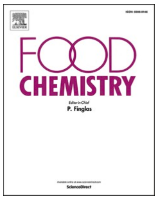
Food Chemistry 457 (2024) 140045

Contents lists available at ScienceDirect

Food Chemistry

journal homepage: www.elsevier.com/locate/foodchem



Organic mulches slightly influence the wine phenolic profile and sensory evaluation

Andreu Mairata, Alicia Pou, Juana Martínez, Miguel Puelles, David Labarga, Javier Portu [*]

Instituto de Ciencias de la Vid y del Vino (Gobierno de La Rioja, Universidad de La Rioja, CSIC), Finca La Grajera, Ctra. de Burgos Km, 6, 26007 Logroño, Spain

ARTICLE INFO

Keywords:
Grapevine
Mulching
Polyphenol
Flavonoid
Circular economy

ABSTRACT

Organic mulching offers numerous agronomical benefits, but its impact on wine quality remains unclear. This study assessed the effect of this practice on wine physicochemical, phenolic composition and sensory properties. Over four years, three organic mulches (grape pruning debris (GPD), straw (STR), and spent mushroom compost (SMC)) and two conventional practices (tillage (TILL) and herbicide (HERB)) were evaluated in two locations. Wines from mulching treatments exhibited higher pH, potassium, hue, and lower tartaric acid. Moreover, the SMC mulch treatment showed lower amounts of wine anthocyanins, flavonols and hydroxycinnamics, probably due to increased nutrient availability. However, no differences were detected in the wine sensory analysis. Therefore, organic mulches could be alternative practices to mitigate the consequences of climate change without significant impact on young wine's phenolic profile and sensory properties compared to HERB and TILL conventional soil management. However, future studies should focus on wine evolution during aging.

1. Introduction

Phenolic compounds are a diverse group of secondary metabolites that are divided into two distinct classes based on their structural characteristics: non-flavonoids (such as phenolic and stilbenes) and flavonoids (including anthocyanins, flavonols, and flavanols). These compounds are synthesised in plants as protection against damage from biotic and abiotic stresses or as signalling molecules. Polyphenols have been extensively studied for their potential health benefits. In this respect, grapes and wine, which are known for their high concentration of phenolic compounds, have been the subject of many studies. For example, many studies have demonstrated that moderate wine consumption exhibits antioxidant effects, which could mitigate the risk of several health issues, including neurodegenerative disorders, cancer, diabetes, and cardiovascular diseases (Artero et al., 2015). Moreover, these compounds play a key role in wine since they contribute to the overall sensory profile of wines and affect their quality by influencing characteristics such as color, taste, and mouthfeel properties (Flamini et al., 2013). Even, aroma compound release during wine tasting could be influenced by the phenolic compound composition, as reported by Pérez-Jiménez et al. (2020). Recently, Allegro et al. (2021) reviewed the role of these compounds in wine quality and sensorial properties. For example, anthocyanins are widely known to be the pigments responsible for red wine color, both by direct contribution or indirectly after reactions and interactions like copigmentation with other phenolic compounds, such as flavonols and hydroxycinnamic acids. In addition, anthocyanins may have beneficial effects on astringency. Besides anthocyanins, other phenolics, like flavanols (i.e. flavan-3-ol monomers and proanthocyanidins), are also directly linked to wine mouthfeel properties such as astringency or bitterness. Flavonols, besides indirectly contribute to wine color, have recently claimed attention as being responsible for unwanted deposit formation and several cases of precipitation (Gambuti et al., 2020). Overall, high concentrations of phenolic compounds have been associated with high quality and high price wines (Allegro et al., 2021). However, as it is widely known, climate change, i.e. global warming and water stress, is predicted to affect wine organoleptic properties through, among other factors, lower accumulation of some phenolic compounds (Gutiérrez-Gamboa et al., 2021).

Climate change significantly impacts agriculture and grapevine production, especially in semi-arid areas like Mediterranean countries, increasing critical temperature and reducing effective precipitation parameters. Moreover, other consequences are earlier phenological events, shorter growing seasons, and earlier harvest, which results in altered grape and wine quality: i.e. increased alcohol level, lower acidity, or poor accumulation of anthocyanins and poor phenolic maturity.

