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Muscat is not dead: A sensory study of young adults' olfactory appreciation revealed a marked preference for terpenic dry white wines made from this underrated variety

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ABSTRACT

In a context of declining wine consumption and ageing of wine consumers, white wines may represent an attractive product for engaging and recruiting younger consumers. This study aimed to assess the olfactory preferences of 134 young consumers for four white wines with distinct profiles (*thiolic*, *terpenic*, *fermentative*, and *woody*) and to identify the consumption contexts related to each wine, thanks to a CATA (Check-All-That-Apply) questionnaire positioned before the liking question. The results showed a clear preference among young adults for the *terpenic* profile of Muscat wine, despite the variety's generally undervalued image and commercial challenges. This profile, associated with consumption during summer, at aperitif time and in the company of a partner, was significantly rated higher than *fermentative*, itself rated higher than *thiolic*, with *woody* receiving the lowest score. Surprisingly, the term *Muscat* was little elicited as a preferred appellation/indication for white wine by panellists who more frequently declared appreciating white wines made from Chardonnay or other cultivars rich in varietal thiols. These findings open a new field of research to understand the perception of the term *Muscat* by young consumers and provide valuable insights for adapting white wine profiles to younger consumers.

KEYWORDS: thiolic, fermentative, woody, Chardonnay, Colombard, aroma preference

INTRODUCTION

The global wine industry is undergoing a significant crisis, driven by a combination of factors. In addition to the slow recovery of the wine trade following the COVID-19 pandemic and changes over the past decade in China's regulations on gifting and public expenditures, the 2022 invasion of Ukraine triggered a major energy crisis in Europe alongside soaring inflation and declining household incomes, all of which have contributed to reduced wine demand (Del Rey & Loose, 2023). This downturn leading to a surplus is especially pronounced for red wines in traditional wine-producing countries such as France, Italy, and Spain, where *per capita* wine consumption has been steadily declining for decades (Villanueva & Ferro, 2022). The trend is even more evident among younger generations, many of whom are cutting back or abstaining entirely from alcohol (Caluzzi *et al.*, 2021) or shifting toward beer or spirits to the detriment of traditional wine consumption (Inserm, 2022). According to a survey conducted by Wine Intelligence (2022), 47 % of French wine consumers were aged 55 and over in 2022, and white wines may play a recruitment role among young adults, especially outside of mealtimes at "aperitif time" due to their approachable taste profile, freshness, and lower complexity.

White wines can exhibit a wide range of olfactory profiles. While Muscat-like varieties (*i.e.*, Muscat à petits grains blancs) can give wines with intense floral aroma due to high concentrations of terpenes, notably in monoterpenols (Cordonnier & Bayonove, 1974), wines made from varieties with high content in precursors of varietal thiols (*i.e.*, Sauvignon or Colombard) frequently express grapefruit, tropical, cat urine, or box hedge notes (Roland *et al.*, 2011; Tominaga *et al.*, 1998). In the context of climate change, which takes in most cases the form of higher temperature during maturation, white wines with green aroma related to 3-isobutyl-2-methoxypyrazine (IBMP) are becoming extremely rare (Cordonnier & Bayonove, 1974; Geffroy *et al.*, 2020; Pons *et al.*, 2017).

Neutral grapes can be used to make wines with high concentrations of fermentative compounds (*i.e.*, fatty acids, ethyl esters or acetates), imparting banana, ester, or candy aromas if the conditions of fermentation, notably the turbidity and nitrogen content of the must, the temperature, and the yeast strain are appropriate (Bell & Henschke, 2005; Robinson *et al.*, 2014).

