Sensory characterisation of Bordeaux red wines produced without added sulfites

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Aim: The evolution of consumer expectations has led to the development of new production methods using low inputs. From an oenological point of view, these methods include the production of wines without any SO2 being added throughout the process. These wines are becoming very popular among consumers, but the absence of SO2 during winemaking increases the risk of stability problems. Such wines have been poorly explored in the literature and there is thus a real need for them to be characterised. This study was developed to evaluate whether Bordeaux quality wines produced without added SO2 have their own typicality, and it provides an insight into current wine production.

Methods and results: From a batch of fifty-two commercial Bordeaux red wines produced without adding SO2 and twenty red wines made according to the usual winemaking methods, a selection tasting was performed to eliminate wines with at least one defect further to a sensory space evaluation. In a second phase, the napping test was applied to defect-free wines to evaluate the sensory specificities of wines produced without SO2 addition. The wines without SO2 addition presented a much higher frequency of defects than those with SO2 (70 % vs 15 % respectively). Defects described in wines without added SO2 were: “Oxidation” (47 %), “Volatile phenols” (31 %), “Mousy off-flavor” (10 %), “Reduction” (8 %) and “Vegetable” (4 %). Since the study focused on quality wines with or without SO2 addition, it was difficult for the tasters to discriminate between them according to their overall technical pathway.

Conclusion: This approach has revealed that despite the large number of “non-added SO2,” wines with defects, upon blind tasting, expert tasters highlighted some “non-added SO2” wines without defects. Nevertheless, at equivalent quality levels within the same geographic region, and in non-targeted sensory tests, wines with and without SO2 addition were considered to be quite similar.

Significance of the study: This study was a first sensory step toward the objective characterisation of “non-added SO2” wines, enabling further work to highlight markers of quality in wines without SO2 addition and to develop the production of “non-added SO2” wines without defects. Nevertheless, at this stage, our results show that the absence of sulfites during the whole winemaking process, including bottling, increases the risk of the development of defects.

Keywords: wines without sulfites, wine defects, sensory analysis, napping, range task
INTRODUCTION

Since the development of the “Dutch match” in the 18th century, sulfur dioxide (SO$_2$) has been widely used in the wine industry (Ribéreau-Gayon et al., 2017), although in the literature the first report of SO$_2$ being used for food preservation dates back to 1664, when sulfur was burned in cider containers (Roberts and McWeeny, 1972). Historically, however, it is thought to have been used by the Romans and Egyptians for sanitising wine vessels. SO$_2$ is generally added throughout the winemaking process for its various properties. This additive is an anti-oxidant (Danilewicz, 2011; Usseglio-Tomasset, 1992) also used in the food industry (Mareschi et al., 1992), and also has specific properties acting against the tyrosinase and laccase from Botrytis cinerea (Dubernet and Ribéreau-Gayon, 1973), the two oxidases that may be present in grapes. It also combines various antimicrobial properties affecting, among others, yeasts as well as lactic acid bacteria (Carr et al., 1976; Solberg, 1991; Zuehlke and Edwards, 2013).

SO$_2$ levels have been legally regulated from country to country since the beginning of the 20th century. In the European Community, Commission Regulation (EC) No 934/2019 formalises the limits laid down by the International Organization of Vine and Wine (OIV). Currently, maximum levels are 150 mg/L for red wine, 120 mg/L for organic red wine and 70 mg/L for certain biodynamic certifications. For wines produced without the addition of sulfites, the limit for total SO$_2$ was laid down as 10 mg/L. During alcoholic fermentation, Saccharomyces cerevisiae is able to produce sulfites from sulfate reduction (Donalies and Stahl, 2002; Heinzel and Trieper, 1978, Wells and Osborne, 2012, Wells and Osborne, 2016), but generally not much more than a dozen milligrams per litre. Therefore, sulfur dioxide levels in wines are mostly of exogenous origin.

