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ORIGINAL RESEARCH ARTICLE

Sensory attributes and quality perception of red natural wines: a comparative study in Spain and France

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ABSTRACT

Although the definition of natural wine remains contested and still lacks official recognition, it can be broadly described as a wine made with organic or biodynamic grapes without oenological additives in the cellar and minimal intervention in all winemaking stages. Despite growing interest in natural wines, uncertainty prevails about their sensory and quality attributes among both consumers and experts. In light of this research gap, this study aims to determine, first, if there are specific sensory dimensions allowing to differentiate natural wine as a wine category from conventional wines; second, if this sensory dimension affects the perception of the quality; and third, to characterise the physicochemical differences in terms of basic oenological parameters between natural wines and their conventional counterparts. To do so, 24 red wines (12 self-defined as natural and 12 conventional wines) were sensory and chemically characterised. The sensory evaluation was first carried out by winemakers from Spain. It consisted of a descriptive task (labelled sorting task) followed by a quality evaluation under two conditions: with and without information regarding the production method. A second panel of French experts carried out the same quality assessment, also with and without information. The aim was to find out whether expectations existed linked to each type of wine and to explore potential cross-cultural effects. The results of the labelled sorting task showed that natural wines tended to be different from conventional wines, but the difference was not clear-cut. However, natural wines were perceived to be of lower quality than their conventional counterparts, both with and without the information provided, regardless of the origin of winemakers. Results of the chemical analysis showed that natural wines presented higher values for volatile and total acidity and turbidity, while they had lower values for total and free sulphur. The study points to the existence of sensory dimensions with an impact on overall quality associated with the production method.

KEYWORDS: Natural wine, sensory analysis, quality, sustainability, wine chemistry, cross-cultural

INTRODUCTION

For decades, natural wine (NW) has been a marginal phenomenon and a niche market with few producers and consumers. Since 2010, however, NW has emerged as a fast-growing sector in Europe and increasingly elsewhere, from Georgia (Svanidze and Costa-Font, 2023) to New Zealand (Urdapilleta *et al.*, 2021), California (Maykish *et al.*, 2021) or South Africa (Chazal, 2023). The definition of NW remains largely contested, with different certification bodies and natural winemakers' associations advocating different regulations, such as AVN and SAINS in France, PVN in Spain or Vinnatur, VAN or Viniveri in Italy (Alonso González and Parga-Dans, 2018; Fabbrizzi *et al.*, 2021). As a result of this controversy, consumers tend to confuse NW with wines without sulphites, as well as organic and biodynamic (Jones and Grandjean, 2018; Vecchio *et al.*, 2021). However, on March 25 2020, NW obtained legal recognition for the first time in France under the designation *vin méthode nature*, opening the way for similar initiatives worldwide. This accreditation has been created by a trade union in collaboration with the French Directorate-General for Competition, Consumer Affairs and Prevention of Fraud (see Sáenz-Navajas *et al.*, 2024 for more details). According to this regulation, NW must be produced from organic or biodynamic grapes and without additives in the cellar. Minimal amounts of SO₂ (< 30 mg L⁻¹) can be employed only before bottling, and this practice must be indicated on the label (Alonso González *et al.*, 2022). Although there are no official statistics on NW production and consumption, in recent years, the world wine market has shown an increase in the consumption of wines with sustainability attributes, whether organic, natural or biodynamic (Capitello and Sirieix, 2019; Migliore *et al.*, 2020; Vecchio *et al.*, 2021). The high demand for these products is related to increased consumer awareness of environmental and human health issues, as well as an increased public awareness that natural products are the solution to the problems of natural resource depletion and food security (Alonso González and Parga-Dans, 2020; Pomarici and Vecchio, 2019).

Despite the commercial success of NW, consumers and experts alike remain uncertain about the sensory attributes and overall intrinsic quality of this new wine category (Parga-Dans *et al.*, 2023). Wine quality perception is complex and multidimensional. It results from the interaction between the product's characteristics and the characteristics of consumers, such as origin, involvement and expectations (Sáenz-Navajas *et al.*, 2016a; Urdapilleta *et al.*, 2021). Moreover, the perception of quality results from intrinsic and extrinsic wine dimensions (Charters and Pettigrew, 2007; Parga-Dans *et al.*, 2022). Intrinsic dimensions are linked to the physical part of the product and its organoleptic properties such as aroma, colour or mouthfeel. Extrinsic dimensions refer to properties that are not part of the product, such as the region of origin, awards or the package design (Sáenz-Navajas *et al.*, 2020). Moreover, consumer perceptions often differ from expert judgments (Sáenz-Navajas *et al.*, 2016a). It has been shown that the production

philosophy also influences wine perception, with most studies focusing on comparisons between organic and conventional wines, and some of them including biodynamic wines (Cravero, 2019; Picchi *et al.*, 2020; Schäufole and Hamm, 2017), but very few on NW.

