OLFACTORY SPECIFICITY OF RED- AND BLACK-BERRY FRUIT AROMAS IN RED WINES AND CONTRIBUTION TO THE RED BORDEAUX WINE CONCEPT

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Abstract

Aims: The first aim of this investigation was to determine whether red- and black-berry fruit aromas were specific to red wines. The second aim was to study their contribution to the red Bordeaux wine concept.

Methods and results: In experiment 1, red wines were presented to expert assessors in dark, then in clear glasses. Assessors selected wines where they detected specific red-/black-berry aromas and then rated the perceived intensity. Results showed a statistically significant impact of visual input on both detection and intensity rating of red-/black-berry aromas in red wines. As part of experiment 2, both red and white wines were rated using dark glasses only. Globally, red-/black-berry aromas were shown to be more specific to red wines. Finally, in experiment 3, red Bordeaux wine experts assessed the degree to which 21 wines (9 red Bordeaux wines, 8 red wines of various origins and 4 white wines) corresponded to their own red Bordeaux wine concept, and then evaluated the intensity of 4 fruity descriptors they had detected in these wines. The results revealed that the expert assessors shared coherent olfactory concepts of red Bordeaux wines, which enabled them to distinguish the red Bordeaux from the other wines presented.

Conclusions: The existence of a red-/black-berry character specific to red wines was demonstrated. Moreover, it was shown for the first time that red Bordeaux wines tend to have their own sensory space. The distinctive character of these wines was found to relate to « black-berry » and « jammy-fruit » olfactory descriptors.

Significance and impact of the study: This study clarified our knowledge of the fruity olfactory descriptors specific to red wines in general and red Bordeaux wines in particular.

Key words: red- and black-berry aromas, olfactory descriptors, wine presentation, distinctive similar fruity character, red Bordeaux wine

Résumé

Objectifs: Cette étude vise à démontrer la réalité sensorielle de l'existence d'une spécificité aromatique fruitée des vins rouges, ainsi que l'existence d'un espace olfactif propre aux vins rouges de Bordeaux.

Méthodes et résultats : Quatre vins rouges ont été présentés en verres noirs, puis en verres transparents à un panel d'experts. Les juges ont sélectionné les vins dans lesquels ils percevaient spécifiquement des arômes de type fruits rouges ou fruits noirs, avant d'évaluer l'intensité de perception de ces nuances aromatiques. Le type de verre utilisé, donnant ou non accès à une information visuelle au cours de la dégustation, s'est révélée influencer significativement non seulement la détection d'arômes de type fruits rouges ou fruits noirs dans les vins, mais aussi l'intensité à laquelle ces arômes étaient perçus par les juges qui les avaient détectés. Le recours à des verres noirs a également montré que ce caractère fruits rouges ou fruits noirs était spécifiquement perçu dans les vins rouges. 11 experts des vins de Bordeaux ont par ailleurs jugé le degré d'exemplarité de 21 vins (9 vins rouges de Bordeaux, 8 vins rouges d'origine géographique autre et 4 vins blancs) par rapport à leurs conceptions personnelles de l'arôme d'un vin rouge de Bordeaux. Ils ont ensuite évalué l'intensité de 4 descripteurs fruités dans chacun de ces vins. Les résultats ont révélé un consensus entre les juges. Partageant des références olfactives communes de ce qu'est un bon exemple de vin rouge de Bordeaux, ils ont globalement reconnu ces vins des autres échantillons proposés.

Conclusion: L'existence d'un caractère fruité spécifique aux vins rouges a été clairement établie. La présence de composés soufrés pourrait influer sur l'intensité de perception de cet arôme. L'existence d'un espace olfactif propre aux vins rouges de Bordeaux a également été mis en évidence. Cet espace est apparu corrélé à un caractère fruité de type « fruits noirs » et « fruits confiturés » des vins.

Impact scientifique de cette étude: Cette étude apporte une contribution à la connaissance de l'arôme fruité des vins rouges en général, et des vins rouges de Bordeaux en particulier.

Mots clés : arômes de fruits rouges et noir, descripteurs olfactifs, présentation du vin, caractère fruité, vin rouge de Bordeaux

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INTRODUCTION

In national and international wine writing, there is a strong preconception that red- and/or black-berry olfactory descriptors are characteristic of red wines. The Larousse Encyclopedia of Wine exemplifies this phenomenon by distinguishing white wine descriptors, which « tend towards citrus and other fruit flavours: lemon, orange, grapefruit, peach, pear, apricot apple… » from those of red wines, which « are more reminiscent of red-berry fruits: red and black cherries, damson, blackcurrant, redcurrant, blackberry, raspberry, strawberry ». It also specifies that « the wines obtained from noble grape varieties have characteristic odours: for example, Cabernet-Sauvignon wine is perceived by a majority of assessors to be reminiscent of blackcurrant » (Larousse Encyclopedia of Wine, 1998). It is a fact that many authors have contributed to characterizing the aromatic compounds responsible for specific fruity nuances in red wines (Aznar *et al.,* 2001; Campo *et al*., 2007; Culleré *et al*., 2004; Kotseridis and Baumes, 2000; Moio and Etiévant, 1995). For example, we have recently published evidence of perceptive interactions between fruity esters, responsible for specific red-/black-berry nuances in red Bordeaux wine (Pineau *et al*., 2009).

