



ORIGINAL RESEARCH ARTICLE

How do Syrah winemakers from two different French regions conceptualise peppery wines?

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Associate editor:
Jordi Ballester



Received:
11 August 2023

Accepted:
21 December 2023

Published:
13 February 2024



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ABSTRACT

This work investigated Syrah producers' conceptualisation of peppery wines from two different wine regions. For the study, a long-term memory approach was used; in addition, the effects of the region of origin, as well as the sensitivity of the participants to detect rotundone, were evaluated. A total of 101 winemakers from the Northern Rhone Valley (NRV) and Languedoc-Roussillon (LR) were interviewed face-to-face after they had participated in two 3-alternative forced tests to assess their ability to detect rotundone. As part of the interview, participants were asked to remember the last peppery red wine they had tasted, to provide technical information about that wine and, more generally, about practices enhancing this character in wine, and to give their overall appreciation of such peppery notes. Only minor differences were observed between participants with either low or high sensitivity to rotundone; in contrast, an important regional effect on the conceptualisation of peppery notes was observed. Experts from the NRV recognised this character as a marker of wines made from under-ripe grapes. Overall, they perceived this flavour as a positive attribute, notably at a moderate level, but some experts also perceived it negatively. For LR participants, peppery notes were associated with powerful, full-bodied wines from very ripe grapes produced in the South of France and were notably perceived as a positive character. Our results are particularly relevant for the wine community as they show that the conceptualisation of a given wine aroma characteristic by winemakers can strongly differ according to their region of origin.

KEYWORDS: Rotundone, peppery notes, conceptualisation, favourable conditions, Northern Rhone Valley, Languedoc-Roussillon

INTRODUCTION

Vitis vinifera L. Syrah is the eighth most planted grape variety in the world, with 190,000 ha under vines, mostly in France (64,000 ha) and in Australia (40,000 ha) (OIV, 2017). Syrah red wines are frequently described as peppery, a sensory characteristic associated with high rotundone levels, a sesquiterpenoid first identified in wines made from this variety (Siebert *et al.*, 2008; Wood *et al.*, 2008). A significant percentage of respondents are hyposmic or anosmic to this molecule, ranging from 20 to 42 % of the population, as reported in previous studies (Gaby *et al.*, 2020; Geffroy *et al.*, 2018; Geffroy *et al.*, 2020; Wood *et al.*, 2008). However, some respondents who failed to identify a sample spiked with rotundone during a formal three-alternative forced choice test (3-AFC) and for whom the omission of rotundone did not provoke any changes in aroma perception (Geffroy *et al.*, 2020) may declare that they can detect peppery notes in wines (O. Geffroy, unpublished data).

One hypothesis to explain this observation is that other molecules and notably other sesquiterpenoids found in grapes, such as α -guaiene or α -ylangene, whose concentrations in grapes are typically correlated with rotundone or the intensity of peppery notes perceived at tasting, may be involved (Parker *et al.*, 2007; Takase *et al.*, 2016; Zhang *et al.*, 2016). Although the aroma contribution to wine of many sesquiterpenoids has been little studied, this hypothesis is unlikely as these volatiles generally impart different, balsamic or woody characteristics and exhibit relatively high odour thresholds compared to rotundone, for example, in the mg/L range as demonstrated for farnesol and nerolidol (Li *et al.*, 2020).

The peppery character perceived in wine by hyposmic or anosmic panellists could also potentially originate from barrel ageing. Indeed, this practice enhances furfural, 4-ethylphenol, guaiacol, 4-ethylguaiacol and eugenol in wine; some of these compounds are well known to contribute to the spiciness of wines (Pérez-Coello and Díaz-Maroto, 2009) and that can be somehow confused with pepperiness.

Overall, the concept of peppery notes in wines and their relationship with sensitivity to rotundone remains unclear and warrants an in-depth study.

For similar research, a long-term memory approach has been recently used to study the ill-defined concept of green wines (Sáenz-Navajas *et al.*, 2021). Spanish winemakers from several wine regions conducted a non-tasting-free description task and cited both origin-related and sensory terms when describing green wines. In comparison with a tasting-based approach, this cognitive-based methodology has the advantage of not generating fatigue typically related to astringency sensations when tasting a large number of red wines and of not leading to a forced scoring of the studied attribute, even if the character is absent or if no differences can be perceived between the wines.