SO$_2$ levels are regulated according to toxicity, with the acceptable daily intake (ADI) of sulfite for humans being 0.7 mg/kg of body weight according to the World Health Organization (WHO) (FAO, 2009). Moreover, this additive can entail health risks for particularly sensitive consumers (Vally and Thompson, 2001). The first study on such SO$_2$ health risks dates back to the 1970s with the observation of the irritant capacities of SO$_2$, as well as anaphylaxis and skin problems with ingestion (Kochen, 1973; Lester, 1995; Prenner and Stevens, 1976).

Professionals are clearly striving to reduce inputs during the winemaking process and a recent study showed that the average concentration of total SO$_2$ in red wines was close to 75 mg/L (Peterson et al., 2000), far below the permissible level. Some winemakers are even producing wines without, or with very low, added sulfites, which are becoming increasingly popular among consumers. Many studies on consumer willingness to pay and on the perception of “non-added sulfites” wines show that consumers prefer wine if it bears a “non-added sulfites” label (Amato et al., 2017; Costanigro et al., 2014; D’Amico et al., 2016). Recently it was shown that consumers had a higher tolerance to off-flavors in wines presented as being closer to natural concepts (Romano et al., 2020). This clearly underlines why an objective characterisation of these trendy “new” wines is essential.

The aim of this study was to evaluate whether wines made without SO$_2$ addition are linked to each other by similar organoleptic descriptors, forming what is known as typicality. Our approach focused on quality wines, with the first definition of quality being purity (i.e., the absence of defects), which is used for foodstuffs in general (ISO 9000, 1994). For this purpose, a two-step study was performed. First, from a large set of “without sulfites” commercial wines, some wines were selected according to their effective SO$_2$ level and the absence of defects. Next, a sensory characterisation of selected wines without added sulfites was carried out.

MATERIAL AND METHODS

1. Wines

The following wines were bought on the market: i) fifty-two red wines described by their producers or retailers as containing less than 30 mg/L of SO$_2$ (hereafter referred to as “without sulfites” or “without SO$_2$”), which were produced in the Bordeaux area or in south-west France from Bordeaux varietals (mainly Merlot and Cabernet-Sauvignon, monovarietals or blends, aged in oak barrels or not), and ii) twenty wines of the same type (same varieties, geographic origins, prices and woody characters), but produced with added SO$_2$, from the 2015 and 2016 vintages. The 52 wines without added SO$_2$" represented the exhaustive
TABLE 1. Wines studied - with and without added sulfites.

<table>
<thead>
<tr>
<th>Sample origin</th>
<th>Wines without added SO₂</th>
<th>Wines with added SO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bordeaux</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Bordeaux supérieur</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Bourg-Côtes-de-Bordeaux</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Castillon-Côtes-de-Bordeaux</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Côtes de Bergerac</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Côtes de Duras</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Franc-Côtes-de-Bordeaux</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Haut-Médoc</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Languedoc-Roussillon</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Moulis-en-Médoc</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Périgord (IGP)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Pessac-Léognan</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Saint-Emilion</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Vin de France (Wines without regional GI)</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>26</strong></td>
<td><strong>26</strong></td>
</tr>
</tbody>
</table>
had to answer the closed question, “Does this wine have a defect?”. They were told to reply with a “yes” if they perceived a sensory character associated with a defect concept. If they identified one or more defects in this way, they had to describe it/them.

A free sorting task (Parr et al., 2010) was assigned to Panel 2. Simultaneously and per vintage, they tasted wines with and without SO2 that had been significantly considered as free of defects according to the X² test applied to Panel 1 results. This was carried out in one session with eleven 2015 wines and another with thirteen 2016 wines. In each session, the wines were simultaneously submitted to the panelists, each in a different randomised tasting order with a Latin square arrangement. In the first part of the session, the panelists had to group wines into clusters according to their similarity as perceived by the taster, with a minimum of two clusters and at least two wines per cluster. In the second part, they had to describe the clusters by freely giving a few descriptors to explain the differences between the groups.