Although the use of barrels, primarily made from oak (*Quercus alba*, *Quercus robur*, and *Quercus petraea*), for fermentation or ageing was largely abandoned during the 20th century, some white wines are still produced using these traditional vessels or alternatives such as oak chips (Jordão & Ricardo-da-Silva, 2021). Depending on the botanical type, the origin of the wood, and the heating parameters, such wines can develop an aroma of vanilla, coconut, toasted bread, or torrefaction (Yoncheva *et al.*, 2024). According to the same author, the use of oak chips is particularly advantageous for imparting subtle woody notes while preserving freshness and fruitiness, which can otherwise be diminished by oxidation during barrel ageing.

While fruitiness is generally considered a highly desirable aroma quality in wines and oakiness a more divisive characteristic, either positive at a moderate level or negative when it is very pronounced (Francis & Williamson, 2015; Lesschaeve *et al.*, 2012), a limited number of sensory studies have been investigating the appreciation by consumers of white wines showing distinct profiles.

Though the study by Bazala *et al.* (2015) focused only on sweetness, sourness, and aroma intensity, most of the works on olfactory profiles were conducted in Australia and New Zealand on Sauvignon wines. For instance, King *et al.* (2011) were able to identify distinct consumer segments: the largest group preferred wines with green characteristics; another group associated tropical and candy aromas with higher liking, while a third segment, in contrast, viewed tropical notes and cat urine aromas as negative attributes. In another study examining consumer responses to various Sauvignon wines produced using multiple yeast co-inoculations, the wine most preferred by the majority of consumers was characterised by pronounced box hedge aromas, whereas the least liked wine displayed prominent ester and floral notes (King *et al.*, 2010). In the same way, another research conducted with consumers from New Zealand showed that the distinctive aroma of local Sauvignon wines that are characterised by very high concentration of IBMP and varietal thiols was particularly enjoyed (Lund *et al.*, 2009).

As for the French market, no research has been conducted to our knowledge up to now to study the sensory appreciation of white wines. Although varietal thiols are generally regarded in the wine industry as important contributors to consumer preference, white wines characterised by *terpenic* profiles, particularly those produced from Muscat, are undervalued and face difficulties in selling. This can be illustrated by bulk market prices, with organic dry Muscat white wines produced under the Protected Geographical Indication (PGI) Pays d'Oc in the Occitanie region of southern France showing, in 2024, the lowest transaction price behind the other varietal wines produced in the area (*e.g.*, Rolle, Colombard, Grenache blanc, Viognier, Sauvignon, and Chardonnay) (www.paysdoc-wines.com).

The objective of this study was to evaluate young consumers' appreciation of fruity white wines exhibiting different olfactory profiles (namely *thiolic*, *terpenic*, and *fermentative*). A *woody* profile wine was also included, in opposition to fruity profiles, to test the hypothesis that fruity wines are generally preferred, while green-profile wines were excluded due to sourcing difficulties, as previously explained. To provide winemakers and marketers with insights into consumption contexts associated with each aroma profile, a CATA (Check-All-That-Apply) questionnaire was administered prior to the liking assessment following the approach proposed by Geffroy *et al.* (2024a).

MATERIALS AND METHODS

1. Wines

The wine selection was carried out in two stages. First, 10 white wines produced in Occitanie (south of France) from the 2024 vintage were chosen by the head winemakers of two cooperative wineries from among the numerous wines available in the tanks of their cellars, based on their diversity of sensory profiles. Selecting wines from tanks prior to blending allows for the identification of more pronounced sensory characteristics. Secondly, four wines were selected among the 10 available during a tasting session conducted with three experts, each wine chosen for exhibiting distinct olfactory profiles (*thiolic*, *terpenic*, *fermentative*, and *woody*). The *thiolic* wine made of pure Colombard was provided by Plaimont Producteurs, a cooperative cellar located in the Gascony region (199, route de Corneillan, Saint-Mont, France). The vineyard used to produce this wine was sprayed with foliar nitrogen at veraison, a practice that has been proven to enhance the varietal thiol concentration of the finished wine (Geffroy *et al.*, 2016). The must was fermented at 18 °C with the yeast strain Selectys® Thiols (Oenofrance, Magenta, France). At tasting, the wine was noted for its pale colour and highly expressive character, featuring intense aromas of grapefruit and tropical fruits. It displayed low viscosity and a pronounced acidity on the palate.