The same cognitive-based methodology could be valuable in investigating how French producers conceptualise the

peppery notes in Syrah red wines and how they link them to production practices. The first hypothesis was that producers with different sensitivity to rotundone also conceptualise peppery wines differently, and consequently, their practices might be differently oriented to produce or avoid these notes. Secondly, the peppery notes have been reported to be mainly driven by rotundone in wine, which is a putative marker of cool and wet climates (Caputi *et al.*, 2011; Zhang *et al.*, 2015; Geffroy *et al.*, 2020). In this context, it was hypothesised that the conceptualisation of peppery wines may differ from a technical and hedonic standpoint, according to the region of production of winemakers and their experience with winemaking in cool vintages. As a further discussion point, rotundone might likely be seen as a positive aroma compound in wine regions experiencing extreme summer climate conditions or as a negative one in cooler wine regions where wine-growing conditions may be more limiting.

The study interviewed 101 winemakers from the Northern Rhone Valley and the Languedoc-Roussillon regions to investigate their conceptualisation of peppery wines. Participants were also assessed for their ability to detect rotundone using two consecutive 3-AFC tests, and interview responses were analysed according to the results of the sensory tasks.

MATERIALS AND METHODS

1. Participants

A total of 101 experts involved in the winemaking of Syrah wines in private and cooperative cellars from two French wine regions (n = 53 for the Northern Rhone Valley (NRV), n = 48 for Languedoc-Roussillon (LR)) were interviewed. They were recruited during two wine fairs that took place in Tain-L'Hermitage and Montpellier for the NRV and LR, respectively.

The Northern Rhone Valley was selected based on being a relatively cool climate region, for which Syrah is the only variety used to make red wines. For this region, participants declared to produce wines from the Protected Designations of Origin (PDOs) Côte-Rôtie, Saint-Joseph, Hermitage, Crozes-Hermitage and Cornas, representing 3,800 ha of vineyard planted mainly with Syrah in 2020 according to the local professional grower association (www.vins-rhone.com).

The Languedoc-Roussillon region was selected as being a warm region and the greatest French wine-growing region planted with Syrah, with 39,206 ha under vines in 2020, according to FranceAgriMer (www.franceagrimer.fr). In this area, Syrah is traditionally blended with Grenache, Mourvèdre and Carignan. The participants were making wine from the Geographical Protected Indication Pays d'Oc, and a large number of PDOs, including Corbières, Costières de Nîmes, Côtes du Roussillon, Faugères, Languedoc, Minervois, Saint-Chinian and Terrasses du Larzac.

As the level of expertise is known to have a major influence on the ability of panellists to perform odour-related sensory

TABLE 1. Gender, age ranges, years of experience (mean and standard deviation) in producing wine and expertise as reflected by the number of participants holding the French National Diploma of Oenologist (DNO).

	Northern Rhone Valley (n = 53)	Languedoc-Roussillon (n = 48)
GENDER		
Male	43	23
Female	10	25
AGE (YEARS)		
18–30	8	6
31–40	16	20
41–50	13	14
51–60	9	6
61–70	3	2
> 70	4	0
EXPERIENCE (YEARS)	19.9 ± 13.2	16.6 ± 8.6
LEVEL OF EXPERTISE		
DNO holder	7	25
Non-DNO holder	46	23

tasks (Koenig *et al.*, 2020), participants were asked if they were holding the National Diploma of Oenologist (DNO), the only degree in France that is an accredited credential for professional oenologists.

Demographic information provided in Table 1 highlights that the NRV panel includes more male, older, and more experienced participants and fewer DNO holders than the LR panel.

2. Procedure

Face-to-face interviews were conducted during the first trimester of 2022. The interviews were organised at the opening of the wine fairs when the environment was still quiet. Four researchers were involved in the interviews that took place directly at the experts' booths just after their recruitment. The whole interview lasted between 5 and 10 minutes and included various parts.

First, participants were evaluated for their ability to perceive rotundone using two consecutive 3-AFC tests. Four-mL glass vials were filled with a wad of odourless cotton wool. For the test samples, 100 µL of a 1 mg/L solution of food-grade rotundone (purity > 99 %) provided by Firmenich (Geneva, Switzerland) was prepared in 10 % v/v ethanol and pipetted onto the wool. For the control samples, a 10 % v/v ethanol solution without rotundone was used. For both samples, the vial was left uncapped for 4 hours to dry out and promote ethanol evaporation and, therefore, limit its sensory contribution.

Such a method has been used for several years by the Australian Wine Research Institute (The AWRI) during wine industry workshops to determine if a person could smell rotundone or not. The intensity of the rotundone smell was also verified before the beginning of the interviews by some

experts involved in the study who had more than one decade of experience with rotundone.