Wines with no sulphites added are a further emerging category that can be confounded with NW by non-specialised consumers. Indeed, the virtual absence of added sulphites is one of the most important features of NW. This is particularly visible because SO₂ is the only oenological input explicitly mentioned in the French label of *Vin Methode Nature* or the acronym of the S.A.I.N.S. association (*Sans Aucun Intrinsic Ni Sulfite*). The category of wines with no added sulphites has been studied in recent years in terms of consumers' behaviour and sensory properties (Amato *et al.*, 2017). Concerning consumers' acceptance of these wines, several marketing studies found little global effect of the "no-sulphites-added" label on the willingness to pay of Italian and Spanish consumers (Amato *et al.*, 2017) and U.S. consumers (Costanigro *et al.*, 2014). These studies showed that only consumers prone to headaches related to sulphite content had a higher willingness to pay for non-sulphited wines. Concerning the sensory properties of wines with no added sulphites, a recent study on Bordeaux red wines has shown that the wines without SO₂ addition presented a much higher frequency of defects than those with SO₂, mostly oxidation and volatile phenols (Pelonnier-Magimel *et al.*, 2020).

Regarding NW, the literature is recent and generally scarce. Several qualitative studies explored consumers' mental and social representations of NW compared to other sustainable wine categories. Some of them reveal some confusion among consumers between organic, biodynamic and natural wine categories (Ginon *et al.*, 2014; Alonso González *et al.*, 2022) as well as a lack of awareness of NW (Moscovici and Reed, 2018; Fuentes *et al.*, 2021). A recent study on Italian consumers showed that NWs obtained a lower willingness to pay than organic wines and that the drivers of the preferences were not related to the sensory characteristics of the wines but rather to their naturalness and healthiness (Vecchio *et al.*, 2023).

Urdapilleta *et al.* (2021) explored social representations of conventional, organic and natural wine in experts and novices from France and New Zealand. The results showed a cultural effect on the content of participants' representations of NW. New Zealanders, regardless of expertise level, provided several negative descriptors (unpredictable, cloudy, flat, bad, trend, orange, expensive), while no negative descriptor was attached to NWs by French participants. In a qualitative survey with Italian consumers, Fabrizzi *et al.* (2021) showed that besides the expected attributes linked to health and environment, consumers elicited some sensory properties they expect NW to have, such as the distinctiveness (typical, peculiar, unique), the acidity (harsh, not attractive) and intense flowery and fruity aromas. In the same vein, Sáenz-Navajas *et al.* (2024) recently showed that Spanish winemakers had quite negative attitudes towards the sensory quality of NW but positive ones regarding some extrinsic

dimensions of NW, such as social identity, ecology, health, or artisanal production.

From a marketing point of view, Galati *et al.* (2019) showed that Italian millennials are willing to pay a premium price for NW. This result is not in agreement with previous studies on sulphite-free wines (Amato *et al.*, 2017; Costanigro *et al.*, 2014), suggesting that for Italian millennials, sulphites are not the only issue when it comes to NW. Rather, being environmentally and socially sustainable is considered more important.

To the best of our current knowledge, only the recent study by Sáenz-Navajas *et al.* (2023) has explored the sensory aspects of NW. The authors focused on Spanish white wines and studied the sensory characteristics of a sample set where half of the samples were conventional wines (CW) and the other half were NW. Three sub-sets, characterised by different between-samples variability, were created and assessed using free-sorting tasks with subsequent group descriptions. Moreover, conventional oenological parameters, volatile compounds and toxic molecules were quantified in the samples. The sensory results showed that no clear separation between conventional and NW was observed for three sub-sets. However, a global analysis indicated that 70 % of the self-defined NWs were associated with various aromatic defects related to their higher content in 4-ethylphenols and volatile acidity. The remaining NWs were fault-free and clustered among the conventional samples.

The present study moves forward from the study by Sáenz-Navajas *et al.* (2023) in several ways. First, it focuses on Spanish red wines. Second, it links the sensory characteristics of the samples and their conventional/natural status to sensory perceived quality by experts. Third, it explores the information effect of knowing the conventional/natural status of a sample on experts' quality assessment. Finally, it examines the effect of experts' culture on their quality assessment. This study hypothesised that NW would be discernible from CW from a sensory point of view, possibly due to the presence of wine faults, as suggested by previous studies. Moreover, we hypothesised that quality scores would differ between CW and NW regardless of the culture of the taster. Since France is more advanced than Spain in terms of NW production, consumption and labelling for NW, we expected cultural differences in the quality assessments. Finally, we also expected an effect of the information on the quality assessments, as well as an interaction between culture and information since different cultures could have different ways of handling the information about wine types.

MATERIALS AND METHODS

1. Wine Samples

Twenty-four Spanish red wines from five different Spanish wine regions have been evaluated: Rioja (2 samples), Navarra (4), Aragón (2), Catalonia (8) and Castilla y León (8). Wine prices ranged between 10 and 20 €/bottle. Although the average prices for NW and CW were 12.73 euros and

9.88 euros, respectively, a Student's t-test did not show significant differences in price ($p = 0.12$).

To obtain a globally balanced sample set, NW and CW subsets were equivalent in terms of grape varieties, wine regions and ageing vessels (stainless steel or oak). Table 1 presents the wines' characteristics and their use in the different tasks of the study.

2. Sensory analysis

2.1. Tasting panels

Eighteen Spanish (La Rioja) and seventeen French (Burgundy) winemakers participated in the study. Panellists had extensive experience in winemaking (between 5 and 30 years). The mean age of the Spanish participants was 39 years (age range = 25–55 years), and there were 5 females and 13 males. The French panel consisted of 10 females and 7 males, with a mean age of 35 years (age range = 25–58 years).