The three other wines were sourced from Dom Brial, a cooperative winery located in the Roussillon region (14, avenue du Maréchal-Joffre, Baixas, France). The *terpenic* wine, made exclusively from Muscat à petits grains, was fermented at 18 °C using the Zymaflore® VL3 yeast strain (Laffort, Floirac, France). It presented intense floral aromas, moderate viscosity, and acidity, along with a slight bitterness.

The *fermentative* and *woody* wines, both produced from Chardonnay, were fermented at 14 °C with Zymaflore® X16 yeast (Laffort, Floirac, France), incorporating medium-toasted oak chips at a dosage of 2 g/L for the *woody* wine. The *fermentative* wine was described as expressive, with intense banana and candy aromas, and a well-balanced palate. The *woody* wine exhibited dominant and intense notes of vanilla and toasted aroma, along with high viscosity and a noticeable sweetness in the mouth.

The four wines were sampled directly from the tanks in October 2024, after alcoholic fermentation and the addition of sulphur dioxide at 50 mg/L. They were not stabilised but were stored at 4 °C in 10 L bag-in-box containers until the sensory analysis was conducted in April 2025, allowing sufficient time to achieve a good degree of limpidity.

Classical oenological analyses were conducted on wines using the Winescan FT-120 technique (Foss France SAS, Nanterre, France). The results are available in Table 1.

2. Procedure for data acquisition

A convenience panel composed of 134 French young consumers with a mean age of 20.7 ± 1.0 years who have been drinking wine for 4.5 ± 2.7 years, currently at least once a month, was recruited from the École d'ingénieurs de Purpan in Toulouse, France. No ethics approval was obtained, but all participants were asked to provide written informed consent prior to participating in the study. The detailed composition of the panel is shown in Table 2. The participants were just informed they were about to evaluate samples of dry white wines.

The session took place in a neutral room, and the spacing between the panellists ensured that no communication could occur. The samples were coded with a three-digit code and served using a Williams' Latin square design. A constant volume of 40 mL was poured at 12 °C into black wine-tasting glasses. This methodological choice was made to focus solely on olfaction, as large differences in colour intensity (as reflected by DO_{420} shown in Table 1), particularly between the *thiolic* and *woody* wines, were likely to influence consumer description and preferences (Morrot *et al.*, 2001). Similarly, due to notable variations in taste and mouthfeel among the four wines as highlighted during the initial tasting session, panellists were instructed to smell the samples only, without tasting them.

Consumers were first asked to respond to a CATA questionnaire inspired by Silva *et al.* (2016) to indicate in which context(s) they would drink the tasted wine. Eight options were selected by a panel of 10 students from the 29 categories proposed by these authors during preliminary research performed a few days before the formal assessment: with family, during the meal, at aperitif time, during winter, during summer, with a partner, with friends, or during parties. The selection was made based on the most frequently cited option associated with a relevant context for white wine consumption.

TABLE 1. Classical oenological analyses conducted on the four white wines used in the study. The uncertainty of measurement is expressed as a 95 % confidence interval.

Olfactory profile	Alcohol content (% *v/v*)	Titratable acidity (g/L tartaric acid)	pH	Malic acid (g/L)	Volatile acidity (g/L acetic acid)	Glucose + fructose (g/L)	DO_{420}	DO_{280}
Thiolic	10.6 ± 0.1	6.2 ± 0.1	3.29 ± 0.05	2.60 ± 0.3	0.21 ± 0.05	0.2 ± 0.5	0.10 ± 0.01	1.17 ± 0.02
Terpenic	11.9 ± 0.1	6.0 ± 0.1	3.35 ± 0.05	1.77 ± 0.3	0.26 ± 0.05	0.1 ± 0.5	0.14 ± 0.01	8.01 ± 0.02
Fermentative	13.0 ± 0.1	5.5 ± 0.1	3.36 ± 0.05	0.47 ± 0.3	0.40 ± 0.05	0.1 ± 0.5	0.13 ± 0.01	5.43 ± 0.02
Woody	11.6 ± 0.1	6.1 ± 0.1	3.56 ± 0.05	2.82 ± 0.3	0.30 ± 0.05	0.1 ± 0.5	0.19 ± 0.01	7.03 ± 0.02