Serving order was randomised and differed for the two 3-AFC tests. The samples were blinded using three-digit codes. Participants had to respect a 2-minute rest period between the two tests. A panellist who failed at least one of the two tests was considered as anosmic (low sensitivity) to rotundone. The persistence of the stimulus at the end of the interviews was confirmed by the experimenters, who smelt some vials spiked with rotundone.

The second part consisted of a non-tasting free description task of the last peppery wines tasted by the participants following the approach previously proposed by Sáenz-Navajas *et al.* (2021): “Remember the last time you tasted a peppery wine, could you please describe it?” (coded as a *description* question).

Thirdly, participants were asked to provide technical information about that wine (coded as a *technical* question) and, more generally, about factors enhancing this character in wine (coded as a *favourable conditions* question).

Fourthly, participants were asked about their overall appreciation of peppery notes in red wines (responses are coded as a *liking* question).

Description, technical, favourable conditions and *liking* questions were open-ended to favour the development of the questions and, thus, capture more information. Before concluding the interview, demographic data (gender, age, years of experience, expertise as reflected by the holding of the DNO and PDOs produced on the estate) together with their *level of familiarity* with peppery wines, assessed on a discontinuous scale ranging from 0 (*I have never tasted a peppery wine*) to 4 (*I am very used to tasting peppery wines*),

were collected. Finally, they were also asked if they had already heard about rotundone.

3. Data treatment

For the four open-ended questions, the terms were lemmatised and grouped into categories and subcategories using a triangulation procedure (Abric, 2005). Three experts were asked to group terms belonging to similar categories and subcategories. Discrepancies were discussed until a consensus was reached. The frequencies of occurrence were calculated for each term and for each of the subgroups (region and ability to detect rotundone or level of expertise). Terms that were cited by at least $\geq 10\%$ of participants in one of the two regions were included in further analyses. These data were treated through either a chi-square test followed by a Marascuilo post hoc test or correspondence analysis (CA).

The number of terms generated for the *description*, *technical* and *favourable conditions* questions was also treated using a Kruskal–Wallis comparison followed by Dunn’s test to detect differences according to the region, the ability to perceive rotundone or the level of expertise. The level of familiarity was analysed through a three-way ANOVA (Region \times Ability to perceive rotundone \times Level of expertise) with first-order interaction. All data treatments were conducted using Xlstat 3.1. software (Addinsoft, Paris).

RESULTS AND DISCUSSION

1. Sensitivity to rotundone, number of terms generated and familiarity with peppery wines

The proportion of anosmic respondents (or with low sensitivity to rotundone) who failed in at least one of the

two 3-AFC tests was 45 % and 44 % for the NRV and LR, respectively. This is similar to previous results obtained in France, highlighting a percentage ranging between 31 % and 46 % (Geffroy *et al.*, 2018; Geffroy *et al.*, 2020). However, the proportion of anosmic panellists in these former studies might have been underestimated as only one single 3-AFC was performed. In such experimental conditions, one-third of the panellists who succeeded in identifying the sample spiked with rotundone are likely to have identified it randomly. In this present study, this percentage was reduced to one-ninth.

The numbers of terms obtained during the interview in response to the *description*, *technical* and *favourable conditions* questions for the studied subgroups are shown in Table 2.

For these three questions, and as it could be somehow expected, the ability to detect rotundone had no significant impact on the number of terms generated by experts. However, overall, experts from the LR region generated more terms in comparison with those from the NRV, which could be related to the higher proportion of DNO-holders that were significantly more talkative in both regions.

Interestingly, the differences between the two regions and their level of expertise, as reflected by the holding of the DNO (Table 2), were less obvious for the *favourable conditions* question that was unrelated to a description task. This observation is consistent with previous findings highlighting that the ability to memorise varietal wine descriptions increased with wine expertise (Honoré-Chedozeau *et al.*, 2019).

The small size of the subgroup composed of DNO-holders for the NRV represented only seven experts and might not

TABLE 2. Numbers of terms obtained and significance of the Kruskal–Wallis test for the description, technical and favourable conditions questions for the different subgroups studied. Different letters indicate means significantly different by the Dunn test. NRV, Northern Rhone Valley; LR, Languedoc-Roussillon; DNO, National Diploma of CEnologist.