Panel 3 was asked to conduct a napping test (Pagès, 2003) on all the wines (with and without added sulfites) for which a consensus had been reached in Panel 1 regarding the absence of defects, as well as on 5 wines with and without added sulfites, selected like the others. Thus, 13 wines from the 2015 vintage and 17 from the 2016 vintage were studied. For each vintage two sessions were conducted: one for orthonasal perception, and the other for overall mouth perception (including retronasal, gustative and trigeminal perceptions). In each session, the wines were simultaneously submitted to the panelists, each of them in a different randomised tasting order with a Latin square arrangement. All the panelists tasted all the wines and placed their wineglasses on an A1 paper tablecloth (59.4 cm × 84.1 cm) according to their own criteria. The instructions given to them were to evaluate the similarities (or dissimilarities) between wines. They had to position all wines on the paper tablecloth, whereby two wines being positioned close to each other meant they were similar, while two wines positioned far from each other indicated their differences according to perception. Data were digitalised, measuring, for each product and each panelist, X-co-ordinates and Y-co-ordinates from the point of origin (bottom left corner). At the end of the test, the panelists had to freely generate three descriptors for each wine or group of wines.

3.4. Data analysis

All data were analysed using RStudio (Boston, 2015). The results of the selection tasting to assess the defects were analysed via the X² test, which was applied to the panelists who perceived at least one defect in the wines. Defect descriptions were analysed through citation and sharing frequencies. For the range task test, the results were analysed by multidimensional scaling (MDS) from a contingency table that showed how often two wines were associated within the same cluster. Napping results were analysed by Multiple Factor Analysis (MFA) in line with Pagès (2003), as well as by hierarchical clustering with K-means methods. For MFA, each panelist represented an independent variable with the X-co-ordinates and Y-co-ordinates for all wines. Concerning the description of groups for the sorting task and description of wines for the napping test, the results were analysed by correspondence factor analysis (CFA). Word clouds were also generated using RStudio (Boston, 2015), with font size representing citation frequency.

RESULTS AND DISCUSSION

1. Wine selection

With a focus on evaluating the typicality of quality wines produced without added sulfites, this study started by selecting the wines with which it was possible to continue.

Free and total SO2 were quantified for all wines, with and without added sulfites. Among the 52 wines indicated as being without sulfites, 43 had a total SO2 concentration below 10 mg/L, 5 between 10 and 30 mg/L and 4 with a higher total SO2 level. The current regulations allow bottles to be labelled “without added sulfites” when wines have a maximum SO2 level of 10 mg/L, with the obligation to specify “contains sulfites” on wines containing more than 10 mg/L (R. EU 2019/33). However, 20 mg/L is considered by some winemakers to be a low value for total SO2 produced during alcoholic fermentation performed with indigenous Saccharomyces cerevisiae. Indeed, in some cases yeasts can produce up to 30 mg/L SO2 during alcoholic fermentation (Donalies and Stahl, 2002), which is why 48 wines with higher total SO2 levels were kept as candidates for
research into a specific sensory space. Therefore, the four wines with more than 30 mg/L were not considered for tasting in the range task and napping test, but were included in the selection tasting. Total SO₂ average concentrations were 4.6 mg/L ± 4.7 mg/L (mean ± SD) for the 48 wines without added sulfites and 67.7 mg/L ± 21.8 mg/L (mean ± SD) for the 20 wines classically produced with sulfites. The maximal value of total SO₂ observed for a “without added sulfites” wine was 51.8 mg/L of total SO₂, and this level was present in more than 8 wines produced with sulfites.

All 72 wines (with and without added SO₂) - were tasted by Panel 1 to evaluate the occurrence of defects, with a wine being considered to have a defect when the frequency of defect detection by panelists was significant according to the Χ² test. The results are shown in Table 2.