TABLE 2. Proportion in % of consumers in the panel by gender, wine knowledge, frequency of wine consumption, average amount spent per bottle, and preferred wine style (*n* = 134).

Category		Proportion (%)
Gender	Male (*n* = 67)	50
	Female (*n* = 66)	49
	Prefer not to say (*n* = 1)	1
Wine knowledge	No knowledge (*n* = 41)	31
	Interested, basic knowledge (*n* = 83)	62
	Passionate (*n* = 10)	7
Frequency of wine consumption	Every day (*n* = 1)	1
	Three–four times a week (*n* = 20)	15
	Once a week (*n* = 57)	42
	Twice a month (*n* = 37)	28
	Once a month (*n* = 19)	14
Average amount spent per bottle	Less than 3 euros (*n* = 7)	5
	Between 3 and 5 euros (*n* = 23)	17
	Between 5 and 10 euros (*n* = 77)	58
	More than 10 euros (*n* = 27)	20
Preferred wine style	Dry white (*n* = 25)	19
	Sweet white (*n* = 41)	31
	Sparkling white (*n* = 11)	8
	Rosé (*n* = 4)	3
	Red (*n* = 53)	39

As proposed by Ares & Jaeger (2023), the position of each answer was randomised across panellists. Then, panellists had to indicate their overall liking on a 9-point hedonic scale from 1, *I extremely dislike*, to 9, *I extremely like*. This order, CATA then liking, was already validated in a previous study (Geffroy *et al.*, 2024a).

After the session, they had to provide demographic information and respond to questions regarding their wine knowledge and consumption behaviours for wine. At the end of the questionnaire, the panellists were asked to name one or more white wine appellations/indications that they particularly enjoy.

Both questionnaires are shown in supplementary data S1 and S2.

3. Data treatment

For the CATA question, the frequencies of occurrence for each wine were treated through a Chi-square test and correspondence analysis (CA), while the liking score was analysed through a two-way ANOVA (panellists × wine). Fisher's least significant difference test was used as a post-hoc comparison of means at $P < 0.05$. All statistical treatments were conducted using XLSTAT version 2022.4.1 (Addinsoft, Paris, France).

RESULTS AND DISCUSSION

Liking scores for the olfactory assessment of the four studied wines highlighted a clear, significant ranking of preferences at $P < 0.001$ (Figure 1). Tentative two-way ANOVA models to integrate other qualitative variables, such as gender or consumption habits, yielded no significant effects ($P > 0.05$), indicating that this ordering is valid for the whole population that appears homogenous.

The *woody* wine, for which the oak and particularly vanilla aromas were marked, received the lowest score in comparison with the fruity wines (*thiolic*, *terpenic*, and *fermentative*), in agreement with previous research (Francis & Williamson, 2015; Lesschaeve *et al.*, 2012). As for the context, such an olfactory profile was related to formal consumption during the meals and during winter (Figure 2, Table 3). These results were not surprising, as they reflect

