, pointing to a relationship between DMS formation and the expression of terroir features (Escudero *et al.*, 2007; Le Menn *et al.*, 2019). Grape withering and vintage are other important factors that have been reported to play an important role in the modulation of DMS content in wines, which might explain the differences observed between the 2018 and 2019 vintages (Samaniego Solis *et al.*, 2023). Indeed, the higher ethanol content found in the Lagrasse wines could be linked to higher grape withering in 2018, thus resulting in higher DMS content in wines. DMS in wine can enhance the jammy red fruity aroma in the presence of esters. However, the red fruit character was attributed to all 2018 wines at a similar intensity, suggesting that other less positive descriptors may have negatively affected the perception of jammy red fruit notes in the Lagrasse wines (Lytra *et al.*, 2016). Nonetheless, since sensorial descriptors are frequently the result of interactions between several aromatic compounds, further experiments should be carried out to assess the real contribution of these compounds to building the profile of the Lagrasse wines. In summary, the significantly higher amounts of aromatic compounds (esters, acids and DMS) in the Lagrasse wines may be due to several factors related to terroir: the richness of the soil in assimilable nitrogen (which promotes higher quantities of amino acids in the musts) the common oenological practice in this region of adding nitrogen to the musts, and the type of yeast that is used for the production of higher amounts of these compounds (especially esters).

By contrast, the wines from the Lézignan sub-region contained significantly lower levels of ethyl esters and fatty acids than the Lagrasse wines, suggesting that their musts contained lower levels of assimilable nitrogen than the Lagrasse musts. Again, this may be linked to soil properties and/or oenological practices. Lézignan wines also contained higher amounts of C13-norisoprenoid compounds in both vintages. In particular, the 2018 Lézignan wines had higher relative amounts of the TDN compound than the other wines. Nevertheless, the relative amounts of this compound was quite low compared to those reported in another study (Slaghenaufi *et al.*, 2022). Methionol was present at significantly higher amounts in 2018 Lézignan wines, compared to Alaric's wines. This compound is known to highly vary depending on the grape variety and/or yeast metabolism during alcoholic fermentation, its occurrence being related to yeast-driven transamination of methionine followed by decarboxylation and reduction (Moreira *et al.*, 2002). The 2018 Alaric wines contained significantly lower relative amounts of this compound than did the Lézignan wines, which may be a result of the different grape varieties in the blend or vinification processes. Despite methionol having a cooked cabbage odour, in this study, the intensity of cooked vegetable notes perceived in the Lézignan wines was not significantly different to that in the Alaric wines, suggesting that methionol did not affect the sensorial profile of the red wines. A similar result has been reported in red wines from Spain by de-la-Fuente-Blanco *et al.* (2016). In summary, the Lézignan wines were characterised by higher relative amounts of compounds whose production could be either related to the composition of the soil in terms of assimilable nitrogen and/or to the winemaking conditions, such as type of yeasts used and/or grape varieties.