Overall, the defect frequency was 15 % for wines produced using SO₂ and 73 % in wines without added SO₂. The defect frequencies for wines without added sulfites were very similar between the 2015 and 2016 vintages (77 % and 69 % respectively), suggesting that aging wine for an additional year in bottles without SO₂ does not affect the development of defects, which were, in any case, very often already present.

The four wines without added SO₂, but with more than 30 mg/L total SO₂, were all described by the panelists as having defects.

The panelists also described the defects they perceived. Among the three wines produced using SO₂, two were described as having “volatile phenols” and the other by the term “reduction”. Figure 1 shows a word cloud of the defect descriptors for wines without added sulfites, with agreement above 60 %.

<table>
<thead>
<tr>
<th>Defect Type</th>
<th>2015</th>
<th>2016</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidation</td>
<td>37.5 %</td>
<td>33.3 %</td>
<td>35.4 %</td>
</tr>
<tr>
<td>Volatile phenols</td>
<td>20.8 %</td>
<td>16.6 %</td>
<td>18.7 %</td>
</tr>
<tr>
<td>Mousy off-flavor</td>
<td>12.5 %</td>
<td>0 %</td>
<td>6.2 %</td>
</tr>
<tr>
<td>Reduction</td>
<td>4.1 %</td>
<td>8.3 %</td>
<td>6.2 %</td>
</tr>
<tr>
<td>Vegetable/Herbaceous</td>
<td>0 %</td>
<td>8.3 %</td>
<td>4.1 %</td>
</tr>
<tr>
<td>Total</td>
<td>74.9 %</td>
<td>66.5 %</td>
<td>70.6 %</td>
</tr>
</tbody>
</table>

**Figure 1.** Citation frequencies and word cloud of descriptors of defects in wines without added sulfites, with agreement above 60 %.

**TABLE 2.** Frequency of wines with at least one defect according to use of sulfites and vintage.

<table>
<thead>
<tr>
<th></th>
<th>03-déc</th>
<th>Wine without SO₂</th>
<th>08/18</th>
<th>18/26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of wines</td>
<td>20/26</td>
<td>0/8</td>
<td>18/26</td>
<td></td>
</tr>
<tr>
<td>Percentage of</td>
<td>77%</td>
<td>0%</td>
<td>69%</td>
<td></td>
</tr>
<tr>
<td>wines with defect</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
key elements to be monitored in winemaking without added sulfites.

As previously mentioned, according to ISO standards, the quality of a product depends on its ability to satisfy consumer demands (ISO 9000, 1994). This implies that quality increases with price. For wines without added SO₂, and in the wine industry in general, consumers expect there to be a correlation between quality and price (Nerlove, 1995). Therefore, in this study, correlations between the retail price and the occurrence of defects in the “non-added SO₂” wines were sought. When comparing the prices of such wines with or without defects, Figure 2 reveals no link between these parameters. Moreover, in this large selection of wines, the most expensive were produced without the addition of SO₂, and all of them showed defects. Factually, for wines without added SO₂, a higher price does not mean a higher quality.

2. Sorting task method

Using the previous approach, cross-referencing the absence of defects with the target total SO₂ level, we were able to select 15 wines from the 2015 vintage and 16 from 2016. Among these wines, all those produced without added SO₂ were considered for this evaluation and, in order to only focus on their real counterparts produced using SO₂, some wines with SO₂ were not taken into account. Thus, range tasks were performed on two sets of wines: 11 wines from 2015 (5 with sulfites and 6 without) and 13 from 2016 (5 with sulfites and 8 without).

A sorting task method, consisting in looking for similarities between products in order to highlight the existence of a specific sensory space, was applied to each of the 2015 and 2016 set of wines.