2.2. General experimental conditions

The experimental conditions common to all the sensory tasks of the study were as follows: twenty mL of each wine were poured into standardised tasting glasses (ISO, 1977), which were covered with a Petri dish to avoid loss of aromas. Each sample was coded with a three-digit code. The bottles with the samples were kept in a cool room at 10–12 °C during the whole test period with oxygen vacuum stoppers to preserve the wine in good condition. The glasses were coded with 3-digit numbers. To limit carry-over effects and memory biases, all wine samples were presented in a different order determined by a Williams Latin square design, specific to each participant for each task. In each country, tests took place in a quiet and odourless tasting room equipped with individual booths to avoid communication between panellists. The room temperature was set at 21 °C. The wines were served at room temperature. Participants were instructed to expectorate the samples and to rinse their palate. They had a spittoon and mineral water at their disposal. No information was given about the wines or the purpose of the study.

All participants were volunteers, and before participating in the study, they signed an informed consent form defining the type of research and voluntary participation. All data were collected anonymously.

2.3. Labelled free sorting task

To test whether NW shared sensory properties that made them perceptually similar, a series of three sorting tasks followed by free descriptions of the groups (Valentin *et al.*, 2012) were carried out exclusively by the Spanish panel. The sample set was divided into three sub-samples of wines characterised by different levels of between-sample variability. The goal of applying the sorting task to three sample sets was to check to which extent the results were generalisable. The first sub-set comprised 8 wines made of Garnacha Tinta variety from different Spanish regions. The second sub-set consisted of 8 wines made of Tempranillo Tinto grapes, again from different Spanish regions. The third sub-set consisted of 12 different wines from several grape varieties and different

TABLE 1. Codes and characteristics of the samples of the study.

Wine code	Production	Wine area	Grape variety	Vintage	Ageing	Price (euros)	Used in sessions**
Gar_Nav_N	Natural	Navarra	Garnacha	2020	-	8.95 €	1,3,4
Gar_Nav_C	Conventional	Navarra	Garnacha	2020	-	9.50 €	1,3,4
Gar_RJ_N	Natural	Rioja	Garnacha	2019	6 mo [*] oak	15.95 €	1,4
Gar_RJ_C	Conventional	Rioja	Garnacha	2019	6 mo oak	8.70 €	1,4
Gar_Ar_N	Natural	Aragón	Garnacha	2020	6 mo oak	7.90 €	1,4
Gar_Ar_C	Conventional	Aragón	Garnacha	2020	10 mo oak	11.35 €	1,4
Gar_Cat_N	Natural	Cataluña	Garnacha	2019	-	18.50 €	1,4
Gar_Cat_C	Conventional	Cataluña	Garnacha	2019	-	6.50 €	1,4
Tem_CL_N	Natural	Castilla y León	Tempranillo	2019	-	10.00 €	2, 3, 4
Tem_CL_C	Conventional	Castilla y León	Tempranillo	2019	-	5.45 €	2, 3, 4
Tem_Cat_N	Natural	Cataluña	Tempranillo	2019	-	8.85 €	2
Tem_Cat_C	Conventional	Cataluña	Tempranillo	2019	-	18.82 €	2
Tem_Toro_N	Natural	Toro	Tempranillo	2020	6 mo oak	13.40 €	2, 4
Tem_Toro_C	Conventional	Toro	Tempranillo	2020	6 mo oak	4.22 €	2, 4
Tem_Nav_N	Natural	Navarra	Tempranillo	2020	-	8.00 €	2, 4
Tem_Nav_C	Conventional	Navarra	Tempranillo	2020	-	7.50 €	2, 4
Sum_Cat_N	Natural	Cataluña	Sumoll	2018	-	19.00 €	2, 4
Sum_Cat_C	Conventional	Cataluña	Sumoll	2018	-	14.33 €	2, 4
Trep_Cat_N	Natural	Cataluña	Trepat	2018	3 mo Amphora	18.35 €	2, 4
Trep_Cat_C	Conventional	Cataluña	Trepat	2018	-	9.10 €	2, 4
Grac_Cas_N	Natural	Castilla-La Mancha	Graciano	2018	-	11.00 €	2, 4
Grac_Cas_C	Conventional	Castilla-La Mancha	Graciano	2018	-	9.29 €	2, 4
Men_Bier_N	Natural	Bierzo	Mencia	2020	-	12.90 €	2, 4
Men_Bier_C	Conventional	Bierzo	Mencia	2020	-	4.95 €	2, 4

* = months; **1 = Garnacha Tinta sorting; 2 = Tempranillo Tinto sorting; 3 = several grape varieties sorting; 4 = Quality assessment.

Spanish regions (see Table 1 for details) and intended to ensure maximum sensory variability among the wines. The three tasks were performed in different order for each expert to avoid carryover effects.

For each free sorting task, participants were asked first to smell and taste all the wines from left to right and then to classify the wines into groups based on their sensory similarity. Once all the samples were tasted in the given order, participants were allowed to re-taste the samples as many times as they wished in any order. They were allowed to make as many groups as they wished and to put as many wines as they wanted in each group. Once the groups were defined, participants were asked to provide 1–3 descriptors to explain the criteria on which their sorting was based. For the three sorting tasks, wines were presented in dark ISO glasses to eliminate visual cues as sources of information during the test. To avoid sensory saturation and to limit astringency carryover effects due to multiple re-tasting of the samples, both water and a pectin solution (1 g L⁻¹) were available.