Both vintages of the Durban wines were characterised by lower amounts of ethyl esters and fatty acids, compared to Lagrasse's wines, and the 2018 wines by higher amounts of acetate esters (ethyl acetate most particularly) and alcohols, compared to Lézignan and Lagrasse's wines. The higher alcohols 2-phenylethanol and 2-methyl-1-propanol allowed us to distinguish the Durban wines from the Lagrasse and Lézignan wines respectively. Higher alcohols are by-products of yeast metabolism and are released during fermentation through the Erlich metabolic pathway; their accumulation depends on the type of yeast used, nitrogen content of the must and or/nitrogen addition during fermentation. The relative amounts of the ethyl esters and fatty acids were lower in Durban's wines, which may be due to the type of yeast used for fermentation. The 2018 Durban wines had higher relative amounts of 3-octanone than the Alaric wines: nonetheless, this compound was not detected in any of the 2019 wines. Previous studies have stated that 3-octanone is derived from 1-octen-3-one, a compound released into grape berries infected by powdery mildew that is reduced by *S. cerevisiae* during the fermentation process (Darriet *et al.*, 2002). In 2018, precipitation during the vegetative period (April-Sept) was almost double that in 2019 in the Durban region; therefore, this region may have been more prone to mildew contamination, thus explaining the significantly higher relative amounts found for 3-octanone for 2018 only. Finally, the relative amounts of ethyl acetate was, on average, higher in the Durban wines than in the wines from all the other sub-regions, except for Alaric. In the literature, the origins of ethyl acetate is linked either to winemaking conditions or to sugar content. In fact, in a study by Luzzini *et al.* (2021b), high concentrations of ethyl acetate were found to be related to the type of yeast used for the fermentation or, when associated with high acetic acid contents, a result of spontaneous fermentation. These authors also suggested that particularly high levels of ethyl acetate may also have been due to an osmotic stress response as a result of the high glucose and fructose content (up to almost 300 g/L) following the withering treatment (Luzzini *et al.*, 2021b). Ethyl acetate is often described as having a nail varnish odour that can be linked to the amyl (chemical) descriptor reported in those wines. The fact that this descriptor was perceived more intensively in the wines from the Durban sub-region than the Lézignan and Lagrasse wines may be due to differences in relative amounts of ethyl acetate in the wines.

The 2018 Alaric wines were characterised as having high relative amounts of acetate esters, in particular isoamyl acetate, and of the higher alcohol 2-methyl-1-propanol. In addition, the Alaric wines from both the 2018 and 2019 vintages contained similar relative amounts of ethyl esters and fatty acids to the Lagrasse wines. The type of yeast in the winemaking process was probably the terroir factor that influenced these particular characteristics of the wines from Alaric sub-region. In addition, isoamyl acetate and 2-methyl-1-propanol may have contributed to the perception of amyl notes in Alaric's wines, as they were perceived at an intensity similar to that of the Durban wine. Also, previous studies have highlighted a role of 2-methyl-1-propanol on the amyl character of wines (Luzzini *et al.*, 2021a).

For both vintages, the volatile compound 4-ethylphenol was detected in the wines from the Maritime sub-region at higher relative amounts than in those from the other sub-regions, except Durban. However, the internal standard deviations for the zone were relatively high, indicating a large variation between the bottles. As has already been mentioned, several phenols (ethylphenols, phenol, cresols, guaiacols and syringols) are associated with leather notes in wine (Escudero *et al.*, 2007). The amounts of those phenols in wine is strain-dependent and some cellars should be more sensitive to the « Brett » problem (Renouf *et al.*, 2006). For example, one study of different vineyards of the Bordeaux region reported that certain microbial species, including *Brettanomyces bruxellensis,* were clearly specific to certain estates and this specificity persisted from one year to another. They concluded that microbial populations have an important role in the specificity of wines of a given estate (Renouf *et al.*, 2006). Therefore, indigenous winemaking processes are probably the terroir factor that contributed to the specific leather attribute of the wines of various estates of the Maritime sub-region. The 2018 wines from the Maritime sub-region contained the lowest relative amounts of β-damascenone of all the sub-regions, and lower relative amounts of TDN than Lézignan wines. C13-norisoprenoids production increases in grapes under certain environmental conditions, such as higher temperatures, extended sun exposure and limited water availability (Koundouras *et al.*, 2006; Schüttler *et al.*, 2015). In addition, because C13-norisoprenoid compounds accumulate during the maturity phase of the grapes, a producer's choice to harvest earlier in order to preserve the sugar/acid ratio of the grapes may also affect the accumulation of volatile C13-norisoprenoids precursors in the grapes (Yuan and Qian, 2016); this is consistent with the lower ethanol content in the Maritime wines (Table S3). Lastly, for both the 2018 and 2019 vintages, the Maritime wines were characterised as having higher relative amounts of estragole, as well as of fenchone, a terpene-derived compound, in the same estragole-containing wine samples, compared to wines from the other sub-regions. The standard deviation for these compounds was relatively high for the zone, and thus related to specific vineyards. Estragole and fenchone have previously been found together in other vegetal matrices (e.g., fennel and anise), and their presence was correlated with balsamic and wood spheres notes (e.g., camphor, anisic and earthy) (Afify *et al.*, 2011). Poitou *et al.* (2017) reported the presence of the 1,8-cineole compound in Bordeaux wines, attributing its presence to airborne contamination from exogenous plants (Artemisia vulgaris) present in the vineyard. This is the first time that aromas originating from exogenous plants have been reported in French wines. Following this reasoning, the presence of Estragole and Fenchone compounds in the present study's wines may be related to the surrounding Mediterranean vegetation.