Paradoxically, a strong controversy exists in the literature about the existence of a fruity expression specific to red wines. This absence of consensus relates mostly to the fact that assessors are known to be strongly influenced by visual cues. As demonstrated by Herz and Engen (1996), olfactory detection is approximately 10 times slower than visual detection. Visual characteristics are thus the first information perceived when tasting wine. It results in colour having a strong influence on the qualitative determination of odours (Gilbert *et al*., 1996; Stillman, 1993; Zellner *et al*., 1991; Lawless and Heymann 1998; Zellner and Whitten, 1999). From this standpoint, results reported by Morrot *et al*. (2001) are of particular interest. In 2001, they showed that the epithets chosen to represent the odour of a wine were generally the same colour as that wine. Consequently, they found wine colour to be detectable in the assessor's description, even if it was not expressly stated. Finally, referring to the ability of untrained assessors to decide on the colour (red or white) of a wine, they reported that « even if the subjects succeed better than chance in this task, the flavour of a white wine was not clearly distinguished from that of a red wine ». In 2003, Piombino *et al*. made similar observations, reporting that only 4 assessors out of 23 were able to identify and distinguish white wines from reds, when presented in dark glasses. In addition, the assessors were shown to attribute berry-like descriptors mostly to the two white wines included in the study. These results contrast with observations reported by Sauvageot and Chapon (1983). In blind tests, assessors were asked to determine the colour of four red wines and four white wines using smell only. The results showed that the colour of wines was recognized at level higher than chance. And very recently, Ballester *et al*. (2009) reported similar observations. Assessors were presented 18 wines in dark glasses, with equal numbers of red, white and rosé wines. When asked to categorize them into the three different types, assessors correctly identified red and white wines but not rosé wines. Moreover, assessors were shown to describe white wines using yellow and orange odorant sources, while red wines were described by dark odorant sources.

The concept of wine typicality relates to the unique chemical and sensory characteristics that can be shared by wines from a delimited geographical area distinguished by similar features. In 2004, Candelon *et al*. developed a sensory methodology to investigate the existence of a Sciaccarello wine concept. The method was based on typicality judgement by expert assessors who were shown to share a common reference of the sensory expression specific to this Corsica variety. From blindfold assessment of 28 wines, including 14 Sciaccarello wines, Candelon *et al*. demonstrated that most of the wines distinguished as being good examples of Sciaccarello wines were, indeed, Sciaccarello wines. Consequently, authors concluded that wines made from this Corsica variety tended to have their own specific sensory space. The methodology developed has since been applied to studies of Burgundy Chardonnay wines (Ballester *et al*., 2005) and New Zealand Sauvignon blanc wines (Parr *et al*., 2007; 2010). Result from Ballester *et al*. demonstrated a good consensus among French wine professionals concerning a shared Chardonnay wine concept. Based on it, Chardonnay wines were shown to have their own, typical sensory characteristics. In 2007, Parr *et al*. successfully demonstrated the existence of a Marlborough Sauvignon blanc wine concept, as wines from this New Zealand region were found to be distinguishable sensorially from French Sauvignon blanc wines.

Overall, it is obvious that contradictions between previous studies failed to provide clear evidence of a fruity aromatic expression specific to red wines. Hence, the first goal of this study was to verify the existence of specific fruity aromas in red wines with focus on two questions: Are assessors able to distinguish white wines from red wines? Are red-/black-berry descriptors attributed specifically to red wines? Moreover, it has been demonstrated that sulphur compounds can contribute to the aroma of red Bordeaux (Blanchard *et al*., 1999) and rosé wines (Murat *et al*., 2001 ; Ferreira *et al*., 2002). Based on these findings, we further investigated the question whether thiols in red Bordeaux wines could impact the perception of its fruity aromas. The second part of this study focused on the concept of wine typicality

applied to red Bordeaux wines and raised two particular questions: Can expert assessors recognize red Bordeaux among red wines from various geographical origins on the basis of their olfactory characteristics? If so, did red- and black-berry aromas contribute to this recognition?

MATERIALS AND METHODS

1. Wines

In this report, 29 commercial wines were studied: 8 white wines and 21 red wines (13 from the Bordeaux region, 7 from other regions of France, and one from Chile). The names, origins and vintages are listed in table 1. The Bordeaux wines were provided by the CIVB (Bordeaux Wine Council) and selected for their quality and representative character. The other wines were selected by a panel of three expert assessors for their clear, intensely fruity aromas. This pre-selection ensured that all wines were defect-free. Wines RW1, RW2, WW1, and WW2 were fermented and aged in stainless steel tanks with no wood ageing. The other 25 wines were aged in oak barrels. All wines were still and contained under 2 g/L residual sugar.

2. Panels of assessors

There were three panels of assessors. Panel 1 consisted of 15 assessors – winemakers and researchers - all members of research laboratories at the Bordeaux Faculty of Enology (France). Panel 2 consisted of 43 assessors - students from the Bordeaux Faculty of Enology - trained in wine tasting methods. Panel 3 consisted of 11 assessors - wine-related professions (winemakers, oenologists and wine researchers). The assessors in panels 1 and 3 had extensive experience in wine tasting and were considered experts in this field.

3. Sensory evaluations

All sensory evaluations were performed under controlled room temperature (20 °C), in individual booths, using either dark or clear AFNOR (Association Française des Normes) glasses containing approximately 40 mL of wine. Glasses were annotated using 3-digit codes. Sensory evaluations were orthonasal (sniffing after swirling). Three experimental procedures were used without any information given to the assessors on the objectives of the studies.

Table 1. Characteristics of the wines studied.