2.4. Quality assessment

The samples Tem_Cat_N and Tem_Cat_C were excluded from the quality assessment due to sample volume restrictions. Spanish and French panellists were asked to categorise the remaining 22 wines into five quality levels (poor, low, medium, high and outstanding). Quality assessments were carried out in two conditions: with and without information. In the first session, samples were assessed without information about the production method of each sample (natural or conventional). In a second session, samples were judged again with different codes and in a different order. The information concerning the actual production method of each wine was displayed on the glass label next to the code. In Spain, the two quality assessment sessions were conducted at least one week apart. In France, due to experts' availability, the two sessions were conducted between 4 and 8 days apart.

3. Chemical analysis

Alcohol content was determined by a near-infrared technique (Spectraalyzer 2.0; Zeutec, Rendsburg, Germany), volatile

acidity and reducing sugars by a QuAAtro 39 segmented flow autoanalyser (Bran+Luebbe, Norderstedt, Germany), pH and total acidity by potentiometry (ATP 3000; Tecnología Difusión Ibérica, S.L., Barcelona, Spain), and malic acid following the method proposed by the International Organisation of Vine and Wine (OIV) (OIV-MAAS313-10). These parameters were analysed by accredited procedures at the *Estación Enológica de Haro* (La Rioja, Spain) following the UNE-EN ISO/IEC 17025 standards. The colour of wines was determined by calculating CIELAB coordinates. For this, the spectra of centrifuged and filtered samples (0.45 µm, recorded every 1 nm between 380 and 780 nm) were acquired in a UV-1800 spectrophotometer (Shimadzu, Milan, Italy) using 0.2-cm path-length quartz cuvettes. From the spectra, colour coordinates were calculated using the CIE method with the CIE 1964 10° standard observer and the illuminant D65, according to the OIV. The turbidity of wines was measured by a portable turbidimeter (HI 93703-11; Hanna Instruments, Woonsocket, RI, USA).

4. Data analysis

The data treatment of the sorting task started with the generation of three co-occurrence matrices (one per sorting task), presenting the number of times two pairs of samples were sorted together. The co-occurrence matrices were then submitted to a non-metric multidimensional scaling analysis (MDS). Stress values below 0.2 were considered an acceptable fit between the MDS configurations and the actual data. To verify whether NW tended to cluster together in the similarity space, the three first dimensions derived from the selected MDS configuration were analysed using hierarchical cluster analysis with the Ward criterion.

To analyse the free vocabulary used by the panellists to describe the groups, a list with each and every attribute used by the judges was first generated. The repeated attributes were subsequently removed from the list. Then, a lemmatisation process was carried out, grouping words with the same root into a single attribute (e.g., structure and structured into structured). Next, a triangulation process was carried out by two researchers. They independently grouped together attributes with similar meanings into categories and chose a representative term as a category label. When finished, the two researchers compared their respective terms grouping and defined by consensus the final attribute list (for term categories, see Supporting information). Finally, the number of times each attribute of the final list was used to describe each wine was counted. Only attributes cited by at least 15 % of the panellists were considered for subsequent analyses. Chi-square tests were applied to test for significant differences in the citation of each descriptor between NW and CW for each sorting task. Moreover, a Correspondence Analysis (CA) was carried out from the contingency matrix (wines in rows and attributes in columns), including the 24 wines and the most frequently cited attributes of the final list. The quality average scores from the two countries and the two conditions (see data analysis below) were projected as supplementary variables on the CA plot.

Concerning the quality assessment, an individual quality score of 1, 2, 3, 4 or 5 was assigned to each wine and participant to wine samples classified in poor, low, medium, high or outstanding quality, respectively. To check for significant effects on the origin of the experts (Spain vs France), information condition (with vs without information) and type of production method (conventional vs natural), a three-way Analysis of Variance (ANOVA) with these three main factors plus all the second order interactions was carried out.

To check for significant effects of the type of winemaking (natural vs conventional) on the different physicochemical variables, one-way ANOVA was carried out for each one. The significance threshold was set at $\alpha = 0.05$. Fisher (LSD) post-hoc tests were carried out on significant effects.

All statistical analyses were carried out with XLSTAT (version 19.03. Addinsoft, Paris, France) except for the correspondence analysis that was carried out with SPAD (version 9.2, Coheris, Suresnes, France).

RESULTS AND DISCUSSION

1. Sensory similarity and description

The MDS on the co-occurrence matrix of the Garnacha Tinta wines yielded a satisfying three-dimensional solution (stress value = 0.137). An automatic partition into two groups suggested a fair separation between NW and CW. Indeed, only one CW was found in the NW group, and conversely, only one NW was found in the CW group (Figure 1a). However, no significant differences between NW and CW were found in the citation frequencies of the descriptors generated during the sorting task.