---

[*] Corresponding author.
E-mail address: javier.portu@icvv.es (J. Portu).

https://doi.org/10.1016/j.foodchem.2024.140045
Received 11 March 2024; Received in revised form 26 April 2024; Accepted 8 June 2024

Furthermore, climate change is accelerating the soil erosion and desertification, which poses a significant risk to the sustainability of viticulture. In this context, it is essential to develop innovative and sustainable agricultural practices to address these implications and safeguard crop production and quality, maintaining economic performance and increasing the sustainability and richness of the ecosystem. Different viticultural techniques are being explored in order to mitigate the effects of global warming on viticulture (Gutiérrez-Gamboa et al., 2021). In relation to soil management practices, for example, cover crops constitute an interesting alternative to the use of tillage and herbicides, but, this soil management practice can negatively affect vines under water stress conditions due to direct water competition. In contrast, organic intra-row mulching could represent a sustainable soil management alternative with an interesting adaptation to semi-arid conditions. The benefits of using organic mulches are described in other works and are widely attributed to the improvement of the physical, chemical, and biological soil characteristics (Mundy & Agnew, 2002). Some of these benefits include the contribution of organic material and nutrients to increase soil biological activity and reduce the inputs of synthetic fertilisers (Agnew et al., 2005). Additionally, organic mulches increase soil porosity and decrease temperature, compaction and evaporation, improving the soil's water storage capacity and reducing irrigation water demand (Pou et al., 2021). Besides, the physical barrier created by the organic mulch reduces the herbicide inputs due to the inhibition of excessive weed emergence (Mairata et al., 2023), which is attractive for ecological vineyard management.

The influence of organic mulching on the soil biological, chemical and physical properties is so significant that it could have indirect effects on grape and wine quality, similar to what has been observed with other agronomic soil management practices. For example, it is known that cover crops could influence phenolic composition by an arise in the competition for water and nutrients, which reduces vigor and enhances fruit exposure (Steenwerth & Guerra, 2012). However, concerning the application of intra-row organic mulches, there are very few published articles and these have shown contradictory results on the effect on general grape phenolic content and wine quality. Some works found an improvement in grape phenolic content by using organic or inorganic mulches (Cataldo et al., 2020; Jiang et al., 2022), while in others, no effect (Gil et al., 2018) or a decrease in phenolic content was observed (Buesa et al., 2021). This lack of agreement is mainly due to the nature of the different mulches used and the significant differences in environmental and field conditions between studies (Steenwerth & Guerra, 2012). On the other hand, most articles agree on how organic mulching affects the physicochemical properties of must and wine. Organic mulching on the vine row generally increases the content of nitrogen (N), phosphorus (P), potassium (K), and organic matter (OM) in the soil, which could lead to higher values of K and pH in the wine (Chan et al., 2010). However, some studies did not find any impact on berry composition and quality (ROU, 2003). Organic mulches have also reported increased plant yield and pruning weight (Varga & Májer, 2004), which could also indirectly affect grape and wine composition. Furthermore, and in contrast to other soil management practices that have been extensively studied, no previous studies have investigated the influence of organic mulching on the detailed wine phenolic composition analysed by chromatographic methods and their organoleptic evaluation.

Therefore, and with the aim to increase the knowledge about the impact of this sustainable viticultural practice on wine quality, this study evaluated the influence of intra-row organic mulching on wine's physical-chemical characteristics, detailed wine phenolic composition, and sensory properties. A four-year field experiment (2019, 2020, 2021, and 2022) was replicated in two vineyards from La Rioja (Spain) to achieve our objective. Five soil management treatments on the vine row were evaluated in each field. Three of them involved organic mulches: (i) shredded grapevine pruning debris from previous years (GPD), (ii) spent mushroom compost (SMC), mainly composed of straw, poultry manure, and urea, and (iii) straw (STR). These treatments were compared with two conventional soil management practices: (iv) herbicide (HERB) and (v) under-row tillage (TILL). This alternative soil management practice is exciting when the organic mulches are subresidues and can be used to improve crop management and reduce the environmental impact on the ecosystem. The main goal of this study was to provide a detailed description and analysis of the physicochemical properties, phenolic content and sensory characteristics of wines made from these five soil management treatments. This paper is the first to broadly examine the impact of different organic mulches on the wine's detailed phenolic composition analysed by UHPLC and on its organoleptic properties. Its novelty and conclusions are underscored by the extensive four-year study conducted across two distinct locations.