CONCLUSION

The chemical and sensory characterisation of blended red wines made from Syrah, Mourvèdre, Grenache and Carignan from different sub-regions of the Corbières appellation has enhanced knowledge regarding both the impact of terroir on the sensorial and aromatic attributes of wines from geographically close areas but also, on the aromatic and sensorial expression/signature of blended red wines. The impact of varying weather conditions is clear; however, by studying commercial wines from the same wineries for both vintages we were able to identify singularities in certain sub-regions for both vintages. The results obtained enabled us to differentiate the wines from geographically different sub-regions, such as the Maritime and Durban wines, and to group together wines from areas near to each other, such as Lézignan and Lagrasse. The wines from the Maritime sub-region seem to have benefited from a more temperate climate, especially in the case of seaside vineyard parcels, with musts richer in assimilable nitrogen and grapes picked at lower ripeness. The Durban wines also seem to benefit from a more temperate climate, especially the higher altitude vineyard parcels, and less water stress. This gives Durban wines less intense red jam notes. A lower acidity was also perceived in the wines from the coastal region than at higher elevations, which may be due to environmental factors. Wines from Lagrasse, Lézignan and Alaric, on the other hand, have sensory and chemical profiles typical of grapes subject to higher temperatures and water stress, as evidenced by the intensity of the red fruit jam notes. The musts of the Lagrasse sub-region, meanwhile, seem to be richer in assimilable nitrogen than those from Lézignan, resulting in wines with higher quantities of ethyl esters and fatty acids. The results of the sensory and chemical analyses have made it possible to provide chemical and sensorial specificities that characterise wines from geographically close areas of the AOC Corbières, and to suggest links with certain terroir factors. These associations are often difficult to establish, and working with an expert sensory panel is certainly an advantage in this field. As part of the process of dividing the appellation into five sub-regions, these results obtained can provide producers with specificities that they can integrate into the description of their wines, thus strengthening their identity for their consumers. The regional specificities of wines identified in this study will be examined in further studies, and particular attention will be paid to the role of specific oenological practices in defining the typicality of a sub-region.

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REFERENCES

Afify, A. E.-M. M. R., El-Beltagi, H. S., Hammama, A. A. E.-A., Sidky, M. M., & Mostafa, O. F. A. (2011). Distribution of Trans-Anethole and Estragole in Fennel (Foeniculum vulgare Mill) of Callus Induced from Different Seedling Parts and Fruits. *Notulae Scientia Biologicae*, *3*(1), 7986. https://doi.org/10.15835/nsb315422

Antalick, G., Šuklje, K., Blackman, J. W., Meeks, C., Deloire, A., & Schmidtke, L. M. (2015). Influence of Grape Composition on Red Wine Ester Profile : Comparison between Cabernet Sauvignon and Shiraz Cultivars from Australian Warm Climate. *Journal of Agricultural and Food Chemistry*, *63*(18), 46644672. https://doi.org/10.1021/acs.jafc.5b00966