Type	Code	Name	Origin	Vintage
Red wine	RW1	Le voyageur – Cuvée tradition	AOC Bordeaux supérieur	2004
	RW2	Château Penin – Tradition	AOC Bordeaux supérieur	2004
	RW3	Domaine de Chastelet	AOC Bordeaux supérieur	2004
	RW4	Château de Rochemorin	AOC Pessac-Léognan	2004
	B1	Domaine Grandmaison	AOC Pessac-Léognan	2004
	B2	Château Vieux Montaiguillon	AOC S^{t} Georges S^{t} Emilion	2004
	B3	Château Anthonic	AOC Moulis	2004
	B4	Château de Viaud	AOC Lalande de Pomerol	2002
	B5	Château Segonzac	AOC Bordeaux supérieur	2002
	B6	Château Saint Christoly	AOC Médoc	2004
	B7	Château Teyssier	AOC Montagne S^{t} Emilion	2001
	B8	Château de Chantegrive	AOC Graves	2002
	B9	Château Mongravey	AOC Margaux	2004
	O1	Domaine Gauby	AOC Côtes du Roussillon	2001
	O2	La Voulte Gasparets	AOC Corbières	2003
	O3	Cassillero del Diablo	Chili	2005
	O4	J-M Roger	AOC Sancerre	2000
	O5	Le Mas de Flauzières	AOC Gigondas	2004
	O6	Château La Colombière – Coste Rouge	AOC Fronton	2005
	O7	François Raguillet – Les Vasées	AOC Mercurey 1er Cru	2005
	O8	Domaine de Souzons	AOC Beaujolais-Village	2004
White wine	WW1	Domaine de Lescure	AOC Entre-deux-Mers	2005
	WW2	Château Penin	AOC Entre-deux-Mers	2005
	WW3	Château Sainte Marie – Vieilles vignes	AOC Entre-deux-Mers	2005
	WW4	Château Camus	AOC Entre-deux-Mers	2005
	W1	Château de Respide	AOC Pessac-Léognan	2006
	W2	Domaine de Bellegarde	AOC Jurançon	2005
	W3	-	VDP d'Oc	2004
	W4	J-M Roger – Cuvée GC	AOC Sancerre	2006

AOC: « Appellation d'Origine Contrôlée » (French certification for registered designation of origin) – VDP: « Vin de Pays » (French certification for registered designation of origin).

In experiment 1, panel 1 evaluated red wines RW1 to RW4 in two sessions, separated by a 20-min break. In the first session, the 4 wines were presented in dark glasses, in a randomized order. In the second session, they were presented in clear glasses, in a different order. Each time, assessors were initially asked to select the wine(s) in which they detected specific red-/black-berry aromas and rate their intensity of perception on a 5-point scale (1 = very low intensity to 5 = high intensity).

In experiment 2, panel 2 assessed red wines RW1 to RW4 and white wines WW1 to WW4, in two series of sensory evaluations, each divided into two sessions, separated by a 20-min break. The first series consisted of wines that had had no contact with wood (i.e. RW1, RW2, WW1, and WW2). In the first session, the wines were presented in dark glasses, in a randomized order. In the second session, each wine was added 50 mg/L copper (eq. Cu^{2+}) and presented in dark glasses, in a different order. The same procedure was applied to the other series. The 4 wines in this series (RW3, RW4, WW3, and WW4) had been aged in oak barrels. The assessors received the same instructions as in experiment 1. Assessors were not informed what types of wine were included in each session.

The procedure for experiment 3 was adapted from Ballester *et al*. (2005). It included 21 wines: 9 red Bordeaux, 8 red wines from various origins and 4 white wines (B1 to B9, O1 to O8, and W1 to W4, respectively, see table 1). They were divided into 2 series of 12 wines, each including 5 different red Bordeaux (one was presented twice), 4 red wines from various origins and 2 white wines. B4 was common to both series. Panel 3 assessed the wines in two sessions, corresponding to the two series of wines, separated by a 20-min break. In each session, the 12 samples were evaluated twice, in a different order each time, separated by a 15-min break. Each session lasted about 1 h. Wine samples at room temperature (around 19 °C) were poured into dark glasses with plastic covers. Sample presentation was monadic and balanced for the presentation order and carry-over effect (MacFie *et al*., 1989). Prior to the first evaluation in each session, assessors received the following instructions: « Imagine that you want to explain what red Bordeaux wine is like, by suggesting a wine to taste. Please answer the following question for each wine: Do you think this wine is a good or bad example of red Bordeaux wine? » Panellists answered on a 10-point scale (1 = « very bad example » to 10 = « very good example »).

After the 15-min break (to change the presentation order), assessors were asked to evaluate the intensity of four descriptors: « red-berry », « black-berry », « fresh fruit » and «jammy fruit ». The intensity of perception for each wine and descriptor was rated on a 5-point scale (1 = very low intensity to 5 = strong intensity). The « red-berry » and « black-berry » descriptors were verbally described as « redcurrant - raspberry - strawberry » and « blackcurrant - blackberry – black cherry », respectively.

4. Data analysis

In experiments 1 and 2, binomial distribution was used to determine the statistical significance of the number of assessors who detected red-/black berry aromas in wines. In experiment 1 and 2, the statistical significance of the differences in perceived intensity of red-/black-berry aromas depending on the glass type and on the copper addition to wine, respectively, were determined using two-factor analysis of variance (factors « assessor » and « glass type », and factors « assessor » and « copper addition », respectively). Post-hoc differences between means were determined using Fisher's Least Significant Difference (LSD) values at α=0.05. In experiments 2 and 3, Principal Component Analyses (PCA) were performed on the averaged sensory scores from all assessors using Statbox 2.1 (Grimmer Logiciels, France) on the correlation matrix. Additional analyses of variance, Normal law distribution, Pearson's chi-square tests, and Student tests were used to determine the statistical significance of the fruity assessment results for each group, i.e.: « red Bordeaux wine », « other red wine », and « white wine ».

RESULTS AND DISCUSSION

Twenty-nine commercial wines were involved in this study (Table 1). The samples were annotated WW and RW for white and red wines, respectively.