2. Materials and methods

2.1. *Chemical and reagents*

Caffeic acid, *p*-coumaric acid, ferulic acid, gallic acid, (+)-catechin, *trans*-resveratrol, and *trans*-piceid were procured from Sigma-Aldrich (St. Louis, MO, USA). *trans*-Caftaric acid and quercetin glucuronide were obtained from Biopurify Phytochemicals (Chengdou, China). Malvidin glucoside was sourced from Extrasynthese (Genay, France). Formic acid (LC-MS grade) was acquired from VWR International (Radnor, PE, USA). Acetonitrile (LC-MS) and methanol (LC-MS grade) were obtained from Scharlab (Barcelona, Spain). The water used was Milli-Q quality (Millipore Corporation, Burlington, MA, USA).

2.2. *Study site and plant material*

This study was conducted over four consecutive years (2019, 2020, 2021, and 2022) in two different fields located in the north of Spain (La Rioja) within the Qualified Designation of Origin Rioja (QDO Rioja). One field was in Aldeanueva de Ebro (Field 1), and the second was in Logroño (Field 2). This region has a warm-summer Mediterranean climate with continental influence. However, Field 1 experienced a drier climate, with an average annual temperature of 14.7 °C and annual precipitation of 381 mm, compared to 13.9 °C and 459 mm in Field 2 (see Appendix Table A1). The grape variety analysed was 'Tempranillo', which was grown using a bilateral Royat Cordon system with spur pruning and a planting frame of 3205 (2.6 m × 1.2 m) and 2778 (3 m × 1.2 m) plants ha^{-1} in Field 1 and Field 2, respectively. As described by Blanco-Pérez et al. (2022), the fields were managed following European Union regulations for IPM (Field 1) and organic farming (Field 2) (EU, 2018) with water drip irrigation to avoid critical water stress situations. Based on the methodology presented by Mairata et al. (2023), the soil physicochemical properties of Field 1 and Field 2 were analysed before the implementation of soil management treatments (Table A2). Field 1 had more sand than Field 2, classifying it as loam and clay soil, respectively. Both fields had an alkaline pH (8.2) and low soil electroconductivity. Field 1 had poor soil with low organic matter (1%) and low nitrogen ratio (0.85‰) compared to Field 2, which had 2.4% organic matter and 1.87‰ nitrogen ratio.

2.3. *Soil treatments and experimental layout*

Five soil management treatments were implemented in February 2019 and restored annually in each field. The three organic mulches consisted of grapevine pruning debris (GPD) from previous years, straw mulch (STR), both provided by the Government of La Rioja and spent mushroom compost (SMC) derived from *Agaricus bisporus* mushrooms enriched with animal manure and urea, supplied by "Sustratos de La Rioja SL". Organic mulches were applied to a thickness of 25 cm. Two conventional soil practices were also studied: under-row tillage (TILL) and herbicide application (HERB). The herbicides used were Terafit (25% *w*/w Flazasulfuron) and Atila (36% *v*/v Glyphosate), applied at a rate of 100 L/ha. These treatments were applied to the under-vine row, extending up to 50 cm on each vine side. The physicochemical properties of the organic mulches were previously analysed by Blanco-Pérez et al. (2022) (Appendix Table A3). The STR and GPD mulches are very similar, with low nitrogen content and high organic matter and C/N ratio. However, the SMC substrate is a fine-textured mulch with high nitrogen content and a low C/N ratio. The two vineyard had the same experimental design following a randomised treatment of three block per soil management, with each block containing between 40 and 50 plants.0

