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Study of the fruity aroma of red wines made from late-ripening grape varieties potentially suited to the Bordeaux vineyards in a context of climate change

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In recent years, changes in the fruity expression of Bordeaux red wines, such as the appearance of cooked and dried fruit notes, have been reported and correlated with climate change. Among the solutions proposed to preserve their aromatic quality, one strategy is to introduce late-ripening grape varieties adapted to future climatic conditions into Bordeaux vineyards. This study offers a better understanding of the fruity aroma of red wines made from Bordeaux grape varieties, as well as Mediterranean grape varieties.

Context

In 2010, researchers revealed the existence of a fruity sensory space specific to Bordeaux red wines, characterized by notes of jammy black-berry fruits[1]. However, in recent years, climatic variations have affected the vegetative cycle of vines, shifting harvests to earlier dates and warmer conditions, which influences the composition of wines[2]. As a result, the fresh fruit notes, particularly in Merlot-based wines, are diminishing, while the aromas of dried and cooked fruit are more pronounced[3]. Merlot, which accounts for 66 % of the red grape varieties planted in Bordeaux (CIVB, 2025), therefore requires adjustments on the part of producers[4].

To address this issue, several measures have already been implemented: vine training, soil and water management, choice of rootstocks, choice of harvest date, and targeted winemaking practices[4 5]. Among the various adaptations, vine management plays a central role: modulating leaf area, raising the bunches, orienting the rows, and managing shade help regulate the temperature and solar radiation received by the berries, thus limiting the risk of sunburn and excessive ripening[4]. Controlling planting density and vine vigor also helps reduce water consumption and maintain a microclimate favorable to grape development[4]. The degree of ripeness of the grapes at harvest time strongly influences the aromatic compounds in the berries and, consequently, the aromas of the wine. Harvesting earlier would limit cooked fruit aromas and preserve fresh aromas[4]. The choice of suitable rootstocks and clones complements these levers by promoting resistance to drought and high temperatures and shifting ripening to more favorable periods[4]. The choice of plant material is therefore a key lever for adapting to climate change, and the thousands of existing varieties of *Vitis vinifera* differ greatly in their phenological cycle. It is with this adaptation in mind that the Bordeaux region is introducing grape varieties that ripen later than Merlot. Selected for their vegetative cycle, which is potentially better suited to future climatic conditions, these grape varieties aim to preserve the identity of Bordeaux wines. This initiative was launched by the association of winegrowers of the Bordeaux and Bordeaux Supérieur AOCs (Appellation d'Origine Contrôlée), with authorization granted by the INAO (Institut National de l'Origine et de la Qualité). As a result, four new red grape varieties—Arinarnoa, Castet, Marselan, and the Portuguese variety Touriga Nacional—are now authorized in these appellations. These varieties may be planted up to 5% in Bordeaux vineyards and blended up to 10% (INAO, 2021). However, their integration requires an in-depth assessment of their contribution to regional typicity and, in particular, to maintaining the fruity expression of red wines. By adapting the grape varieties, it would then be potentially possible to modulate the chemical and sensory compositions of the wines.

The aim of this work is to provide knowledge about the aromatic compounds that contribute to the qualitative fruity expression of red wines and to better understand the role of odor compounds that can help preserve the fruity aroma of Bordeaux red wines.

A fruity expression shared by Bordeaux and Mediterranean red wines

Fourteen single-varietal red wines were analyzed: five from Bordeaux (Merlot, Cabernet Sauvignon, Cabernet Franc, Petit Verdot, Carmenère) and nine from late-ripening Mediterranean grape varieties (Agiorgitiko and Xinomavro from Greece, Grenache and Tempranillo from Spain, Yiannoudin and Mavro from Cyprus, Nebbiolo from Italy, Syrah from the South of France, Touriga Nacional from Portugal), grown in hot climates to simula 's future climatic conditions. The 14 wines (2018 vintage) were chosen for their aromatic typicity and were evaluated in 2022 by a panel of experts to analyze their typical aromas after approximately three years of aging (a period during which the amylic and banana notes of young wines diminish and the fruity nuances typical of red wines, such as red- and black-berry fruits, are already developed). This sensory evaluation was carried out exclusively by the orthonasal route, using a descriptor generation methodology. A total of seven descriptors were identified: fresh red-berry fruit, fresh black-berry fruit, jammy red-berry fruit, jammy black-berry fruit, cooked fruit, freshness, and vegetal aroma.