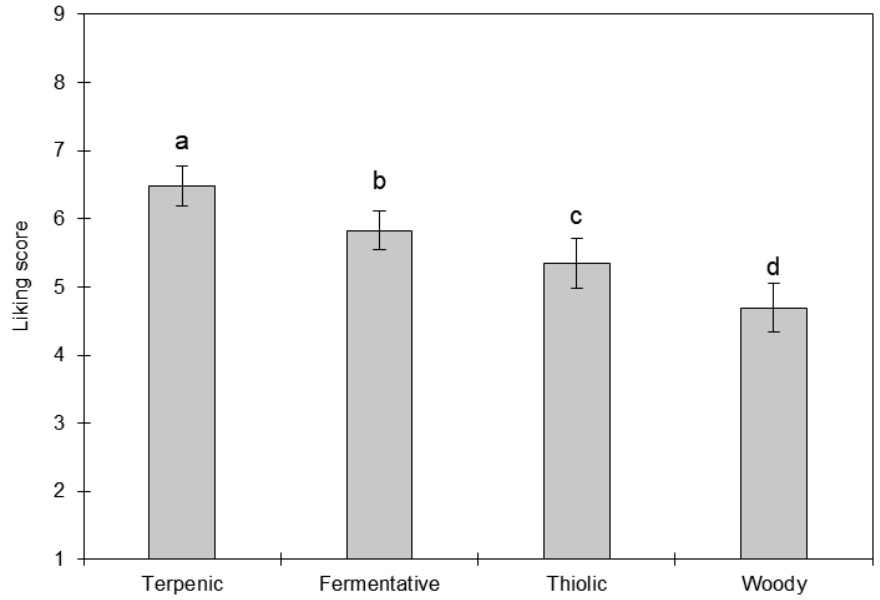


FIGURE 1. Impact of the wine olfactory profile on the liking score (mean values ± 95 % confidence interval). Different letters indicate means significantly different at $P < 0.05$ by Fisher's test.

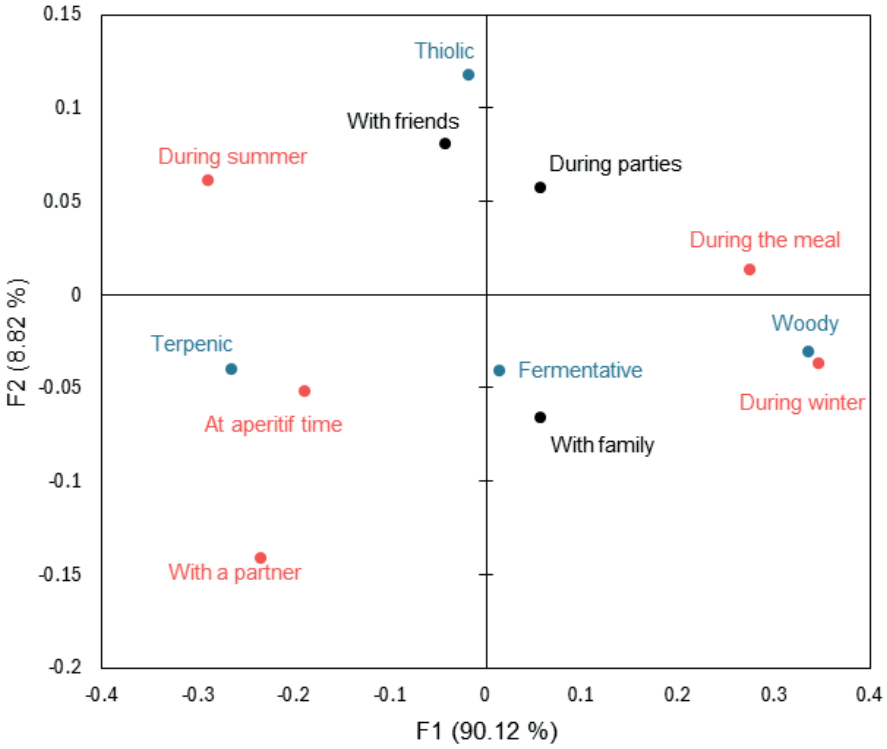


FIGURE 2. Correspondence analysis space projection on Factors 1–2 of the four studied wines and consumption contexts associated with each olfactory profile. Contexts highlighted in red enable the discrimination of the wines according to the Chi-square test.

the typical recommendations of sommeliers, who suggest drinking full-bodied, creamy, barrel-aged Chardonnay wines during the winter season (Larson, 2025). They are also consistent with a recent online survey of 3,000 regular wine consumers from Australia, the United Kingdom, and the USA, which showed that chocolate and other related aromas, such as vanilla, were clearly preferred in winter (Ristic *et al.*, 2019).