	Question		
	<i>Description</i>	<i>Technical</i>	<i>Favourable conditions</i>
NRV anosmic	1.87 b	1.67 b	2.66 a
NRV non-anosmic	1.34 b	1.52 b	2.50 a
LR anosmic	3.71 a	3.43 a	3.24 a
LR non-anosmic	3.67 a	2.96 a	2.70 a
<i>P</i>	< 0.001	< 0.001	0.145
NRV DNO holder	7.86 a	7.14 a	5.86 a
NRV non-DNO holder	0.91 b	0.89 b	2.43 b
LR DNO holder	5.60 a	4.16 a	3.96 a
LR non-DNO holder	2.78 a	2.65 a	2.30 b
<i>P</i>	< 0.001	< 0.001	< 0.001

necessarily be representative of the DNO population of the NRV region. When discussing informally with experts from the NRV, this feature is characteristic of the area where wine estates are small, family-managed and distant from the nearest DNO formation centres that are located at least 200 km away, in Montpellier or Dijon. It must also be pointed out that more than one-sixth of the wineries producing at least one wine from the targeted PDOs were interviewed during the study, whose total number was estimated at around 300 by the local professional grower association (www.vins-rhone.com). Although much smaller, this percentage is impossible to estimate for LR given the greatest number of PDOs and because this vineyard is the largest in France, with 240,000 ha under vines (www.franceagrimer.fr).

The level of familiarity (scored on a 0–4 scale, from *I have never tasted a peppery wine* to *I am very used to tasting peppery wines*) was 2.91 ± 0.95 and 2.78 ± 0.78 for the NRV and LR, respectively, 2.83 ± 0.87 and 2.83 ± 0.88 for anosmic and non-anosmic participants respectively, and 3.04 ± 0.65 and 2.62 ± 0.94 for holders and non-holders of the DNO. The ANOVA treatment performed on the level of familiarity with peppery wines did not reveal any significant differences between the two regions ($F = 0.538$; $P = 0.465$), the ability of participants to detect rotundone ($F = 0.0001$; $P = 0.994$) and the level of expertise ($F = 3.651$; $P = 0.059$), just like first-order interactions between these

factors (results not shown). The fact that experts from the NRV are not more familiar with peppery wines is somehow unexpected as the cool climate conditions of this area are favourable to the production of Syrah red wine containing significant rotundone concentrations, notably within the PDOs Côte-Rôtie, Saint-Joseph and Crozes-Hermitage (Geffroy *et al.*, 2020; Takase *et al.*, 2015). However, it cannot be discarded that climate change, which takes in most cases the form of higher temperatures and low precipitation during summer and maturation, might have contributed to limiting the intensity of this character in Syrah wine produced in this region during the last decade (van Leeuwen and Darriet, 2016).

Given that no significant differences between anosmic and non-anosmic respondents were observed, together with the terms generated by the two subgroups for the *description* question, supports the initial hypothesis underlying this study, that the level of sensitivity of winemakers to rotundone is independent of their ability to conceptualise peppery red wines.

2. Conceptualisation of peppery red wines: analysis of answers from the description question

Minor differences in the conceptualisation of peppery wines were observed among anosmic and non-anosmic experts, but the regional effect was greater (Figure 1).