As for the previous sorting task, a three-dimensional solution was also obtained from the sorting task of Tempranillo Tinto wines (stress value = 0.116). The dendrogram was automatically partitioned into three groups, and, in this case, the separation between NW and CW was not clear since all three clusters had NW and CW samples (Figure 1b). Despite this apparent lack of separation, Chi-square tests showed that NWs were significantly more associated with off-odours (sum of citations of “faulty”, “animal” and “acetic acid/ethyl acetate”) ($\chi^2 = 9.0$; $p = 0.0027$) than CWs. NWs also tended to be less associated with berry aromas ($\chi^2 = 3.2$; $p = 0.074$) than their conventional counterparts.

Concerning the sorting task with multiple varieties, the MDS offered an acceptable three-dimensional solution as well (stress value = 0.144). Two clusters emerged from the automatic partition of the HCA (Figure 1c). The separation between CW and NW was almost perfect and was consistent with the citation frequency of “acetic acid/ ethyl acetate”, which was significantly higher for NW ($\chi^2 = 4.76$; $p = 0.029$). Moreover, CW tended to be more associated with “berry” ($\chi^2 = 3.27$; $p = 0.071$) and “vegetal” aromas ($\chi^2 = 3.0$; $p = 0.083$).

Taken together, the results of the sorting task suggest that the sensory discrimination between NW and CW is not systematic,

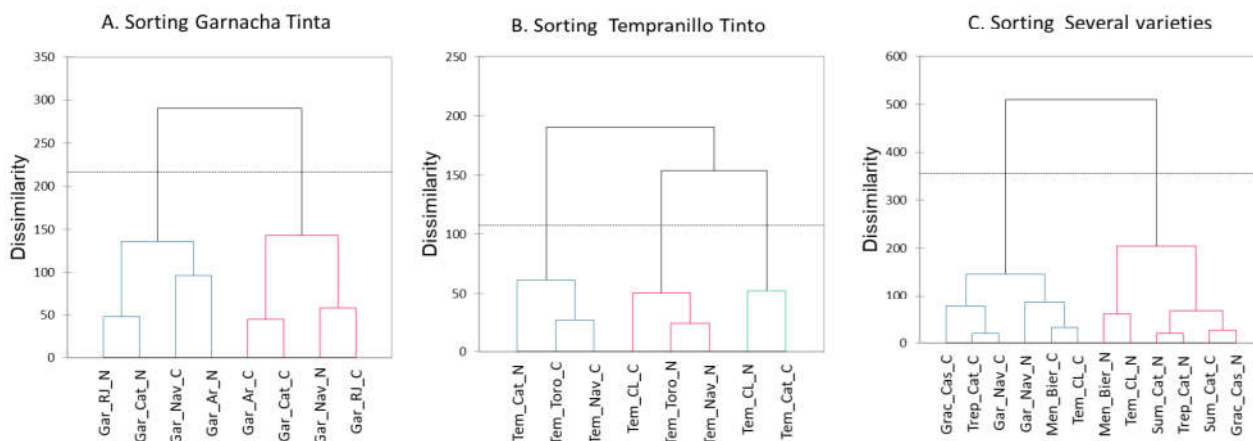


FIGURE 1. Dendrograms obtained from the first three dimensions of the *Garnacha Tinta* (a), *Tempranillo Tinto* (b) and several varieties (c) of sorting tasks. The dotted line indicates the automatic partition level of each dendrogram.

although a subset of the NW has sensory dimensions related to off-odours in common. This result is consistent with recent findings from Honoré-Chedozeau *et al.* (2020), who suggested that one of the main spontaneous classification strategies of wine experts was based on the presence of wine faults.

2. Information and cultural effects on quality assessment

ANOVA results showed two significant main effects for “origin of the taster” ($F = 72.8$; $p < 0.0001$) and “type of wine” ($F = 62.8$; $p < 0.0001$) on quality scores. No significant effect of information was found ($F = 0.53$; $p = 0.46$). Only the interaction “origin of the taster * type of wine” was significant ($F = 6.27$; $p = 0.012$). The nature of this interaction can be seen in Figure 2, which shows the average quality scores for the two cultures and the two types of wine.

Experts from both cultures provided significantly higher quality scores to CW than to NW. However, French experts gave significantly higher scores than Spanish experts to both types of wine, which explains why the “origin of the taster” effect is significant. These results suggest that French and Spanish experts agree that NWs have lower quality globally than CW, but French experts penalise NWs less, possibly because they are more familiar with them. This result agrees with previous research showing that French participants have a less negative attitude towards NW than participants less familiar with NW, such as those in New Zealand (Urdapilleta *et al.*, 2021).

3. Relationship between quality assessment and description

The F1–F2 plot of the CA resulting from the citation frequencies of the descriptors generated during the sorting task is represented in Figure 3. The mean quality scores for

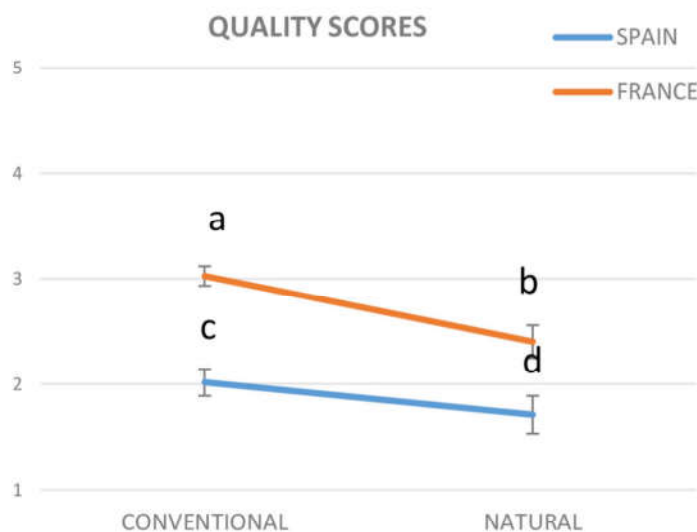


FIGURE 2. Average quality scores for the two cultures and the two types of wine. Values associated with different letters are significantly different according to a Fisher (LSD) test.