In our study, the *terpenic* wine obtained the highest score, followed by the *fermentative* profile, which was itself followed by the *thiolic* one. This finding is somewhat in contradiction with previous research conducted in Australia that examined the appreciation of several Sauvignon wines fermented with distinct mixtures of yeasts (King *et al.*, 2010). Interestingly, in this previous study, most consumers did not prefer the white wine that had the

TABLE 3. Citation frequencies (expressed in %) for the best contexts selected by consumers to drink the four studied wines, and significance *(P)* calculated from the Chi-square test within each option. Different letters within each column indicate significant differences based on the post-hoc Marascuilo test ($P < 0.05$).

	With family	At aperitif time	During summer	With friends	During the meal	During winter	With a partner	During parties
Thiolic	11.1 a	12.9 a	15.6 bc	17.8 a	15.1 b	9.2 ab	5.7 ab	12.7 a
Terpenic	12.2 a	17.9 b	18.6 c	15.2 a	10.1 a	6.0 a	9.9 c	10.1 a
Fermentative	13.1 a	13.9 ab	12.4 b	15.5 a	14.7 b	10.6 b	8.2 bc	11.6 a
Woody	14.1 a	10.3 a	7.5 a	13.5 a	21.8 c	15.8 c	4.9 a	12.1 a
P	0.642	< 0.05	< 0.001	0.461	< 0.001	< 0.001	< 0.05	0.700

highest ester and floral aroma, and favoured the *thiolic* wines (King *et al.*, 2010). In comparison with our research, it should be noted that panellists in this previous work may have been more accustomed to wines with strong *thiolic* characteristics, as it has been proven that New Zealand wines contained greater concentrations of varietal thiols than French wines (Lund *et al.*, 2009). This divergence in results could therefore be attributable to differences in familiarity, a key factor impacting wine appreciation (Saliba *et al.*, 2009). Conversely, these results highlighting the superiority of the *terpenic* profile are consistent with observations frequently made by the authors of the present study. As part of a pedagogic blending activity conducted with students each year, aiming at creating a white wine blend from 10 single-varietal base wines sourced from different regions of southern France, Muscat is among the varieties most often selected by the students (Geffroy *et al.*, 2024b). This recurrent choice suggests a marked positive appreciation for its sensory profile of young consumers. In the same way, in a study aiming at developing a sensory method for describing wine using young adult participants from southwest France (Beaulieu *et al.*, 2022), it was observed that a dry white wine, produced from a hybrid variety with Muscat in its lineage and characterised by an intense floral aroma, received the highest hedonic rating, suggesting strong acceptability of *terpenic* white wine among this consumer group.