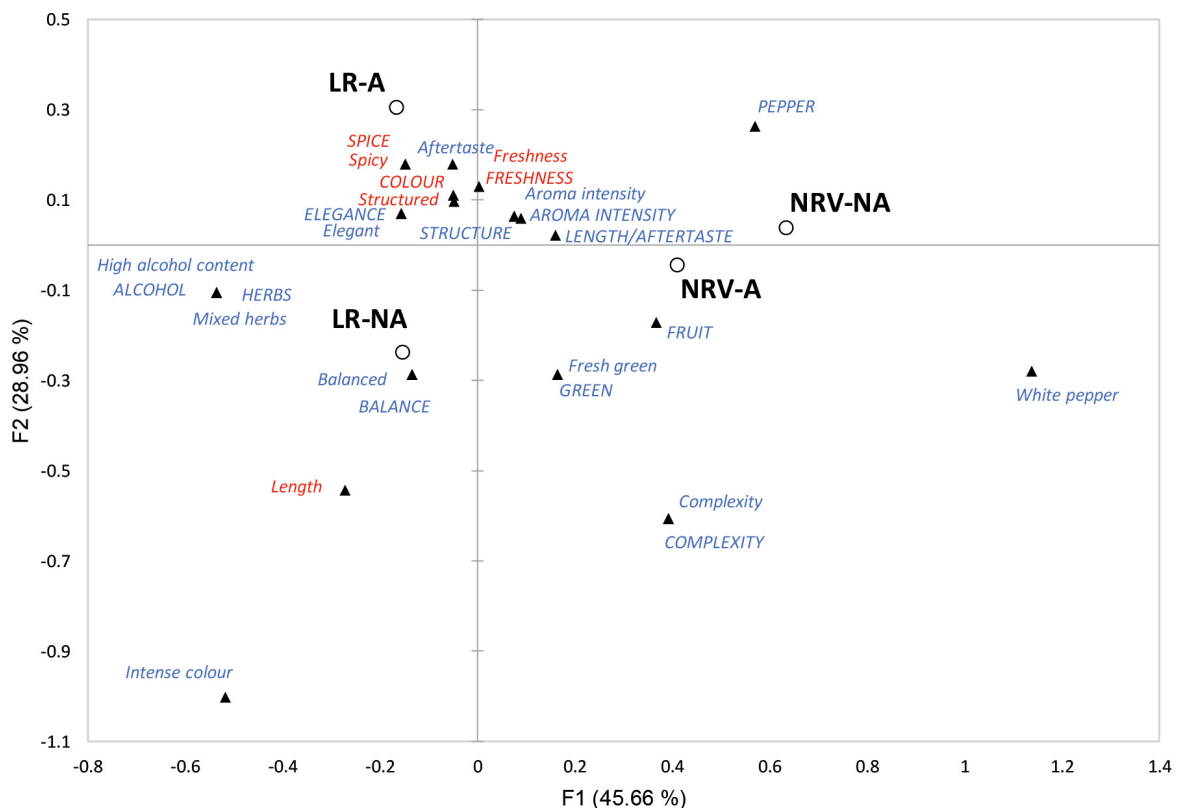


FIGURE 1. Correspondence Analysis space projection on Factors 1–2 of CATEGORIES and subcategories elicited for the description task by participants divided into four subgroups according to their region of origin and their ability to detect rotundone. Terms highlighted in red enable the discrimination of the subgroups according to the chi-square test. NRV, Northern Rhone Valley; LR, Languedoc-Roussillon; A, anosmic; NA, non-anosmic.

Spicy, *Freshness* and *Length/aftertaste* were among the most frequently cited terms in the description task. These terms illustrate the confusion that may exist between peppery and spicy notes and the possible somæsthetic nature of the molecule, as previously proposed (Geffroy *et al.*, 2018).

Among the 28 categories and sub-categories of terms included in the CA treatment, only 7 significantly contributed to discriminate among the four subgroups of participants (i.e., with different *origin*-LR or NRV- or *sensitivity to rotundone*-anosmic (A) or non-anosmic (NA)). They included three categories: *SPICE*, *COLOUR* and *FRESHNESS*, and four subcategories: *Spicy*, *Structured*, *Freshness* and *Length*. In most cases, a higher frequency of occurrence was observed for experts from LR as a likely consequence of the greater number of terms generated, as previously discussed.

The conceptualisation of the peppery wines by experts from the NRV is not clear. However, it can be underlined that these experts tend to more accurately describe the type of pepper perceived at tasting, evoking more frequently, although not significant from a statistical standpoint, the term *White pepper*. This finding was unexpected as the black pepper attribute is the preferred one used to describe the smell of rotundone (Wood *et al.*, 2008). The use of the term

White pepper might simply reflect differences in cultural or historical background.

The peppery terms used by experts from LR might reflect that the wine is similar to the style of Syrah red wines produced in their region. It is structured and well-coloured with a high content of ethanol, which is somehow in contradiction with the cool climate wine style in which high levels of rotundone concentration are generally found. Indeed, rotundone is positively correlated with the absence of water deficit during maturation, which can make it difficult to produce peppery wines with a high content of phenolic compounds (Geffroy *et al.*, 2016).

3. Technical aspects related to peppery wines

The wines chosen for the description were, in most cases, made from *Syrah*, but also *Mourvèdre* and *Malbec*, with a lesser frequency of occurrence (Table 3). For these two latter cultivars, rotundone, which was quantified at concentrations ranging from 11 to 32 ng/L for *Mourvèdre* and from 16 and 51 ng/L for *Malbec* (Geffroy *et al.*, 2020), may play a significant contribution to wine aroma. The significantly lower frequency of occurrence observed for NRV for the category *VARIETY* and subcategory *Syrah* might

TABLE 3. ‘Technical’ question: total number of occurrences, frequency of citation (expressed in %) of categories and subcategories for the four subgroups, and significance (*P*) calculated from chi-square test (ns: non-significant; **P* < 0.1; ***P* < 0.05; ****P* < 0.001). Different letters for a line mean significant differences by the Marascuilo test.