Analysis of the data generated by the experts (AFC, Figure 1) made it possible to differentiate the wines according to "qualitative descriptors" (fresh red-berry fruit, fresh black-berry fruit, jammy red-berry fruit, jammy black-berry fruit, freshness) and "non-qualitative descriptors"

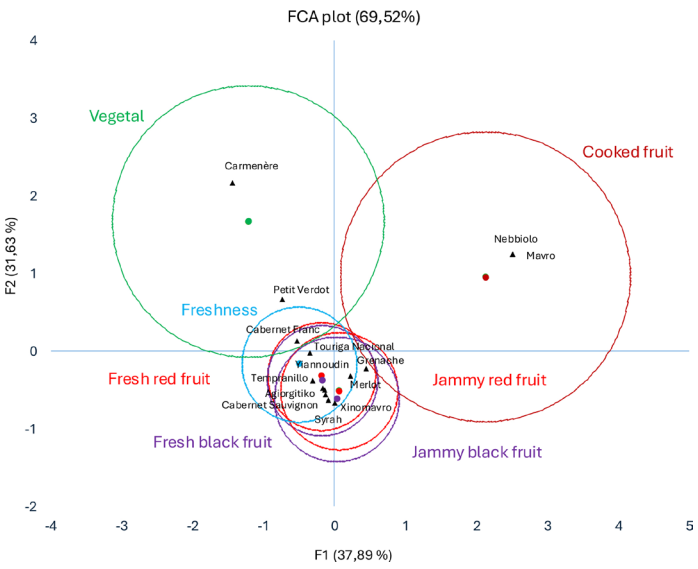


FIGURE 1. Factorial Correspondence Analysis (FCA) of the 14 red wines, based on the citation frequencies of the panel's seven descriptors.

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(vegetal aroma and cooked fruit). Wines made from Carmenère and Petit Verdot grapes were associated with vegetal notes, while those made from Nebbiolo and Mavro were characterized by cooked fruit aromas. Three Bordeaux wines and seven Mediterranean wines had common sensory profiles, described by "qualitative descriptors." These results highlight that the Bordeaux red wines selected in this study share fruity sensory similarities with red wines made from later-ripening grape varieties than Merlot, grown in warmer wine regions.

Differences in the aromatic composition of wines

Several volatile compounds associated with fruity notes were quantified in red wines: esters, monoterpenic compounds, C13-norisoprenoids, and C6-alcohols[6]. Figure 2 shows variations in concentrations for each family of these volatile compounds in red wines. The total concentration of esters is highest in Tempranillo and lowest in Carmenère. For monoterpenic compounds, the total concentration is highest in Xinomavro and lowest in Mavro. For C13-norisoprenoids, Grenache has the highest total concentration. Finally, the total concentration of C6-alcohols is highest in Yiannoudin and lowest in Cabernet Franc.

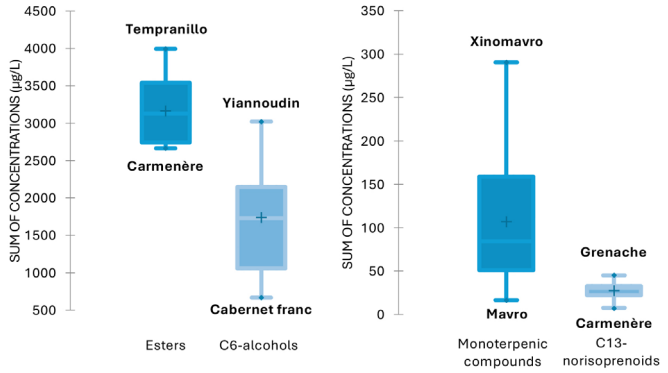


FIGURE 2. Total concentration of each chemical family in wines.