2.4. Harvest and vinification

Grapes from each replicate and treatment were harvested with an average field °Brix ranging from 22° to 24°. They were vinified separately to assess the impact of soil management treatments on wine quality. Three repetitions were made for each treatment and field. The vinification followed the usual methodology for producing red wines, and approximately 90 kg of grapes were crushed, destemmed, and vatted in 100 L tanks. The samples were treated with potassium metabisulfite to achieve a final total SO_2 concentration of 50 mg/L. Subsequently, the musts were inoculated with the commercially available *Saccharomyces cerevisiae* strain Uvaferm VRB (Lallemand) at a rate of 25 g/hL. The process of maceration of the must with the skins lasted for eight days, with daily punching to promote the release of the components of the berry into the must. Alcoholic fermentation occurred at a controlled temperature of 25 °C, monitored by reducing sugar measurements. When the alcoholic fermentation concluded, the wines were inoculated with lactic bacteria *Oenoccocus oeni* Lalvin SILKA (Lallemand) to develop malolactic fermentation at 20 °C. Once the malolactic fermentation was finished, wine samples of each replicate were taken for physicochemical analysis. Aliquots of each wine were frozen and stored at −20 °C until the phenolic compounds were analysed. Wines from Field 1 in 2021 have not been included in the analyses described below due to an issue during the vinification process.

2.5. Determination of wine physicochemical parameters

Each wine replicate was characterised by measuring alcoholic strength, pH, total acidity, volatile acidity, color hue, potassium, CI and CIELab parameters according to the International Organisation of Vine and Wine (OIV, (International Organisation of Vine and Wine), 2022) and tartaric acid by the Rebelein method (Lipka & Tanner, 1974). Total phenolics were determined as TPI by spectrophotometric absorbance at 280 nm after the prior dilution of samples (Portu et al., 2023). Malic and lactic acids were analysed using enzymatic methodology using an automatic enzymatic analyser (Y200, Biosystems SA, Barcelona, Spain).

2.6. Sample preparation and quantification of wine phenolic compounds by UHPLC-QqQ-MS/MS

Before UHPLC analyses, wine samples were defrosted and centrifuged. The samples were filtered using LLG Syringe Filters SPHEROS with a pore size of 0.22 μm (LLG Labware, Meckenheim, Germany). Wine phenolic compounds were analysed using a Shimadzu Nexera chromatograph (Shimadzu Corporation, Kyoto, Japan) equipped with a 3200QTRAP® triple quadrupole mass spectrometer (AB Sciex, Framingham, MA, USA) and an atmospheric pressure ionisation source (ESI and APCI).

The methodology followed for the UHPLC analyses of wine phenolic compounds was described by Portu et al. (2023). A Waters Acquity BEH C18 analytical column (100 × 2.1 mm, 1.7 μm) with a VanGuard precolumn Acquity BEH C18 (5 × 2.1 mm, 1.7 μm) from Waters (Milford, MA, USA) was used. The mobile phase solvents comprised Milli-Q water, LC/MS grade acetonitrile, and LC/MS grade formic acid. Both methods were set with a flow rate of 0.45 mL/min, and 2.5 μL of wine samples were analysed. The autosampler and oven temperatures were maintained at 7 °C and 40 °C, respectively.

For the analysis of anthocyanins, the mobile phase consisted of 2% formic acid in water (eluent A) and 2% formic acid in acetonitrile (eluent B). The elution gradient was as follows: 0–0.5 min, 1% B isocratic; 0.5–1.5 min, 1–8% B; 1.5–4 min, 8% B isocratic; 4–5 min, 8–12% B; 5–5.5 min, 12% B isocratic; 5.5–6 min, 12–14% B; 6–7 min, 14% B isocratic; 7–9 min, 14–22% B; 9–12 min, 22–30% B; 12–13.5 min, 30–90% B; 13.5–14.5 min, 90% B isocratic; 14.5–15 min, 90–1% B; 15–18 min, 1% B isocratic.