CATEGORY / Subcategory	Total number of occurrences	Northern Rhone Valley		Languedoc-Roussillon		<i>P</i>
		Non-anosmic (n = 29)	Anosmic (n = 24)	Non-anosmic (n = 27)	Anosmic (n = 21)	
VARIETY	56	34 % a	21 % a	89 % b	81 % b	***
Syrah	46	34 % a	21 % a	74 % b	52 % ab	***
APPELLATION/REGION	43	31 %	29 %	52 %	62 %	ns
VINTAGE	28	21 %	13 %	37 %	43 %	ns
Côtes du Rhône	27	28 %	33 %	19 %	29 %	ns
Sud	15	3 % a	0 % a	33 % b	24 % ab	***
VINIFICATION	15	3 %	8 %	26 %	24 %	ns
AGEING	14	3 %	8 %	22 %	24 %	ns
MATURITY	11	3 % a	4 % a	26 % b	10 % ab	*
SOIL/TERROIR	9	10 %	4 %	15 %	5 %	ns
Soil/Terroir	9	10 %	4 %	15 %	5 %	ns
Barrel ageing	8	0 %	8 %	11 %	14 %	ns
Extended maturity	7	0 % a	0 % a	22 % b	5 % ab	*
Mourvèdre	6	0 %	0 %	11 %	14 %	ns
2020	6	0 %	0 %	11 %	14 %	ns
2017	5	0 %	4 %	4 %	14 %	ns
Traditional vinification	5	0 %	4 %	11 %	5 %	ns
2019	4	0 % a	4 % ab	0 % a	14 % b	*
Malbec	3	0 % a	0 % a	0 % a	14 % b	*
2018	3	0 % a	0 % a	11 % b	0 % a	*

be the consequence of the overall lower number of terms elicited in this region, as previously discussed.

The selected peppery wine was produced in specific regions, such as the Rhone Valley for all the subgroups or the South (of France) for experts from LR. Climatic conditions in the South of France are known to be warm and dry and not particularly favourable for the production of wines with a high rotundone content (Caputi *et al.*, 2011; Zhang *et al.*, 2015). The experts from LR described the wine as made from grapes with an *Extended maturity* or category related to *MATURITY*. This is in accordance with previous works emphasising that rotundone accumulates late during the maturation process and that delayed harvest can help produce wines with an enhanced rotundone content (Geffroy *et al.*, 2014; Geffroy *et al.*, 2019b). These three terms, mainly elicited by LR experts, are in accordance with their description and their conceptualisation of peppery wines that are more likely to be found in powerful, concentrated and full-bodied red wines.

The wine described by the experts was produced during particular seasons (i.e., 2017, 2018, 2019 or 2020), which were generally warm and dry, with some significant differences between the four studied subgroups. Surprisingly, the 2021 vintage, which was the coolest and rainiest season since 2013 in both regions, showed only small increases in rotundone concentrations. This contrasts with the concept that the conditions of this particular vintage are favourable for the production of high-rotundone wines.

Rotundone is known to be relatively chemically stable over time, while other aroma compounds produced during the alcoholic fermentation, such as acetates, ethyl esters or polyfunctional thiols, are generally hydrolysed or oxidised during maturation and storage (Herderich *et al.*, 2012; Robinson *et al.*, 2014). It can be hypothesised that the peppery character of wines made in 2021 was masked through perception–interaction mechanisms involving fermentative aromas (McKay *et al.*, 2020) and might not fully reveal their peppery potential at the time of the study that took place less than six months after the harvest.

Terms related to the subcategory *Soil/Terroir* were also frequently elicited by experts without observing significant differences in frequency of occurrence between the subgroups. Indeed, several studies have shown that rotundone content in grapes could be impacted by topography, soil resistivity or microbiome (Gupta *et al.*, 2019; Scarlett *et al.*, 2014).

Technical aspects provided by the experts on the wine described also included terms related to the category *VINIFICATION*, including specific terms such as *Barrel ageing* or *Traditional vinification*. The term *Barrel ageing* may well serve as an example that illustrates the confusion that can exist between the spicy aroma provided by the ageing in oak containers and peppery notes attributed to rotundone. The fact that *Traditional vinification* was cited is particularly interesting as such winemaking practice, notably an 8-day maceration at 25 °C, was identified in previous research as the most effective oenological approach to maximise rotundone in wine (Geffroy *et al.*, 2017).