Aznar, M., López, R., Cacho, J., & Ferreira, V. (2003). Prediction of Aged Red Wine Aroma Properties from Aroma Chemical Composition. Partial Least Squares Regression Models. *Journal of Agricultural and Food Chemistry*, *51*(9), 27002707. https://doi.org/10.1021/jf026115z

Bartowsky, E. J., & Henschke, P. A. (2004). The 'buttery' attribute of wine—Diacetyl—Desirability, spoilage and beyond. *International Journal of Food Microbiology*, *96*(3), 235252. https://doi.org/10.1016/j.ijfoodmicro.2004.05.013

Bonada, M., Jeffery, D. W., Petrie, P. R., Moran, M. A., & Sadras, V. O. (2015). Impact of elevated temperature and water deficit on the chemical and sensory profiles of Barossa Shiraz grapes and wines: Temperature and water effects on grapes and wines. *Australian Journal of Grape and Wine Research*, *21*(2), 240253. https://doi.org/10.1111/ajgw.12142

Cameleyre, M., Lytra, G., Tempere, S., & Barbe, J.-C. (2015). Olfactory Impact of Higher Alcohols on Red Wine Fruity Ester Aroma Expression in Model Solution. *Journal of Agricultural and Food Chemistry*, *63*(44), 97779788. https://doi.org/10.1021/acs.jafc.5b03489

Cameleyre, M., Lytra, G., Tempere, S., & Barbe, J.-C. (2017). 2-Methylbutyl acetate in wines: Enantiomeric distribution and sensory impact on red wine fruity aroma. *Food Chemistry*, *237*, 364371. https://doi.org/10.1016/j.foodchem.2017.05.093

Casassa, L. F., Vega-Osorno, A., Catania, A. A., & Harbertson, J. F. (2022). Chemical and Sensory Effects of Cofermentation and Blending of Malbec and Merlot Wines from the Central Coast of California. *Australian Journal of Grape and Wine Research*, *2022*, 117. https://doi.org/10.1155/2022/3453978

Coulon-Leroy, C., Pouzalgues, N., Cayla, L., Symoneaux, R., & Masson, G. (2018). Is the typicality of "Provence Rosé wines" only a matter of color? *OENO One*, *52*(4). https://doi.org/10.20870/oeno-one.2018.52.4.2125

Cravero, M. C. (2020). Musty and Moldy Taint in Wines: A Review. *Beverages*, *6*(2), 41. https://doi.org/10.3390/beverages6020041

Darriet, P., Pons, M., Henry, R., Dumont, O., Findeling, V., Cartolaro, P., Calonnec, A., & Dubourdieu, D. (2002). Impact Odorants Contributing to the Fungus Type Aroma from Grape Berries Contaminated by Powdery Mildew (Uncinula necator); Incidence of Enzymatic Activities of the Yeast Saccharomyces cerevisiae. *Journal of Agricultural and Food Chemistry*, *50*(11), 32773282. https://doi.org/10.1021/jf011527d

Davis, P. M., & Qian, M. C. (2019). Effect of Ethanol on the Adsorption of Volatile Sulfur Compounds on Solid Phase Micro-Extraction Fiber Coatings and the Implication for Analysis in Wine. *Molecules*, *24*(18), 3392. https://doi.org/10.3390/molecules24183392

de-la-Fuente-Blanco, A., Sáenz-Navajas, M.-P., & Ferreira, V. (2016). On the effects of higher alcohols on red wine aroma. *Food Chemistry*, *210*, 107114. https://doi.org/10.1016/j.foodchem.2016.04.021

Escudero, A., Campo, E., Fariña, L., Cacho, J., & Ferreira, V. (2007). Analytical Characterization of the Aroma of Five Premium Red Wines. Insights into the Role of Odor Families and the Concept of Fruitiness of Wines. *Journal of Agricultural and Food Chemistry*, *55*(11), 45014510. https://doi.org/10.1021/jf0636418