1. Experiment 1: Specific fruity aromas in red wines

In order to determine if assessors were able to distinguish white and red wines, sensory evaluations were performed without or with visual information on the wines (i.e.: presentation in dark or clear glasses) (Table 2). For RW1 to RW3, the number of assessors who detected specific red-/black-berry aromas was highly significant (a very low probability according to the Binomial distribution of the assessors' responses), irrespective of the wine presentation used. Consequently, the first three wines were globally perceived as fruity by the panel. On the contrary, the results for RW4 differed significantly, depending on the type of glasses used. It was not perceived as fruity ($p > 0.05$) in dark glasses, whereas specific red-/black-berry aromas were generally detected ($p < 0.001$) in clear glasses. To summarize, one to five assessors out of fifteen did not detect fruity aromas when the wines were in dark glasses, while the perception was unanimously positive when the same wines were presented in clear glasses.

Table 2. Numbers of assessors who detected red- or black-berry aromas and mean intensities of perception, when red wines were presented in dark or clear glasses.

Wine	Number of assessors (out of 15) who detected red-/black-berry aroma in wines presented in: dark glasses	clear glasses	Mean perceived intensity (± standard deviation) of red-/black-berry aromas in wines presented in: dark glasses	clear glasses	*P*-value
Red wine 1	**12** [b]	**15** [c]	2.07 (±1.33)	2.47 (±0.92)	0.253
Red wine 2	**12** [b]	**15** [c]	1.67 (±1.11) **b**	2.73 (±1.10) **a**	**0.050**
Red wine 3	**14** [c]	**15** [c]	2.47 (±1.13) **b**	3.27 (±1.03) **a**	**0.031**
Red wine 4	10	15 [c]	1.33 (±1.18) **b**	2.80 (±1.32) **a**	**0.004**

Statistical probability of obtaining the numbers of assessors out of the total members in the panel was determined using a Binomial distribution of the assessor responses (b: $P < 0.01$ - c: $P < 0.001$). Statistical significance of the differences in perceived intensity of red-/black-berry aromas in wines depending of the glass type was determined using two-factor analysis of variance (factors 'assessor' and 'glass type', respectively).

In addition, table 2 shows the average intensities of red-/black-berry aromas perceived in each of the four wines, following presentation in both glass types. Assessors perceived more intense red-/black-berry aromas in each of the wines when presented in clear glasses. With p-values inferior (or equal) to 0.05, differences in perceived intensities are statistically significant for three wines out of the four presented (RW2, RW3, and RW4 wines). Consequently, visual input exerted a statistically significant influence, not only on the specific red-/black-berry aromas detected in red wines, but also on the perception of their intensity. These results are in agreement with studies by Sauvageot and Chapon (1983) and Morrot *et al*. (2001). Both highlighted the difficulty of identifying the colour of a wine without visual input. Thus, Morrot *et al*. (2001) observed a success rate of nearly 70% for determining the colour (red or white) of a wine presented in an opaque glass. They concluded that « even if the subjects succeed better than chance in this task, the flavour of a white wine was not clearly distinguished from that of a red wine ». This fact, together with our results from experiment 1, justifies the use of dark glasses in experiment 2.

2. Experiment 2: Red-/black-berry aromas in white and red wines

Sensory evaluation in experiment 2 investigated the detection and perceived intensity of red-/black-berry aromas in white wines compared with red wines, with or without adding copper to the wines. Two phenomena were observed from the results shown in table 3.

Firstly, the results obtained without adding copper revealed significant differences in the detection of specific red-/black-berry aromas, depending on the type of wine. A statistically significant high number of assessors detected these fruity aromas in red wines, whereas a statistically significant low number of assessors perceived them in white wines.

Inter-assessor agreement in scoring perceived intensity of red-/black-berry aromas was checked by principal component analysis (PCA) performed on averaged scores (Figure 1). The loading plots corresponding to the assessors were mostly on the positive side of the first principal component axis, which explains 57% of the original variability (15% is explained by the second principal component axis). Five assessors only (assessors 16, 23, 24, 26, and 42) were found to score differently, as shown by their negative positioning on this F1-axis. Consequently, the scores provided by the assessors can be considered as globally correlated, showing that the panel shared common references of red-/black-berry aromas in wines. Based on this global consensus, one-factor analysis of variance with post-hoc Fisher's tests

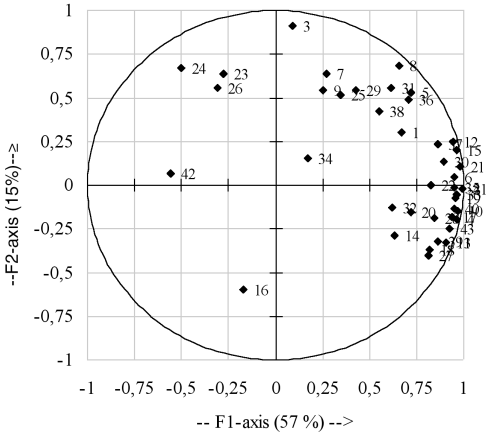

Figure 1. Correlation circle of PCA for « red-/black-berry aroma » averaged scores showing agreement among 38 assessors out of 43.

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was applied to the averaged intensity scores in wines grouped by colour. It revealed significant differences between white and red wines ($F_{1,6} = 54.29$; $p < 0.001$). It is important to notice that assessors were not informed in advance that both red and white wines would be presented. Consequently, three conclusions may be drawn from the results from experiment 2. First of all, the fact that, statistically speaking, red-/black-berry aromas were detected at a significant level only in red wines indicated that these aromas were really specific to these wines. Nevertheless, irrespective of the session considered, about 25% of the assessors attributed these aromas to white wines. Based on inter-assessor agreement results in Experiment 2, this phenomenon may be accounted for by the proportion of assessors who do not share the reference of red-/black-berry aromas common to the wide majority of the assessors. Finally, at least 85% of the assessors detected red-/black-berry aromas in red wines, confirming the results of experiment 1 and contradicting Piombino's findings (2003).