For the analysis of the other phenolic compounds, the mobile phase consisted of 0.1% formic acid in water (eluent A) and 0.1% formic acid in acetonitrile (eluent B). The elution gradient was the same as for anthocyanins.

Tandem MS analyses were conducted using a 3200QTRAP triple quadrupole mass spectrometer (AB Sciex) with an electrospray ionisation source (ESI Turbo V™ Source). The ionisation mode was positive $[M\text{-}H]^+$ for anthocyanin analysis and negative $[M\text{-}H]^-$ for other phenolic compounds. Data acquisition was performed through multiple reaction monitoring (MRM). The ionisation source parameters included an ion spray voltage of ±4.5 kV, a source temperature of 700 °C, and gas pressures of curtain gas 50 psi, GS1 50 psi, and GS2 60 psi. Nitrogen (>99.99% purity, degasified liquid nitrogen from a tank, Air Liquide, Paris, France) was used as the source and collision gas.

The dwell time for each transition was optimised using the Scheduled MRM tool based on the chromatogram, with a retention time, MRM detection window of 60 s, and a target scan time of 0.75 s. Data acquisition was conducted using the Analyst® 1.6.2 software (AB Sciex). Some anthocyanins and non-colored phenolic compounds were quantified using calibration curves of corresponding pure commercial standards. For other compounds, tentative quantification was achieved using calibration curves of standards with similar chemical structures: i. e. *p*-coumaric acid for coutaric acid, ferulic acid for fertaric acid, quercetin glucuronide for flavonols, catechin for flavanols, resveratrol for viniferins and piceatannol, piceid for astringins, malvidin glucoside for anthocyanins.

All wine replicates were injected twice without dilution and diluted 10 times with a solution of Milli-Q water/ethanol (80:20, *v*/v). Concentrations in wine samples were reported as milligrams per litre of wine (mg/L).

2.7. Sensorial analysis

The organoleptic study was assessed every year after the completion of vinification. The three wines made from each replicate and treatment were combined so one single wine was evaluated per treatment and block every year by a panel of the seven experienced wine tasters, 3 males and 4 females aged between 35 and 65 years, with extensive group trained and expertise in sensory analysis. Participants were required to sign a consent form before undertaking the sensory testing. The wine tasters were not informed about the study's objective and were not paid to participate. In addition, the sensory research was performed in compliance with relevant laws and institutional guidelines and was approved by the ethics committee of the University of La Rioja. The samples were blindly assessed and served in a random sequence. The sensory analysis of wines followed UNE 87–022-92 regulations. All wines were tasted at room temperature individually in standard wine-tasting glasses in random order without any identification. The evaluation was an official scoring sheet based on the criteria employed in various wine competitions and recognised by specific designations of origin. The scoring system focused on identifying defects, indicating that lower scores corresponded to higher wine quality. The sensory attributes assessed included visual, olfactory, taste and overall harmony. Furthermore, the evaluation included a quantitative assessment of aromatic descriptors on a scale of 1 to 10: fresh, ripe, and raisin fruit, herbaceous notes, spices, dairy characteristics, and their respective intensities. Similarly, the taste characteristics, such as freshness, acidity, structure, oiliness, bitterness, vegetal notes, astringency, persistence, balance, and intensity were also quantitatively evaluated.

2.8. Statistical analysis

Due to variations in climate, vineyard management, soil type and water availability, the different soil management practices were independently analysed for each field. The statistical analysis used a linear mixed effects model (LMM) to examine the relationship between the dependent variable and the soil management treatments. Years of study were used as a categorical random variable. An analysis of variance (ANOVA) was performed to assess the significance of the categorical variable, and Tukey's post hoc tests were used for pairwise multiple comparisons between their levels. More detailed information about the statistical results of the generalised linear model (GLM) of variables and their interactions is presented in Appendix Table A4. Principal component analysis (PCA) and canonical discriminant analysis (CDA) were used to plot differences between soil management treatments using phenolic compound amounts from the complete data. Data analysis was performed using SPSS 22.0 (IBM Corp., Armonk, NY, USA) and RStudio software, version 4.3.1. Any differences were accepted with a p-value ≤ 0.05.