Frost, S. C., Blackman, J. W., Hjelmeland, A. K., Ebeler, S. E., & Heymann, H. (2018). Extended Maceration and Cap Management Impacts on the Phenolic, Volatile, and Sensory Profiles of Merlot Wine. *American Journal of Enology and Viticulture*, *69*(4), 360370. https://doi.org/10.5344/ajev.2018.17062

Garcia, L., Perrin, C., Nolleau, V., Godet, T., Farines, V., Garcia, F., Caillé, S., & Saucier, C. (2022). Impact of Acetaldehyde Addition on the Sensory Perception of Syrah Red Wines. *Foods*, *11*(12), 1693. https://doi.org/10.3390/foods11121693

Geffroy, O., Buissière, C., Lempereur, V., & Chatelet, B. (2016). A sensory, chemical and consumer study of the peppery typicality of French gamay wines from cool-climate vineyards. *OENO One*, *50*(1), 35. https://doi.org/10.20870/oeno-one.2016.50.1.53

Gómez-Plaza, E., Olmos, O., & Bautista-Ortín, A. B. (2016). Tannin profile of different Monastrell wines and its relation to projected market prices. *Food Chemistry*, *204*, 506512. https://doi.org/10.1016/j.foodchem.2016.02.124

Hjelmeland, A. K., King, E. S., Ebeler, S. E., & Heymann, H. (2013). Characterizing the Chemical and Sensory Profiles of United States Cabernet Sauvignon Wines and Blends. *American Journal of Enology and Viticulture*, *64*(2), 169179. https://doi.org/10.5344/ajev.2012.12107

Hopfer, H., Ebeler, S. E., & Heymann, H. (2012). How Blending Affects the Sensory and Chemical Properties of Red Wine. *American Journal of Enology and Viticulture*, *63*(3), 313324. https://doi.org/10.5344/ajev.2012.11112

Koundouras, S., Marinos, V., Gkoulioti, A., Kotseridis, Y., & van Leeuwen, C. (2006). 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. *Journal of Agricultural and Food Chemistry*, *54*(14), 50775086. https://doi.org/10.1021/jf0605446

Kustos, M., Gambetta, J. M., Jeffery, D. W., Heymann, H., Goodman, S., & Bastian, S. E. P. (2020). A matter of place : Sensory and chemical characterisation of fine Australian Chardonnay and Shiraz wines of provenance. *Food Research International*, *130*, 108903. https://doi.org/10.1016/j.foodres.2019.108903

Le Menn, N., van Leeuwen, C., Picard, M., Riquier, L., De Revel, G., & Marchand, S. (2019). Effect of Vine Water and Nitrogen Status, as Well as Temperature, on Some Aroma Compounds of Aged Red Bordeaux Wines. *Journal of Agricultural and Food Chemistry*, *67*(25), 70987109. https://doi.org/10.1021/acs.jafc.9b00591

Leriche, C., Molinier, C., Caillé, S., Razungles, A., Symoneaux, R., & Coulon-Leroy, C. (2020). Development of a methodology to study typicity of PDO wines with professionals of the wine sector. *Journal of the Science of Food and Agriculture*, *100*(10), 38663877. https://doi.org/10.1002/jsfa.10428

Lisanti, M. T., Gambuti, A., Genovese, A., Piombino, P., & Moio, L. (2014). Earthy off-flavour in wine: Evaluation of remedial treatments for geosmin contamination. *Food Chemistry*, *154*, 171178. https://doi.org/10.1016/j.foodchem.2013.12.100

Luzzini, G., Slaghenaufi, D., Pasetto, F., & Ugliano, M. (2021a). Influence of grape composition and origin, yeast strain and spontaneous fermentation on aroma profile of Corvina and Corvinone wines. *LWT*, *143*, 111120. https://doi.org/10.1016/j.lwt.2021.111120