To summarize, the first two experiments provided evidence that red-/black berry aromas existed and were specifically perceived in red wines. Nevertheless, about 15% of the assessors had difficulty identifying the fruity aromas as « red- and black-berry » without knowing the wine colour. This phenomenon was previously observed by Morrot *et al*. (2001), who demonstrated that a white wine coloured in red was perceived by assessors as having red wine aromas. Thus, wine colour provides significant sensory information, which influences the description of flavours by the subjects. In other words, colour is used implicitly in verbalizing odours. In addition, Morrot *et al*. (2001) observed that the error rate was higher when the white wines were coloured in red than when they had no visual input at all. Parr *et al*. (2003) extended this result as they reported that expert's aroma judgement on white wines coloured in red were more accurate when wines were presented in opaque glasses than when presented in clear glasses. These findings are particularly interesting, suggesting that specific white wine aromas can be distinguished from those of red wines in blind tests. Consequently, the use of dark glasses provided comparable sensory perception results, by eliminating the influence of visual input.

Interestingly, adding copper to the wines to study the impact of the absence of thiols on wine aroma (Blanchard *et al*. 2004) gave similar results for all wines except RW2 and RW4 with both $p < 0.001$ (Table 3). The detection results showed that the perception of RW4 was significantly modified, as 40 assessors out of 43 detected specific red-/black-berry aromas in RW4, and 25 only continued to do so when copper was added. Thus, in statistical terms, RW4 was no longer described as exhibiting the red-/black-berry aromas specific to red wine in the absence of thiols, although a higher proportion of assessors detected these notes than in white wines. For RW2 wine, detection results were statistically similar, but the absence of thiols significantly lowered the intensity they perceived red-/black-berry aromas. The examples of RW2 and RW4 thus indicate that thiols may affect the specific red- and black-berry aromas in red wines. The intensity ratings provided further clarification (Figure 2). The average intensity of the red-/black-berry aromas in wines by colour is shown before and after copper addition.

Table 3. Numbers of assessors who detected red- or black-berry aromas and mean intensities of perception in white and red wines, presented in dark glasses.

	Number of assessors (out of 43) who detected red-/black-berry aroma in wines		**Mean perceived intensity (± standard deviation) of red-/black-berry aromas in wines**		
Wine	no copper added	50 mg/L copper added	no copper added	50 mg/L copper added	***P*-value**
White wine 1	8 ^{c}	11 ^{b}	0.42 (±1.01)	0.58 (±1.16)	0.368
White wine 2	10 ^{c}	15 ^{a}	0.90 (±1.74)	0.95 (±1.57)	0.840
White wine 3	11 ^{b}	10 ^{c}	0.79 (±1.52)	0.58 (±1.22)	0.420
White wine 4	8 ^{c}	11 ^{b}	0.40 (±0.95)	0.56 (±1.08)	0.484
Red wine 1	39 ^{c}	37 ^{c}	2.41 (±1.37)	2.09 (±1.39)	0.113
Red wine 2	42 ^{c}	35 ^{c}	3.06 (±1.06) **a**	2.14 (±1.44) **b**	**< 0.001**
Red wine 3	34 ^{c}	37 ^{c}	2.14 (±1.39)	1.98 (±1.37)	0.302
Red wine 4	**40** ^{c}	**25**	2.55 (±1.48) **a**	1.21 (±1.37) **b**	**< 0.001**

The wines were spiked with 50 mg/L copper (Cu^{2+}) or not prior to sensory evaluation. Statistical probability of obtaining the numbers of assessors out of the total members in the panels was determined using a Binomial distribution of the assessor responses (a: $P < 0.050$ - b: $P < 0.01$ c: $P < 0.001$). Statistical significance of the differences in perceived intensity of red-/black-berry aromas in wines depending of the copper addition was determined using two-factor analysis of variance (factors « assessor » and « copper addition », respectively).

One-factor analysis of variance on the white wine groups (without or with copper) revealed a 0.80 probability of random distribution in the two groups. Consequently, the thiols had no impact on the perception of specific red-/black-berry aromas in white wines. This was expected, as these aromas were not statistically detected in white wine. The findings for red wine were much more interesting as they were significantly divided into two groups, with or without thiols, with a 0.04 probability. In fact, panel 2 perceived more intense specific fruity aromas in red wines without added copper, indicating that thiols may indeed contribute to the perception of their specific red-/black-berry aromas. The role played by thiols in the fruity aroma of rosé wines (Murat *et al.*, 2001; Ferreira *et al.*, 2002) can thus be extended to red wines.

3. Experiment 3

Experiment 3 investigated the concept of specific fruitiness in red wines in greater detail. The results of the first evaluation in each session, judging whether wines were typical of Bordeaux, were subjected to principal component analysis (PCA) (Figure 3). The loading plots corresponding to the 11 assessors in panel 3 were all on the positive side of the first principal component axis, which explains 46 % of the original variability. As already discussed by Ballester *et al.* (2005), this indicated a good correlation among assessors. Consequently, a consensus emerged from the panel, revealing a coherent concept of red Bordeaux wine. Despite occasional disagreements, revealed by the second principal component axis which corresponded to inter-individual differences among assessors, the panel shared common references concerning red Bordeaux wine overall sensory characteristics.