3. Results and discussion

3.1. Effect of organic mulches on wine physicochemical parameters

Table 1 presents the results of the physicochemical analyses of the wines elaborated from different soil management practices within and between fields. Regarding the influence of soil management practices, more significant differences were found in Field 1 than in Field 2. In both fields, the main differences affected the parameters related to wine acidity and color. To start, the use of organic mulching (STR, GPD, and SMC) showed minimal differences in alcohol content compared to traditional practices (HERB and TILL). Only STR resulted in a decrease in alcohol content in wine from Field 2. Conversely, there were notable variations in acidity parameters. Mulch soil management (GPD, SMC, and STR) led to increased pH, lactic acid, and potassium levels (the latter only significant in Field 2), while decreasing tartaric acid compared to HERB and TILL soil treatments. However, there were few significant differences in total acidity. Variations in these parameters, particularly pH, might account for the differences observed in other parameters, such as hue value, which was higher in wines from organic mulches, indicating potentially more brownish tones. No differences were noted in other parameters like volatile acidity, while minor differences were observed in color intensity, CIELab parameters, or total polyphenol index. Nevertheless, it is worth noting that SMC wines exhibited the lowest color intensity and total polyphenol index, and highest L* in Field 1.

In agreement with previous studies (Agnew et al., 2005; Cataldo et al., 2020), our results have shown that using organic mulches could significantly affect the physicochemical properties of wine, especially acidity parameters (i.e. pH and tartaric acid) and hue. Acidity stands out as a fundamental trait of wines, shaping their sensory attributes, chemical stability, and microbiological resilience, while also influencing their potential for aging. In this regard, pH serves as a more accurate indicator than total acidity, offering insights into the levels of organic acids, primarily tartaric acid, and cations, primarily potassium (Poni et al., 2018). Previous works have shown that organic mulches contribute significant amounts of potassium to the soil (Blanco-Pérez et al., 2022; Mairata et al., 2023) resulting in higher concentrations of this element in grape berries, increasing pH values due to the substitution of K^+ for H^+ in grape berry skins (Chan & Fahey, 2011). This correlation was in line with the results reported by Agnew et al. (2005), who observed increases of up to 7–19% in juice potassium amounts after applying organic waste mulches. High potassium concentration could also lead to excessive loss of tartaric acid through precipitation as potassium bitartrate, which makes the adjustment of pH during wine production more difficult and expensive. Lower levels of tartaric acid and high pH values in wine are undesirable as they have been linked to unstable, oxidised, and degraded flat wines, reduced wine quality and color, altered microbiological stability and fermentation process (Gutiérrez-Gamboa et al., 2021; Mpelasoka et al., 2003). Actually, the fact that pH level causes anthocyanins to exist in different chemical species with different coloration, probably explains that wines from mulches consistently had higher hue values than conventional treatments (Table 1). On the other hand, enhanced plant physiological capacity could improve yield (Burg et al., 2022). This consequence, that it was observed in the case of SMC in Field 1 (data not shown), could also explain the reduction in tartaric acid levels in wine made from organic mulches due to dilution effects (de Souza et al., 2019), which could also

Table 1

Results from the analyses of enological parameters of wines made from grapevines managed according to five different intra-row treatments (herbicide (HERB), intra-row tillage (TILL) and organic mulching with straw (STR), grapevine pruning debris (GPD) and spent mushroom compost (SMC)) in two fields (Field 1 and Field 2) during a 4-year study.