On the one hand, these data highlight that four red wines made from Mediterranean grape varieties (Tempranillo, Yiannoudin, Xinomavro, and Grenache) and described by "qualitative descriptors" had the highest total concentration of esters, C6-alcohols, monoterpenic compounds, and C13-norisoprenoids. These compounds may therefore play a positive role in the expression of fruity aroma. On the other hand, wines described by "non-qualitative descriptors" had the lowest total concentration of esters and C13-norisoprenoids (Carmenère), as well as monoterpenic compounds (Mavro).

Olfactory impact of compounds of interest on the perception of fruity aroma

The focus was on the impact of monoterpenic compounds, C13-norisoprenoids, and C6-alcohols. To this end, a wine described as having notes of cooked fruit was selected and two glasses were prepared. One contained the red wine described as having notes of cooked fruit, while the other contained the same wine to which the compounds of interest had been added at concentrations measured in red wines described as having "positive descriptors." Sixteen judges evaluated the intensity of six descriptors (fresh red- and black-berry fruits, jammy red- and black-berry fruits, cooked fruits, and vegetal aroma) in the two samples using sensory profiles[7].

The results showed that the addition of certain monoterpenic compounds, C13-norisoprenoids, and C6-alcohols increased the fresh black-berry fruit notes and reduced the cooked fruit notes, highlighting their key role in the perception of the qualitative fruity aroma of red wines (Figure 3).

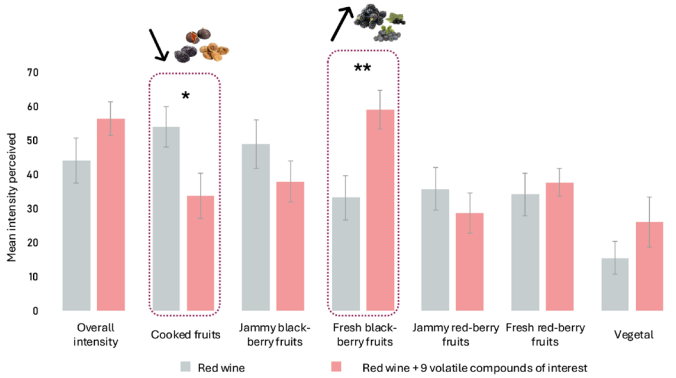


FIGURE 3. Average intensities of aroma descriptors (volatile compounds added: linalool, geraniol, 1,4-cineole, 1,8-cineole, α-terpinene, α-terpineol, α-ionone, β-ionone, and (E)-3-hexenol) *, $p < 0.05$ and **, $p < 0.01$, determined by ANOVA.

Conclusion and outlook

This work has revealed sensory similarities between the fruity aroma of single-varietal Bordeaux red wines and wines made from Mediterranean grape varieties, which ripen later than Merlot. The integration of these grape varieties into Bordeaux vineyards and blends thus offers a potential alternative to Merlot in order to preserve the typical characteristics of Bordeaux wines in the face of climate change. Future sensory tests could assess whether partially replacing Merlot with grape varieties from elsewhere, or with other Bordeaux grape varieties such as Cabernet-Sauvignon, Cabernet franc, Petit Verdot, or Carmenère, contributes positively to the aromatic and sensory typicity of Bordeaux wines. This work has also contributed to enriching our knowledge of the fruity expression of red wines, highlighting key volatile compounds such as certain monoterpenic compounds, C13-norisoprenoids, and C6-alcohols.

One of the prospects for our work would be to determine whether variations in the concentrations of the compounds studied are specific to grape varieties and can be used to differentiate between them. In addition, controlling these volatile compounds could help preserve the fruity aromatic quality of red wines, thus opening up prospects for developing oenological techniques that promote their controlled release. ■

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Sources: *Sourced from the research article: "Development of a New Method for the Quantitative Analysis of Aroma Compounds Potentially Related to the Fruity Aroma of Red Wines" (Journal of Agriculture and Food Chemistry, 2023).*

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