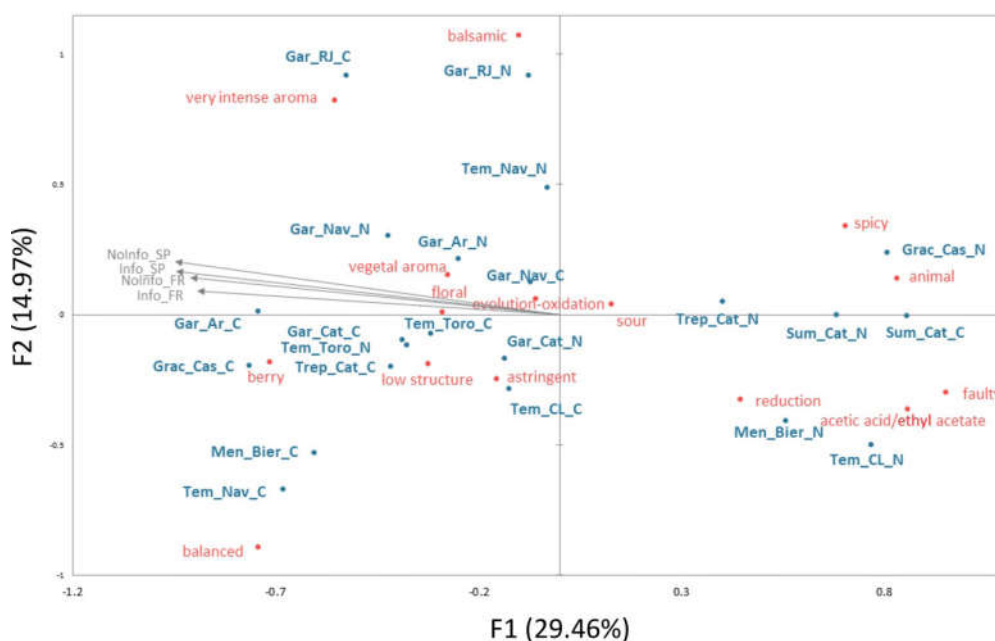


FIGURE 3. CA carried out on the citation frequencies of the descriptors generated during the sorting task. The mean quality scores for the two cultures and the two information conditions are projected as illustrative variables.

the two groups of experts and the two information conditions have been projected as illustrative variables.

The first axis, accounting for 29.46 % of explained variance, can clearly be interpreted as a quality continuum since quality judgements from both groups of experts (Spanish and French) for the two information conditions were highly correlated ($r = 0.77-0.91$; $p < 0.01$). This unexpected absence of cultural difference can be explained by the fact that all our participants had followed similar academic oenology training, which could have “erased” cultural differences in terms of attitudes towards NW. Similar results have been found by Parr *et al.* (2015), who showed, despite the expected cultural differences, a global agreement between French and New Zealand experts in their minerality assessments and quality assessments (Valentin *et al.*, 2016).

The samples associated with higher quality are situated on the left side of the plot and are mostly characterised by positive descriptors such as “very intense aroma”, “berry” and “balanced”. This group of wines comprises 2/3 of CW and 1/3 of NW. The right side of the plot is dominated by six samples characterised by low-quality ratings and some negative descriptors such as “reduction”, “acetic acid” or “faulty”. Five out of the six samples of this group are NW. The exception is the sample Sum_Cat_C that, despite being made without the strict limitations of the natural winemaking itinerary, was often characterised by animal notes, possibly as the consequence of a *Brettanomyces* contamination. The partition into these specific two groups was supported by a hierarchical cluster analysis followed by an automatic partition (data not shown).

If the ANOVA showed a significantly lower quality for NW compared to CW, the CA shows a more nuanced result; CW and NW are not linearly separable categories from

a sensory point of view. Indeed, some of the NWs have sensory characteristics that are very similar to CWs and do not present off-odours. The others (45 %) do show off-odours and explain the lower average quality for the whole NW category.

Our sensory results globally converge with those of Sáenz-Navajas *et al.* (2023) carried out on white wines. NWs have more off-odours than CWs. However, in our study, the percentage of faulty NW was 45 %, while Sáenz-Navajas *et al.* (2023) showed that 70 % of the white NW presented faults. This difference is not easy to interpret. On the one hand, red wines are more resistant to oxidation than white wines because of their polyphenol content, which is a key production strategy in the absence of SO₂. Indeed, most natural winemakers resort to the production of orange rather than white wines to profit from polyphenols provided by skin and even stem contact and, thus, prevent rapid oxidation. On the other hand, red wines, unlike whites, have the precursors used by *Brettanomyces* to generate volatile phenols, which, above a certain limit, can negatively affect quality, especially perceived quality among wine experts (Sáenz-Navajas *et al.*, 2016b).