A total of 84 different white wine designations or appellations were mentioned by young consumers, with an average of 1.5 ± 1.0 terms cited per participant and 116 participants citing at least one term. This diversity resulted in overall low citation frequencies. Among the white wine designations or appellations most frequently cited as preferred by young consumers (*i.e.*, with citation frequencies above 5 %), *Muscat* ranked last, tied with *Côtes-de-Gascogne*—a Protected Geographical Indication (PGI) from southwestern France known for wines produced primarily from Colombard—and *Tariquet* (5.2 %), a winery located within the Côtes-de-Gascogne PGI. These were preceded by *Chablis* (6.7 %), *Sauternes* (9.0 %), *Jurançon* (10.4 %)—a Protected Designation of Origin (PDO) from southwestern France producing sweet white wines mainly from Gros Manseng and Petit Manseng—*Sauvignon* (11.9 %), and *Chardonnay* (13.4 %). This ranking underscores the greater recognition of white wines made from Chardonnay or Sauvignon, a cultivar rich in varietal thiols, as well as sweet white wines, which is consistent with the self-reported preferred wine style, with this category accounting for 31 % of responses (Table 2). The low recognition of the Muscat variety among young adults may stem from its association with PDO sweet, fortified wines produced in the south of France (*e.g.*, Muscat de Rivesaltes, Muscat de Frontignan), which are often perceived as old-fashioned and less popular, typically consumed as aperitifs by older generations (Geffroy, unpublished). Interestingly, this aperitif context, together with consumption during summer or with a partner, was also related to Muscat wine (Figure 2). This finding is not trivial for the wine industry, as nowadays most of the wines are consumed outside of regular mealtimes, typically as an aperitif (Wine Intelligence, 2022). As for the other olfactory profiles (*i.e.*, *fermentative* and *thiolic*), no clear context of consumption emerged (Table 3).

It can be pointed out that our study was olfactory-based, and the only information provided to the panellists was limited to the fact that they were smelling samples of dry white wines. To investigate the perception of the term *Muscat*, qualitative research under the form of focus group or face-to-face interview, and experimental auctions, which are controlled market simulations used to elicit consumers' willingness to pay for products under realistic conditions rather than relying solely on stated intentions (Lusk & Shogren, 2007), could be very valuable. However, young adults generally tend to focus more on factors such as awards received, label design, and alcohol content instead of emphasising the region of origin or grape variety when assessing wine quality (Atkin & Thach, 2012).

It is also important to note that the panel in this study was a convenience sample of French agricultural science students who shared similar social and cultural backgrounds, demonstrated a marked interest in wine (Table 2), and had been consuming wine for several years (4.5 ± 2.7 years). Consequently, they had moved beyond the initial recruitment stage, with 39 % reporting a preference for red wine (Table 2), a product generally associated with more experienced consumers (Wine Intelligence, 2022). Therefore, the results might have differed if the study had included French consumers with more varied and heterogeneous characteristics and incorporated more newbies in wine.

It must be borne in mind that the study was limited to an exclusively olfactory evaluation of four wines with distinct and stereotypical profiles. While these wines may be relatively easy to reproduce from an olfactory perspective, they might not be commonly found on the market and might be primarily used for blending purposes. Neither the visual aspect, specifically colour, nor the sensory perceptions in the mouth (*e.g.*, viscosity, sweetness, sourness, balance) were assessed, even though these attributes play a central role in the overall appreciation and quality perception of wine (Francis & Williamson, 2015). However, it should be noted that winemakers and oenologists have access to a range of practices to modulate these sensory characteristics, notably by adjusting the harvest date (Rouxinol *et al.*, 2023).

CONCLUSION

This study demonstrated a clear preference among young adults for the *terpenic* olfactory profile of Muscat white wine. Participants expressed willingness to consume this wine, particularly during summer, as an aperitif, and in the company of a partner. The *terpenic* profile was followed in preference by the *fermentative*, itself rated higher than the *thiolic*, and *woody* profiles, the latter receiving the lowest liking scores.

The superiority of the *terpenic* profile is a notable finding, considering that wines from the Muscat variety are generally underrated, face commercial challenges, and that the term *Muscat* was rarely mentioned by panellists as their preferred white wine appellation/indication. This discrepancy may be explained by the product's outdated image, often associated with fortified, sweet wines produced from this grape variety.

Although further research is needed to better understand young consumers' perceptions of Muscat wines, for example, overall tastings (appearance, nose, palate) would be interesting. Nevertheless, our results offer valuable insights for winemakers and marketers to develop their white wine range and to adapt products to young consumers' profiles.

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