Figure 3 shows the results for the 2015 vintage, with range results and description results given separately. As shown in Figure 3A, such an approach does not differentiate between wines with and without SO₂; with this set of wines, the tasters did not discriminate between wines according to the presence or absence of added sulfites. Despite this, two groups seem to be represented by the MDS test on the second axis of the representation. Additionally, the descriptions of clusters were analysed to understand the absence of discrimination, depending on whether SO₂ was used during the whole winemaking process. Figure 3B reveals that the most-cited descriptors were associated with defects like volatile phenols and oxidation. Indeed, the two groups observed in the MDS results were found on the CFA repartition map: the first group was represented by the defect descriptors, “Mousy off-flavor”, “Volatile phenols” and “Oxidation”, and the second group comprising wines without added SO₂ (WS-6 and WS-5) and wines with added SO₂ (S-3, S-4 and S-5) was linked to the descriptors, “Woody”, “Spicy” and “Floral”. Similar to the wine selection stage, “Oxidation” was the dominant defect to be described, with a twenty percent citation frequency, and was the most commonly generated descriptor after “Fruity”. “Volatile phenols” was the second most cited defect described. The CFA also revealed that six out of fourteen descriptors were associated with defects such as fungus odour, mousy off-flavor, oxidation, reduction, volatile phenols and acescence. The citation frequency of these defect descriptors accounts for 42 % of all panel answers. For the 2016 vintage, a range task was performed by the same panel and the results showed the same behavior as for 2015, with wines selected statistically as being free of defect, but whose clustering was influenced by defect perception (“Oxidation”, “Vegetable” and “Volatile phenols”). These results highlight the limits of sensorial selection associated with the statistical test we used in the first step of this study. Indeed, some tasters in Panel 1 were also members of Panel 2; therefore, a defect perceived in one wine by a panelist during the selection tasting, which would not have been statistically rejected, could logically also be

**FIGURE 2.** Boxplot illustrating price distribution of wines without added sulfites with and without defects
Mean represented by a dotted line.
perceived by the same panelist in this sorting test. Moreover, Panel 2, with only 8 tasters, was too small to be representative of the overall sensibility of a population. This first approach was elaborated to evaluate the existence of a sensory space by panelists with similar backgrounds, which could, as observed by Picard et al. (2015), elicit more accurate discriminations than a less specific panel. For instance, wines which were described as containing defects by only one or two tasters in Panel 1 were statistically considered as free of defects. The results of the range task tasting highlight that this “statistical” wine selection was not restrictive enough, because it was possible for the wines statistically considered as being free of defects during the selection tasting to be described as having defects in the range task tasting. Furthermore, the presence of wines with defects clearly impacted the range task method, as the tasters had made defect clusters. Indeed, despite the potential hypersensibility of the panelists involved in the first step of the selection, and despite a high elimination of wines, some wines were described here as having defects; for most of these defects (“Oxidation”, “Volatile phenols” and “Mousy off-flavor”) a consensual description was given. These results highlight that the presence of defects is a limitation of a study dedicated to the sensory space of wines “without added SO₂”.

3. Approaches to research the sensory space of “non-added SO₂” wines: napping test

A second approach to research the sensory space of “wines “without added SO₂” was tested via the napping sensory test.

The problems previously encountered linked to defect perception were taken into account and another wine selection methodology was used: a wine considered to have any defect by at least one taster in Panel 1 was eliminated. This approach drastically reduced the number of selected samples, and additional wines from the same vintages were selected using the same process. Thus, two wines from the 2015 vintage were eliminated and replaced by two others, whereas three wines from the the 2016 vintage were rejected and replaced by four others.

The napping test was carried out by a bigger panel than for the range task, because the effect of the tasters’ expertise could be modulated by the larger number of tasters (Pagès, 2003). This choice aimed to reduce the impact of individual tasters and to accentuate group phenomena. Four napping tests were performed on each of the two vintages: olfactory tests on one hand, and global mouth perceptions (including retronasal, gustative and trigeminal perceptions) on the other.