4. Conditions favourable to produce peppery wines

Among the categories (and subcategories) already expressed by the participants for the *technical* question and previously discussed, some are also associated with *favourable conditions* questions such as those related to the *VARIETY*, *SOIL/TERROIR*, *MATURITY*, *VINTAGE*, *VINIFICATION*, *APPELLATION/REGION* or *AGEING* (Table 4).

Additional subcategory for *VARIETY* includes *Carignan*, in which rotundone has never been quantified to our knowledge, and *weak maturity* for *MATURITY*. Although not significantly ($P = 0.056$), the subcategory *weak maturity* was in trend more frequently used by experts from the NRV, which indicates that their conceptualisation strongly differs from LR experts for whom the peppery wine previously described was made from grapes harvested with an *Extended maturity* (Table 3).

Other viticultural categories with a close meaning were also evoked, such as *VINEYARD ORIENTATION* or *VIGOR/EXPOSITION*, some characteristics that are likely to have a strong impact on mesoclimate or be impacted by the level of water constraint experienced by the wine and, therefore, influence rotundone accumulation (Geffroy *et al.*, 2019a; Geffroy *et al.*, 2014; Geffroy *et al.*, 2016). *MACERATION* and, particularly, *Advanced maceration* were cited as parameters that enhance rotundone concentration in wine. In a study conducted at a laboratory scale, the use of winemaking techniques or fermentation variables enhancing maceration (i.e., pectolytic enzyme, maceration temperature and length) did not enable the production of wine with an increased rotundone content. However, as other work highlighted that ethanol concentration of wine and the contact time between the skin and the fermenting must affect rotundone (Zhang *et al.*, 2017), it cannot be ruled out that promoting maceration might favour rotundone extraction under typical commercial winemaking conditions.

CLIMATE is a category that deserves further comments. While the total number of occurrences was higher for *Cool and wet conditions* in accordance with previous research (Caputi *et al.*, 2011), the term *Hot and dry conditions* was also quoted, notably by LR experts, in accordance with their conceptualisation of peppery notes previously discussed. Experts from the LR region proposed *Diurnal amplitude* as an environmental factor affecting the peppery character of red wines. Even if this hypothesis has never been investigated, the Cool Night Index, a thermal indicator of nighttime temperature conditions during maturation that might be correlated with the Diurnal amplitude, was identified before as the main driver of rotundone at an intra-block scale (Geffroy *et al.*, 2019c)

Among the 28 categories or subcategories that were cited by at least 10 % of participants in one of the two regions, only *CLIMATE*, *Syrah* and *Maturity* enable one to discriminate the subgroups. This might reflect the broad consensus between all participants or could be an artefact from differences in the different number of terms elicited between participants

TABLE 4. 'Favourable conditions' question: total number of occurrences, frequency of citation (expressed in %) of categories and subcategories for the four subgroups, and significance (*P*) calculated from chi-square test (ns: non-significant; **P* < 0.1; ***P* < 0.05; ****P* < 0.001). Different letters for a line mean significant differences by the Marascuilo test.

CATEGORY / Subcategory	Total number of occurrences	Northern Rhone Valley		Languedoc Roussillon		<i>P</i>
		Non-anosmic (n = 29)	Anosmic (n = 24)	Non-anosmic (n = 27)	Anosmic (n = 21)	
VARIETY	56	55 %	54 %	48 %	67 %	ns
Variety	40	48 %	54 %	30 %	24 %	ns
SOIL/TERROIR	36	28 %	54 %	26 %	38 %	ns
CLIMATE	33	17 % a	21 % ab	56 % b	38 % ab	**
MATURITY	26	24 %	17 %	26 %	38 %	ns
Terroir	24	17 %	38 %	19 %	24 %	ns
Cool and wet conditions	19	14 %	8 %	26 %	29 %	ns
Syrah	18	7 % a	8 % a	26 % b	33 % b	*
VINIFICATION	14	21 %	13 %	11 %	10 %	ns
AGEING	14	17 %	21 %	7 %	10 %	ns
Hot and dry conditions	13	10 %	4 %	19 %	19 %	ns
Weak maturity	12	21 %	13 %	7 %	5 %	ns
Soil	11	3 %	17 %	7 %	19 %	ns
MACERATION	11	10 %	0 %	15 %	19 %	ns
Barrel ageing	9	7 %	17 %	7 %	5 %	ns
VINEYARD ORIENTATION	8	7 %	13 %	4 %	10 %	ns
Vineyard orientation	8	7 %	13 %	4 %	10 %	ns
Advanced maceration	8	10 %	0 %	7 %	14 %	ns
VINTAGE	7	7 %	13 %	0 %	10 %	ns
Type of vinification	7	10 %	8 %	4 %	5 %	ns
Climate	6	10 %	8 %	4 %	0 %	ns
VIGOR/EXPOSITION	6	3 %	4 %	11 %	5 %	ns
Carignan	5	0 %	0 %	7 %	14 %	ns
Mourvèdre	5	0 %	0 %	7 %	14 %	ns
APPELLATION/REGION	5	0 %	0 %	11 %	10 %	ns
Vintage	5	0 %	13 %	0 %	10 %	ns
Diurnal amplitude	5	0 %	0 %	11 %	10 %	ns
Maturity	5	3 % ab	0 % a	0 % a	19 % b	**