Luzzini, G., Slaghenaufi, D., & Ugliano, M. (2021b). Volatile Compounds in Monovarietal Wines of Two Amarone Della Valpolicella Terroirs: Chemical and Sensory Impact of Grape Variety and Origin, Yeast Strain and Spontaneous Fermentation. *Foods*, *10*(10), 2474. https://doi.org/10.3390/foods10102474

Lytra, G., Tempere, S., de Revel, G., & Barbe, J.-C. (2012). Distribution and Organoleptic Impact of Ethyl 2-Hydroxy-4-

methylpentanoate Enantiomers in Wine. *Journal of Agricultural and Food Chemistry*, *60*(6), 15031509. https://doi.org/10.1021/jf204378u

Lytra, G., Tempere, S., Marchand, S., De Revel, G., & Barbe, J.-C. (2016). How do esters and dimethyl sulphide concentrations affect fruity aroma perception of red wine? Demonstration by dynamic sensory profile evaluation. *Food Chemistry*, *194*, 196200. https://doi.org/10.1016/j.foodchem.2015.07.143

Maitre, I., Symoneaux, R., Jourjon, F., & Mehinagic, E. (2010). Sensory typicality of wines: How scientists have recently dealt with this subject. *Food Quality and Preference*, *21*(7), 726731. https://doi.org/10.1016/j.foodqual.2010.06.003

Moreira, N., Mendes, F., Pereira, O., Guedes De Pinho, P., Hogg, T., & Vasconcelos, I. (2002). Volatile sulphur compounds in wines related to yeast metabolism and nitrogen composition of grape musts. *Analytica Chimica Acta*, *458*(1), 157167. https://doi.org/10.1016/S0003-2670(01)01618-X

Poitou, X., Thibon, C., & Darriet, P. (2017). 1,8-Cineole in French Red Wines: Evidence for a Contribution Related to Its Various Origins. *Journal of Agricultural and Food Chemistry*, *65*(2), 383393. https://doi.org/10.1021/acs.jafc.6b03042

Rapp, A. (1990). Natural flavours of wine: Correlation between instrumental analysis and sensory perception. *Fresenius' Journal of Analytical Chemistry*, *337*(7), 777785. https://doi.org/10.1007/BF00322252

Renouf, V., Miot-Sertier, C., Strehaiano, P., & Lonvaud-Funel, A. (2006). The wine microbial consortium: A real terroir characteristic. *OENO One*, *40*(4), 209. https://doi.org/10.20870/oeno-one.2006.40.4.864

Reynard, J.-S., Zufferey, V., Nicol, G.-C., & Murisier, F. (2011). Soil parameters impact the vine-fruit-wine continuum by altering vine nitrogen status. *OENO One*, *45*(4), 211. https://doi.org/10.20870/oeno-one.2011.45.4.1502

Ribéreau-Gayon, P., Dubourdieu, D., & Donèche, B. (2006). *Handbook of enology* (2nd ed). John Wiley.

Rousseau, J., & Roux, C. (2021). ODG CORBIERES Délimitation et caractérisation des vins des dénominations géographiques complémentaires. *Groupe ICV*, Version 4, 1-28.

Sabon, I., de Revel, G., Kotseridis, Y., & Bertrand, A. (2002). Determination of Volatile Compounds in Grenache Wines in Relation with Different Terroirs in the Rhone Valley. *Journal of Agricultural and Food Chemistry*, *50*(22), 63416345. https://doi.org/10.1021/jf025611k

Samaniego Solis, J. A., Luzzini, G., Slaghenaufi, D., & Ugliano, M. (2023). Dimethyl Sulfide (DMS) in Amarone Wines: Influence of Aging, Withering, Grape Variety, and Geographical Origin. *Journal of Agricultural and Food Chemistry*, acs.jafc.3c00728. https://doi.org/10.1021/acs.jafc.3c00728