First of all, as intended, this global napping approach was not affected by defect perception: once the wines had been positioned on each sheet, any descriptor associated with the slightest defect was given by any panelist to describe them. Figure 4 shows the wine distribution maps by MFA. From this analysis we were able to produce four illustrations which represent between 30 and 35 % of total variability. Thus, the majority (around 70 %) of variabilities was not represented by this approach. However, Figures 4A and 4B, which show the results for the 2015 vintage, highlight...
that “non-added SO₂” wines were differentiated from wines with SO₂ when carrying out a mouth evaluation. More precisely, regarding this mouth evaluation result (Figure 4B), wines with and without added sulfites were differentiated on the first axis, because all the wines “without added SO₂” (except WS-1) were on the same side of Axis 1. This means that tasters could distinguish wines “without added SO₂” in a mouth evaluation more readily than via olfactory tasting. With regards the 2016 vintage (Figures 4C and 4D), the results are not so clear, and the panelists were unable to differentiate between wines according to SO₂ use.

Clustering the napping results with 50% variability represented was also explored (Figure 5). For the 2015 vintage, Figures 5A and 5B highlight that tasters differentiated between wines with and without sulfites. In this illustration, the dotted lines represent the significance of the representation. For the 2016 vintage (Figures 5C and 5D), the judges could not differentiate between wines with and without sulfites via direct olfaction; however, they were able to highlight two clusters of wines “without added SO₂” and one cluster of wines with sulfites via mouth evaluation. This approach shows that it is possible to differentiate wines with and without added sulfites by tasting, specifically via a mouth evaluation. However, other parameters would seem to limit these results, as revealed by the 2016 vintage. Figure D strongly suggests that geographical origin within the Bordeaux wine area impacts differentiation. Indeed, wines “without added SO₂”, WS-6, WS-7, WS-1, WS-4 and WS-10 are produced on the right bank of the Garonne river, and WS-5, WS-3, WS-2 and WS-8 on the left bank; it would therefore seem that, in this case, geographic typicality has more impact than the use of SO₂. For the 2015 vintage, all the wines

**FIGURE 4.** Representation of distribution map of wines with MFA treatment with napping results: (A) 2015 wines evaluated by direct olfaction, (B) 2015 wines evaluated by mouth evaluation, (C) 2016 wines evaluated by direct olfaction, and (D) 2016 wines evaluated by mouth evaluation.
used came from the right bank, so without this additional source of variation the panel was more efficient in differentiating between wines with and without sulfites.

**CONCLUSION**

Comparing similar Bordeaux red wines produced with or without SO₂ in order to evaluate whether wines “without added SO₂” have their own typicality, this work was a first approach toward their sensory characterisation. Covering all wines without added SO₂ from the 2015 and 2016 vintages available to consumers on the Bordeaux market in mid-2018, it showed that defect frequencies for such wines were much higher than for wines produced using SO₂, and that most of them contained at least one defect. This finding raises questions about the concept of typicality among these wines, which represent an overall commercial offering. Despite this, a restrictive selection blind tasting method with expert judges evidenced some “non-added SO₂” wines without defects. Focusing on the wines without defects, tasters had difficulty in differentiating wines “without added SO₂” from those produced with. Nevertheless, certain tests performed via an overall mouth evaluation sometimes led to good discrimination, even though the panelists were unable to agree about why this was. In general, this initial study highlights the difficulties related to the production of quality wines without adding SO₂; however, it nonetheless shows that such production is possible, and it provides some initial answers about the existence of typicality in wines without added SO₂ when the wines with

**FIGURE 5.** Representation of clustering of wines with MFA treatment with napping results (A) 2015 wines evaluated by direct olfaction, (B) 2015 wines evaluated by mouth evaluation, (C) 2016 wines evaluated by direct olfaction, (D) 2016 wines evaluated by mouth evaluation. WS corresponds to “non-added SO₂” wines and S corresponds to wines with SO₂.
defects are discarded. Finally, this study could be repeated with producers of wines made without any added sulfites. Indeed, Gómez-Corona et al. (2017) observed differences in the categorisation and discrimination of craft versus industrial beers depending on the consumption habits of the taster. The repeated tasting of a type of wine may perhaps influence the ability of tasters to evaluate these wines.

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