from the two regions rather than a real difference in conceptualisation.

5. Liking of peppery wines and rotundone knowledge

Peppery wines were positively perceived by 66 and 81 % of the panellists from the NRV and LR regions, respectively, with no significant difference between participants from the two regions (*P* = 0.085). This observation is consistent

with previous work showing that, in most cases, rotundone is neutrally or positively perceived at tasting (Geffroy *et al.*, 2018). However, a significantly higher proportion of experts from the NRV (*P* < 0.01), 32 % versus 6 % for LR, qualified their liking by specifying it was positive at a moderate level of concentration. This information suggests that this character can be excessive in Syrah wines from this region, potentially overpowering other aromas and/or reducing perceived wine complexity. Indeed, rotundone was identified

as a very potent impact aroma compound that has the ability to break the aroma buffer caused by ethanol and other major volatiles (Ferreira, 2012).

A greater percentage of experts from the NRV (24 %) than from LR (4 %) declared that they disliked peppery wines ($P < 0.01$). Even if the reason for this negative feeling remains unclear, this could be a consequence of the *Lack of maturity* perceived for such wines and previously expressed.

In accordance with one of our initial hypotheses, it can be assumed that being a marker of cool and wet vintage, peppery wines and rotundone are occasionally related to maturity difficulties in the NRV and, therefore, to wines with other quality deficiencies, even if this characteristic was not elicited for the *description* question.

While no difference was noticed between the two regions for the rotundone knowledge, a higher proportion of DNO-holders (92 % for LR, 86 % for the NRV) in comparison with experts that did not hold this diploma (13 % for LR, 20 % for the NRV) had already heard about rotundone ($P < 0.001$). This finding tends to validate the choice of the DNO diploma as a good indicator of wine expertise, notably in the field of wine aroma. As the proportion of DNO-holders is greater in LR, it cannot be excluded that this theoretical knowledge, such as the predominance of peppery notes in cool and wet wine regions (Caputi *et al.*, 2011) may have biases, especially for the *favourable conditions* question by gaining the upper hand over empirical knowledge.

CONCLUSION

Our work enabled us to study the conceptualisation of peppery wines by Syrah experts from the Northern Rhone Valley and Languedoc-Roussillon. While only minor differences were observed between participants with different sensitivity to rotundone, this conceptualisation still greatly varied between the two regions. It was less clear for experts from the Rhone Valley, who consider this characteristic to be a marker of wines made from grapes harvested with a low level of maturity. In most cases, it was positively perceived, notably at a moderate level. For participants from Languedoc-Roussillon, peppery associations were related to powerful, full-bodied wine produced from very ripe grapes in the South of France under hot and dry climatic conditions. These notes were positively perceived by experts without restriction. The fact of holding the French National Diploma of Oenologist (DNO) was identified as a good proxy of the level of expertise, with such participants generating significantly more terms for the *description* and *technical* questions, having heard more about rotundone which reflects overall a better knowledge of wine aroma.

ACKNOWLEDGEMENTS

We are grateful to the experts from the two regions who participated in the study. We also would like to thank Christophe Gerland (Intellioeno), Jean-Philippe Granier (Maison des Vins du Languedoc), Tatiana Paricaud

(Laboratoires Dubernet), Agathe Bernard, Léonie Robin, Nicolas Tracol and Christophe Santos (Ecole de Sommelier de Tain-l'Hermitage), for their help in performing the interviews in both regions. The AWRI is supported by Australian grapegrowers and winemakers through their investment body Wine Australia, with matching funds from the Australian Government. The AWRI and the University of Adelaide are members of the Wine Innovation Cluster (WIC) in Adelaide.

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