4. Relationship between quality assessment and physico-chemical parameters

The average values of the physico-chemical parameters measured in the study for each wine type are presented in Table 2.

The results show that NWs present significantly higher total acidity, volatile acidity (VA) and turbidity, while, as expected, CW presented higher total and free SO₂ contents. The standard deviations and the range of values are systematically higher for NW than for CW, suggesting that this wine category is quite heterogeneous. The wines

TABLE 2. Median (\pm standard deviation among the wines of the category), range of occurrence and significance (according to one-way ANOVA considering the production method as a fixed factor) of physicochemical parameters for natural and conventional wines. Significance: $p < 0.001$ ***; < 0.05 ** ; < 0.1 *.

	Total acidity (g tartaric acid/l)	Volatile acidity (g acetic acid/l)	Malic acid (g/l)	Reducing sugars (g/l)	Alcohol content (%, v/v)	pH	Free SO ₂ (mg/l)	Total SO ₂ (mg/l)	Colour intensity (CI, a.u.)	Total polyphenol index (TPI, a.u.)	Hue	Turbidity (NTU)	Colour coordinate a ₁₀ *	Colour coordinate b ₁₀ *	Colour coordinate L*
Gar_Nav_N	5.4	0.69	0.1	1.7	14.11	3.68	5	22	9.7	46.25	0.78	17.29	40.22	11.77	54.7
Gar_Nav_C	5.4	0.5	0.1	2	14.13	3.52	28	77	4.745	44.9	0.8	0.05	26.26	6.07	74.2
Gar_RJ_N	6.3	0.54	0.83	2	15.65	3.39	18	59	9.18	51.5	0.68	9.2	44.13	8.68	55.9
Gar_RJ_C	5.6	0.48	0.13	2.1	13.97	3.52	14	68	6.1	46.9	0.8	0.02	31.38	8.64	68.3
Gar_Ar_C	4.7	0.56	0.1	4.7	13.5	3.7	20	61	5.725	41.3	0.78	12.22	29.28	7.73	69.8
Gar_Ar_N	5.7	0.5	0.1	2.1	14.02	3.59	5	20	6.105	48.65	0.82	45.4	29.16	8.09	68.3
Gar_Cat_N	6.2	0.49	0.1	1.9	15.11	3.32	5	20	9.195	47.1	0.68	19.32	42.89	10.08	56.3
Gar_Cat_C	5.2	0.52	0.1	1.9	14	3.62	5	55	5.09	40.65	0.86	11.13	25.51	10.66	73.8
Tem_CL_N	7.4	1.56	0.1	1	14.25	3.79	5	20	9.43	49.9	0.79	57.44	37.65	10.42	54.7
Tem_CL_C	5.4	0.67	0.11	1.6	14.47	3.73	5	36	10.71	62.15	0.79	0	42.9	15.23	52
Tem_Cat_N	5	0.31	0.19	1.8	13.18	3.71	20	86	4.79	32.3	0.85	3.25	24.53	7.47	74.5
Tem_Cat_C	5.7	0.43	0.1	1	10.18	3.29	5	20	3.78	26.6	0.71	35.97	23.47	5.58	78.5
Tem_Toro_C	4.4	0.44	0.12	1.5	14.47	3.73	7	38	5.795	36.2	0.78	0	29.44	7.68	69.2
Tem_Toro_N	4.9	0.75	0.1	1.2	13.16	3.77	5	20	8.025	39.45	0.71	24.77	38.23	5.85	59.1
Tem_Nav_N	4.6	0.69	0.1	1.2	14.83	3.98	5	20	9.805	51.15	0.83	4.54	37.39	10.16	53.6
Tem_Nav_C	5.1	0.52	0.1	1.2	12.03	3.59	8	40	5.36	38.5	0.7	0	30.28	3.48	70.4
Sum_Cat_C	6.9	0.42	0.11	1	11.68	3.14	5	26	3.27	29.4	0.83	2.28	19.24	6.47	81.7
Sum_Cat_N	7.9	0.89	0.1	1	11.97	3.03	5	20	4.75	40.3	0.83	6.18	25.63	10.13	75.1
Trep_Cat_N	5.6	0.47	0.1	1	10.26	3.2	5	20	1.05	10.05	1.29	59.69	4.24	5.83	94.9
Trep_Cat_C	5.2	0.35	0.4	1.2	11.11	3.57	13	71	2.415	19.7	0.91	15.94	13.04	4.93	86.6
Grac_Cas_N	6.2	0.49	0.1	1	13.36	3.36	5	20	8.47	33.75	0.88	471.11	35.22	16.43	60.3
Grac_Cas_C	6.5	0.29	0.12	1.8	14.24	3.27	5	37	8.105	39.3	0.76	1.44	40.12	8.55	59.7
Men_Bier_C	5.2	0.47	0.1	1.6	13.13	3.66	19	55	8.02	45.25	0.66	3.35	41.76	5.55	59.9
Men_Bier_N	6.1	1.05	0.1	1	13.37	3.79	7	20	8.865	48.2	0.74	91.03	37.96	7.97	56.5
median NW	5.90 \pm 0.94	0.62 \pm 0.33	0.10 \pm 0.21	1.10 \pm 0.45	13.7 \pm 1.8	3.49 \pm 0.29	<5.00 \pm 3.74	<20.0 \pm 11.2	8.67 \pm 2.81	46.7 \pm 12.4	0.79 \pm 0.16	30.4 \pm 128.9	37.5 \pm 11.1	9.4 \pm 3.0	57.8 \pm 12.8
range NW	4.60–7.90	0.43–1.56	0.10–0.83	1.00–2.10	10.2–15.7	3.03–3.98	<5.00–18.00	<20.0–59.0	1.05–9.81	10.05–51.5	0.68–1.29	4.5–471.1	4.2–44.1	4.2–44.1	58.6–94.9
median CW	5.20 \pm 0.70	0.48 \pm 0.11	0.11 \pm 0.09	1.70 \pm 0.95	13.7 \pm 1.1	3.61 \pm 0.19	10.5 \pm 7.8	55.0 \pm 18.9	5.5 \pm 2.2	40.0 \pm 10.4	0.8 \pm 0.1	1.86 \pm 5.64	29.4 \pm 8.9	7.6 \pm 3.0	70.1 \pm 9.5
range CW	4.40–6.90	0.29–0.67	0.10–0.40	1.00–4.70	11.1–14.5	3.14–3.73	<5.0–28.0	26.0–86.0	2.4–10.7	19.7–62.2	0.7–0.9	0.00–15.94	13.0–42.9	3.5–15.2	52.0–86.6
F	3.35	6.39	0.10	2.98	0.00	0.23	6.07	23.45	2.14	0.09	0.13	3.14	0.74	1.55	1.70
p	*	**	ns	ns	ns	ns	*	***	ns	ns	ns	*	ns	ns	ns