Thus, the panel's scores were averaged to obtain a sensory representation of the wines from the previous PCA (Figure 4). The 21 wines were distributed along the F1 axis. Their coordinates on this axis were highly correlated with the mean scores attributed by the panel (r=0.99). This is logical as the ACP only concerned the assessment of « red Bordeaux character ». Consequently, the F1 axis strictly represented the conformity of the wines to this character. The wines globally considered by the

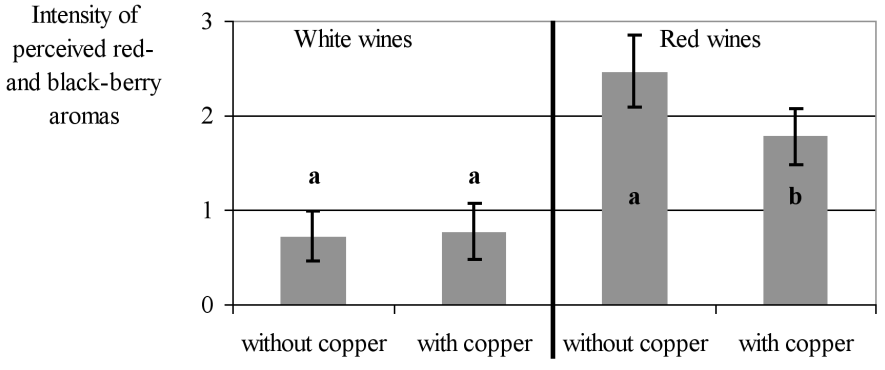

Figure 2. Mean intensity of perceived red- and black-berry aromas in wines in experiment 2, with or without the addition of copper.

a, b: statistically significant groups revealed by one-factor analyses of variance of the mean intensity scores attributed to each type of wine.

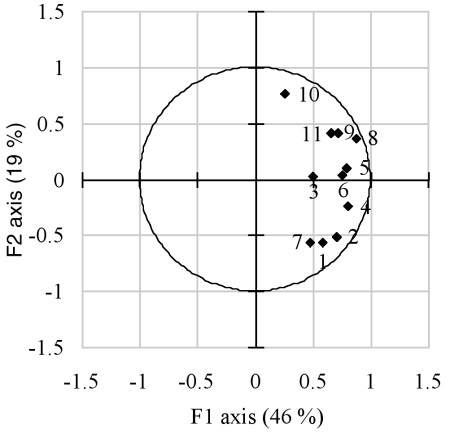

Figure 3. Correlation circle of PCA performed on assessors' averaged scores for « red Bordeaux character ».

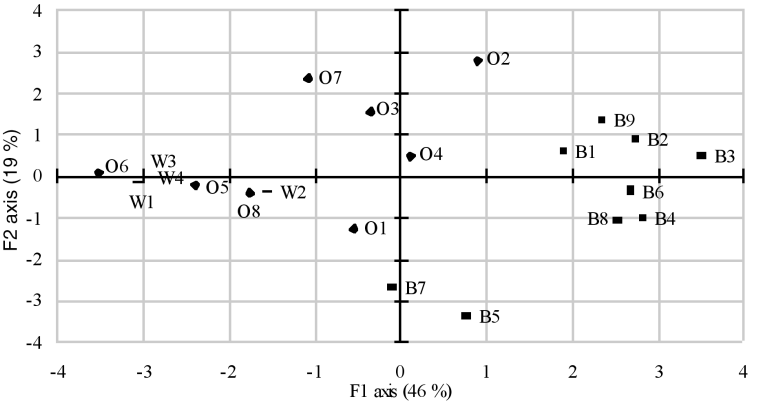

Figure 4. Sensory representation of wines on the basis of PCA performed on the « red Bordeaux character » averaged scores (key to codes in table 1).

panel as bad examples of red Bordeaux were plotted on the negative side of the F1 axis, whereas wines generally perceived to be good examples were located on the positive side of the axis. The results showed that white wines (bad examples) contrasted with red Bordeaux wines (good examples), whereas red wines of other origins were more unevenly positioned along the axis. For example, wine O6 (AOC Fronton) was considered the worst example of red Bordeaux wine (with position on F1-axis even lower than white wines, paradoxically), whereas wine O2 (AOC Corbières) was positioned higher on F1-axis than B5 or B7, both red Bordeaux wines! Typicality scores were thus compared between O2 and B5 then between O2 and B7 using 2-factors analyses of variance (factors « assessors » and « wine », respectively) with post-hoc Fisher's tests. With $F_{1,10} = 0.052$; $p = 0.823$ and $F_{1,10} = 0.025$; $p = 0.879$, O2 was not judged significantly more typical than B5 nor B7, respectively. Interestingly, B5 and B7 showed high coordinates on the F2 axis (around -2.5, and -3.5, respectively), unlike those of the other red Bordeaux wines, which were close to 0. This illustrated the panel disagreeing about wines B5 and B7, whereas a consensus emerged from the assessment of the other red Bordeaux wines. These occasional differences in judgement revealed differences of opinion among some of the experts concerning wines that were more difficult to assess. Nevertheless, comparison of typicality scores between B5 (or B7) and each of the other red Bordeaux wines did not show any significant differences. Only trends were observed for B7 wine, which tended to be considered less typical than B3, B4 and B8 wines ($F_{1,10} = 4.014$; $p = 0.073$, $F_{1,10} = 3.819$; $p = 0.079$, and $F_{1,10} = 3,350$; $p = 0.097$, respectively)

Finally, one-factor analysis of variance was performed on the averaged typicality scores of the wines previously grouped by type/origin i. e. « red Bordeaux wine », « other red wine », and « white wine ». With $F_2 = 16.08$; $p > 0.001$, the three groups were found to be significantly different, confirming the concept of wine groups revealed in figure 4. In fact, the assessors' expertise gave statistically significant results for recognizing a group of red Bordeaux wines. Consequently, as observed by Ballester *et al.* (2005) for Chardonnay wines, red Bordeaux wines tend to have their own sensory space, definable by olfactory input.