Schüttler, A., Friedel, M., Jung, R., Rauhut, D., & Darriet, P. (2015). Characterizing aromatic typicality of Riesling wines: Merging volatile compositional and sensory aspects. *Food Research International*, *69*, 2637. https://doi.org/10.1016/j.foodres.2014.12.010

Segurel, M. A., Baumes, R. L., Riou, C., & Razungles, A. (2009). Role of Glycosidic Aroma Precursors on the odorant profiles of Grenache noir and Syrah Wines from the Rhone valley. Part 1: Sensor. *OENO One*, *43*(4), 199. https://doi.org/10.20870/oeno-one.2009.43.4.793

Slaghenaufi, D., Vanzo, L., Luzzini, G., Arapitsas, P., Marangon, M., Curioni, A., Mattivi, F., Piombino, P., Moio, L., Versari, A., Ricci, A., Rio Segade, S., Rolle, L., & Ugliano, M. (2022). Monoterpenoids and norisoprenoids in Italian red wines: This article is published in cooperation with Macrowine 2021, 23-30 June 2021. *OENO One*, *56*(3), 185193. https://doi.org/10.20870/oeno-one.2022.56.3.5387

Souza Gonzaga, L., Capone, D. L., Bastian, S. E. P., Danner, L., & Jeffery, D. W. (2019). Using Content Analysis to Characterise the Sensory Typicity and Quality Judgements of Australian Cabernet Sauvignon Wines. *Foods*, *8*(12), 691. https://doi.org/10.3390/foods8120691

Úbeda, C., del Barrio-Galán, R., Peña-Neira, Á., Medel-Marabolí, M., & Durán-Guerrero, E. (2017). Location Effects on the Aromatic Composition of Monovarietal cv. Carignan Wines. *American Journal of Enology and Viticulture*, *68*(3), 390399. https://doi.org/10.5344/ajev.2017.16086

Ugliano, M., & Henschke, P. A. (2009). Yeasts and Wine Flavour. In M. V. Moreno-Arribas & M. C. Polo (Éds.), *Wine Chemistry and Biochemistry* (p. 313392). Springer New York. https://doi.org/10.1007/978-0-387-74118-5_17

van Leeuwen, C., Barbe, J.-C., Darriet, P., Destrac-Irvine, A., Gowdy, M., Lytra, G., Marchal, A., Marchand, S., Plantevin, M., Poitou, X., Pons, A., & Thibon, C. (2022). Aromatic maturity is a cornerstone of terroir expression in red wine: This article is published in cooperation with Terclim 2022 (XIVth International Terroir Congress and 2nd ClimWine Symposium), 3-8 July 2022, Bordeaux, France. *OENO One*, *56*(2), 335351. https://doi.org/10.20870/oeno-one.2022.56.2.5441

van Leeuwen, C., Roby, J.-P., & De Rességuier, L. (2018). Soil-related terroir factors: A review. *OENO One*, *52*(2), 173188. https://doi.org/10.20870/oeno-one.2018.52.2.2208

Yang, Y., Jin, G.-J., Wang, X.-J., Kong, C.-L., Liu, J., & Tao, Y.-S. (2019). Chemical profiles and aroma contribution of terpene compounds in Meili (*Vitis vinifera* L.) grape and wine. *Food Chemistry*, *284*, 155161. https://doi.org/10.1016/j.foodchem.2019.01.106

Yuan, F., & Qian, M. C. (2016). Development of C13-norisoprenoids, carotenoids and other volatile compounds in *Vitis vinifera* L. Cv. Pinot noir grapes. *Food Chemistry*, *192*, 633641. https://doi.org/10.1016/j.foodchem.2015.07.050

Zea, L., Moyano, L., Ruiz, M. J., & Medina, M. (2010). Chromatography-Olfactometry Study of the Aroma of Fino Sherry Wines. *International Journal of Analytical Chemistry*, *2010*, 15. https://doi.org/10.1155/2010/626298.