showing the lowest quality scores (Figure 3) had very low concentrations of free and total SO₂ (close to 5 mg/l and 20 mg/l, respectively). Some of the effects are in line with the sensory results reported above. For instance, higher VA is consistent with the higher frequency of citation of the “acetic acid/ethyl acetate” attribute for NW, which in turn may have affected the perceived quality. The presence of acetic acid/ethyl acetate, as well as animal notes, can reflect some sort of microbiological spoilage by acetic bacteria or *Brettanomyces* yeasts that could be in part explained by the lower global amounts of SO₂ found in NW, as well as the use of native yeasts to achieve alcoholic fermentation.

It must be considered that the conventional sample Sum_Cat_C, which was the only conventional wine in the lower-quality group, shows a surprisingly low concentration of free and total SO₂ (5 g L⁻¹ and 26 g L⁻¹, respectively). Conversely, the sample Gar_RJ_N had a surprisingly high total SO₂ concentration of 59.0 g L⁻¹, which is beyond what one could expect for a NW. This is consistent with the fact that this sample does not show any off-odour and is characterised by balsamic notes. This calls for a stricter definition and control of NWs in the market.

Concerning the parameters involved in the visual appearance of the wines, no significant differences were found for colour parameters. This result diverges from Sáenz-Navajas *et al.* (2023), who found higher levels of yellow and more colour intensity for NW, which was interpreted as the result of the oxidation of some phenolic compounds. However, our results showed that turbidity was significantly higher for NW. The presence of cloudiness is usually considered a flaw (Jackson, 2009) and has already been associated with NW in a negative way by consumers from New Zealand (Urdapilleta *et al.*, 2021).

CONCLUSION

Our investigation substantiates and extends prior research on the sensory attributes of natural wines (NWs). Initially, our findings indicate that the distinction between conventionally produced wines (CWs) and NWs is not clear-cut from a sensory standpoint. Nevertheless, our study reveals a discernible trend: the prevalence of off-odours in NWs surpasses that in CWs, aligning with earlier research (Sáenz-Navajas *et al.*, 2023; Pelonnier-Magimel *et al.*, 2020). Our results introduce nuance into the binary discourse surrounding NWs, in particular to the idea that NWs are systematically flawed. Our study indicates this assertion is not entirely accurate, as only 45 % of NWs exhibited off-odours. Notably, these NWs differed from CWs in their cloudier appearances and an increased incidence of off-odours associated with the absence of sulphur dioxide and the lack of microbial control during alcoholic and malolactic fermentation. Sensory results were corroborated by chemical analyses, revealing notably higher levels of volatile acidity and turbidity, along with lower values for free and total SO₂ in NWs. The remaining 55 % of NWs demonstrated positive attributes and clustered with CWs. Thus, our findings demonstrate the technical feasibility

of producing “clean” wines through natural winemaking methods. A pertinent question for future inquiries revolves around the evolution of sensory quality in NWs after several years of bottle ageing.

From a cognitive point of view, we aimed to check the potential effect of culture and information on the experts’ quality assessment of NW and CW. Our results showed agreement that NW had significantly lower quality scores than CW, but French scores were significantly higher than Spanish. This suggests that oenology training fosters a common framework among experts from diverse countries but that the French were more tolerant than the Spanish, possibly due to a higher familiarity with this wine category. Subsequent research should study consumer acceptance of NWs in tasting scenarios and comprehend the trade-off between wine sensory properties (including the risk of occasional faults) and the positive associations with naturalness and health.

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