Interestingly, white wine group showed a mean typicality score of 2.27. This might be indicative of confusion between red and white wines assessed by experts. As assessors were asked to judge whether the wines were exemplary of a red Bordeaux wine concept, a mean score around 0 would have been expected.

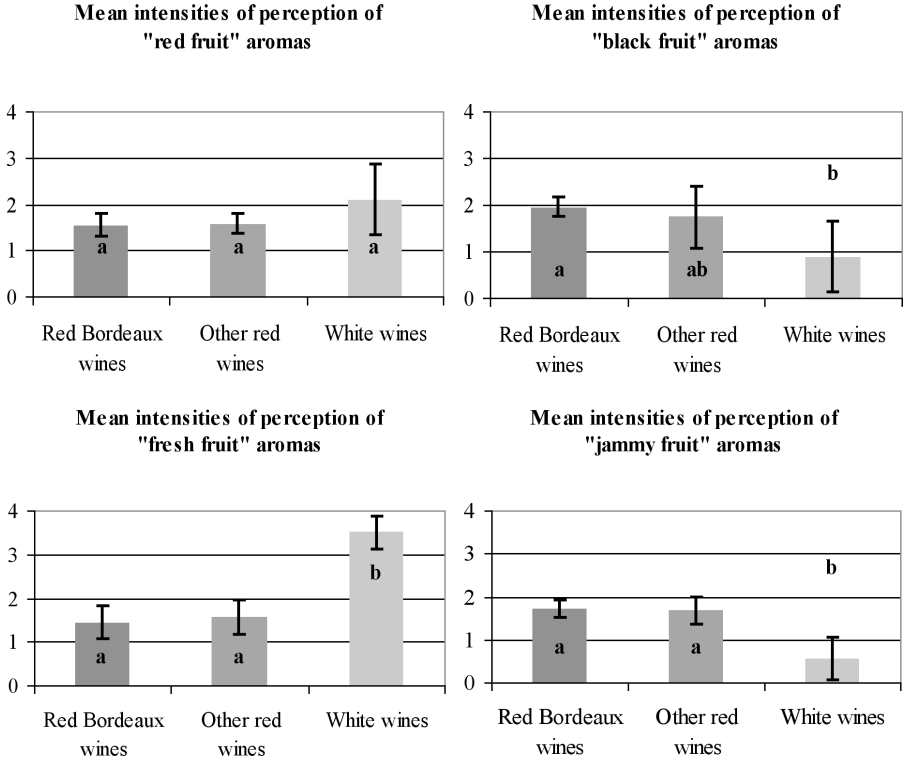

Figure 5. Mean intensity of perception of « red-berry », « black-berry », « fresh fruit » and « jammy fruit » descriptors in the wines used in experiment 3.

a, b: statistically significant groups revealed by one-factor analyses of variance of the mean intensity scores attributed to each type of wine.

To take this analysis further, four principal component analyses (PCA) were performed on results from the second evaluation in each session of experiment 3, corresponding to intensity ratings of « red-berry », « black-berry », « fresh fruit », and « jammy fruit » descriptors. Contrary to the findings of the previous assessment (see Figure 3), the loading plots corresponding to the 11 assessors were randomly positioned along the first principal component axes. This lack of consensus among the panel made it necessary to ensure that the distributions of mean score residues obeyed a Normal law for each of the fruity descriptors assessed. Except for the « black-berry » descriptor, good agreement was observed between the theoretical and observed distributions. Pearson's chi-square tests to evaluate the probability of obtaining this agreement found scores of 0.49, 0.37, and 0.28 for « red-berry », « fresh fruit », and « jammy fruit », respectively (0.04 for « black-berry »). As the distribution of « black-berry » scores was bimodal, scores were changed into ranks, on which Friedman's test detected statistically significant differences between wines (Friedman's chi-square = 39.61; $p < 0.001$). Consequently, it was possible to average the panel's fruity scores and perform one-factor analyses of variance on the mean scores for each type of wine. As shown in figure 5, the wine types were statistically distinguished by the experts according to their mean scores for « fresh fruit » and « jammy fruit », with a probability of less than 0.1% of observing the distribution in the three groups -« red Bordeaux wine », « other red wine », and « white wine »- at random. Student's tests, consisting of pairwise comparisons of wine groups, gave the origin of the significance of the analyses of variance. Two significantly different groups were revealed on the basis of both the « fresh fruit » and « jammy fruit » descriptors. The panel perceived more « fresh fruity » aromas in white wines than reds, while the reverse was true of « jammy-fruity » nuances (Student's test: $p < 0.001$ between both red wine groups and white wines, in each case). Interestingly, experts did not distinguish red Bordeaux from red wines of other origins on the basis of these two fruity descriptors. Consequently, either both groups of red wines had similar « fresh fruit » and « jammy fruit » characteristics, or the two types of wines were difficult to distinguish, based on orthonasal assessment of these attributes only.

« Red-berry » and « black-berry » evaluations were also of interest. For « red-berry » aromas, there was no statistical separation of the wines by type, showing that the panel perceived similar intensities of red-berry aromas in white wines and reds. Paradoxically, the panel tended to give higher « red-berry » scores to white wines than reds (Student's test: $p = 0.055$). Conversely, two significantly different groups were revealed from « black-berry » results. The panel perceived this aroma as more intense in red Bordeaux wines than in white wines (Student's test: $p = 0.015$). In addition, red wines from other origins were not statistically distinguished from the other two groups of wines, even though differences between red wines from other origins and white wines approached significance (Student's test: $p = 0.063$). So, all red wines were characterized on average by similar intensities of « red-berry » notes, but red Bordeaux wines and other red wines exhibited and tended to exhibit stronger intensity of this aroma than white wines, respectively.

Figure 5 presents the final PCA undertaken on the sensory assessment data with vectors for « typicality », « red-berry », « black-berry », « fresh fruit » and « jammy fruit » included on the map. The plot shows the first two principal components (PC) of the PCA that together explained 80% of the total variance in the data. The first PC (50% of the variance) has high positive loadings on « typicality », « black-berry » and « jammy fruit » variables and negative loadings for « fresh fruit ». The second PC (30% of the variance) mostly relates to « red-berry » attribute with high positive loadings. Reflecting results from the analyses of variance presented previously, « fresh fruit » and « jammy fruit » attributes were found to be negatively correlated ($r = -0.58$). This resulted in wines to be positioned along the first PC according to a continuum from fresh to jammy perception of fruitiness in wine. Moreover, « typicality » was found to be correlated with both « black-berry » and « jammy fruit » ($r = 0.50$ and $r = 0.55$, respectively), the latter two correlating also with each other ($r = 0.77$). On the other hand, « fresh fruit » and « red-berry » were significantly associated ($r = 0.52$).

Consequently, on the positive side of the first PC, wines that were a good fit to the concept of red Bordeaux wines were also judged as having specifically high black-berry-like and jammy fruity aromas. According to wine plots in figure 6, this can be applied to all of the red

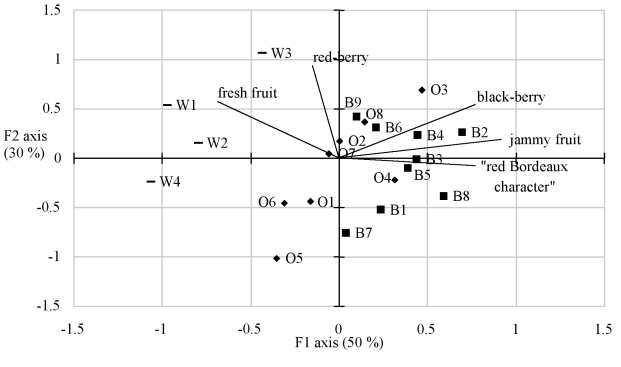

Figure 6. Sensory representation of wines based on PCA performed on both « red Bordeaux character » and « fruity character » averaged scores (key to codes in table 1).

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Bordeaux wines. On the other side of this PC, wines perceived as bad examples of red Bordeaux wines were also characterized by red-berry-like and fresh fruity nuances. Again, this can be applied to all of the white wines included in the experiment. Finally, red wines from other regions are shown to be more unevenly positioned on the first PC. In fact, half of them loaded negatively, indicating that they were perceived as more fresh-fruity and red-berry-like that red Bordeaux wines were. The other half loaded positively, indicated that they were perceived as more typical of the red Bordeaux wine concept, more jammy-fruity and black-berry-like than white wines were. Furthermore, in contrast to the assessment based solely on red Bordeaux character (see Figure 3), the red Bordeaux wines were not found to be isolated from the other red wines. This reflects observations from analyses of variance presented previously and could result from similarities between red wines in fruity nuances over-passing typicality differences.

Interestingly, no correlation was observed between « red-berry » and « black-berry » attributes (r = 0.52). Again, considering results from the analyses of variance presented previously, this was not unexpected. As noticed, red Bordeaux wines tended to be scored lower than white wines, based on perceived intensity of « red-berry » aromas, but exhibited significantly higher « black-berry » notes. Paradoxically, red wines in experiment 2 were found to be scored significantly higher than white wines, based on perceived intensity of red-/black-berry aromas. As all of the red wines in experiment 2 originated form Bordeaux, it might be assumed that « red-berry » aromas accounted less than « black-berry » notes in global assessment of red-/black-berry nuances. In other words, it is possible that scores for specific red-/black-berry aromas in this experiment related mainly to the perception of « black-berry »-like aromas by the panellists.

Another explanation could result from a limitation of the present work. In our experiments, panellists were asked to rate fruitiness in wines, with exclusive focus on aromas reminiscent of red- and/or black-berry fruits. In the absence of other attributes, we cannot exclude the occurrence of a « dumping effect » (Lawless and Heymann, 1998). This bias corresponds to the inflation in the rating of an attribute in the absence of another attribute that better fits the panellists' perception. In this particular study, the absence of white or yellow fruit attributes could have resulted in panellists' tendancy to increase their scoring of red-/black-berry and red-fruits attributes in white wines included in experiment 2 and 3, respectively.

CONCLUSION

This study clarifies our knowledge of the fruity olfactory character specific to red wines in general and red Bordeaux in particular. It highlights the extreme difficulty of studying specific red- and black-berry aromas in wines, providing evidence that the assessors' perception of these descriptors is heavily influenced by visual input. When assessors know that a wine is red, they tend to over-estimate its red-/black-berry fruit aromas. Nevertheless, this study demonstrated the existence of a red- and black-berry character specific to red wines, perceptible in blind tests. It also revealed that the intensity of perception was partly dependent on the presence of sulphur compounds in the wines. In addition, this work demonstrated for the very first time that expert assessors shared coherent olfactory concepts of red Bordeaux wines, which, therefore, tend to have their own sensory space. Finally, « red Bordeaux character » was found to be correlated to « black-berry » and « jammy-fruit » olfactory descriptors. Further research is required to investigate this correlation. In the future, it could be of interest to work with an expert panel to establish a list of specific descriptors, that they consider characteristic of fruitiness in red Bordeaux wine. The methodology presented here could then be applied, using the most relevant descriptors.

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