	Field 1					Field 2					Field 1	Field 2	
	HERB	TILL	STR	GPD	SMC	HERB	TILL	STR	GPD	SMC	Average	Average	
Alcoholic degree (%, v/v)	14.00	13.92	14.04	13.94	13.61	13.05 A	12.91 A	12.30b		12.68ab	12.62ab	13.91 A	12.71B
pH	3.73b	3.73b	3.87 A	3.90a	3.98a	3.67b	3.67b	3.82 A		3.8a	3.83a	3.84 A	3.76B
Total acidity (g/L)	5.48a	4.63ab	5.16ab	4.49b	4.58ab	5.10 A	5.10 A	4.90ab		4.91ab	4.70b	4.88	4.94
Tartaric acid (g/L)	2.15a	2.15a	1.9b	1.8b	1.75b	2.26a	2.19a	1.80b		1.95b	1.9b	1.95	2.02
Lactic acid (g/L)	1.18bc	1.18c	1.37ab	1.43 A	1.41ab	1.47c	1.42c	1.79a		1.63b	1.65ab	1.32B	1.59 A
Potassium (mg/L)	954.9b	958.6b	1101.1ab	1158.3a	1130.3ab	995.0b	988.5b	1193.5a		1144.8a	1160.9a	1063.4	1096.5
Volatile acidity (g/L)	0.57	0.49	0.56	0.47	0.64	0.45	0.45	0.51		0.50	0.49	0.54 A	0.48B
Color intensity (CI)	9.45 A	9.55a	8.97 A	8.20 A	6.74b	8.81	9.07	7.52		7.98	7.91	8.60	8.26
Hue	0.57c	0.56c	0.64ab	0.64b	0.69a	0.56b	0.56b	0.63a		0.61 A	0.64 A	0.62	0.60
a* (CIELab units)	46.95ab	46.94ab	44.29b	47.38ab	50.67a	49.55	48.25	50.00		49.37	47.66	47.42B	48.97 A
b* (CIELab units)	24.41	24.88	22.00	25.21	27.93	25.87	25.03	24.45		25.32	23.66	24.82	24.87
L* (CIELab units)	15.32b	15.22b	13.96b	16.59ab	20.15a	18.17	16.75	19.19		18.02	17.51	16.18B	17.93 A
C* (CIELab units)	52.96ab	53.18ab	49.56b	54.08ab	57.88a	55.99a	54.39a	55.72 A		55.5a	46.89b	53.44	53.7
H* (CIELab units)	27.21	27.76	25.49	27.77	28.86	27.48	27.33	26.07		27.12	26.37	27.38	26.87
TPI [a]	54.07a	52.05 A	53.95a	53.18a	43.17b	44.50	46.85	45.24		46.07	44.78	51.46 A	45.49B

The soil management treatments were independently compared within each field, and a separate comparison was made between the average values of the fields. Concerning each parameter, minor letters represent significant differences between treatments, while major letters indicate significant differences between fields (p-value ≤ 0.05). The absence of letters indicates a non-statistical difference.

[a] Total polyphenol index.

increase pH (Chan & Fahey, 2011). Finally, in the same way, as in the case of SMC in Field 1, other works have also reported that the STR mulch could decrease the TPI in wine grapes (Buesa et al., 2021).

Another finding from our study is that wines from vineyards with organic mulching had higher levels of lactic acid in both fields (Table 1). This difference is likely because grapes from mulched vines had higher levels of malic acid, possibly due to increased water availability from mulching (data not shown). Additionally, variations in lactic acid levels could also be influenced by different microbial populations during fermentation (Benito, 2018), as organic mulches are known to positively impact soil and grape microbial communities (Blanco-Pérez et al., 2022). However, since we did not directly analyze the microbiology of fermentation, this remains a hypothesis.

As for the significant reduction of alcoholic degree in Field 2 by mulches, especially STR, previous studies, such as Caruso et al. (2013) and Zhang et al. (2014) described a delayed maturation in potatoes using biodegradable black films. This delay in sugar accumulation could be due to reducing plant stress resulting from increased soil water retention and a decrease in extreme soil temperatures (Pou et al., 2021).

Organic mulches have been widely reported to benefit the soil, such as increased organic matter content, fertility, moisture, and belowground biodiversity (Blanco-Pérez et al., 2022; Mairata et al., 2023). This study shows that this could lead to wines with higher potassium and lower acidity values, resulting in wines with lower color intensity and higher hue, especially in SMC soil treatment in Field 1. This could have negative implications in wine microbial stability and the evolution of wine organoleptic properties during aging. This behaviour was most evident in Field 1, where the field was traditionally managed according to conventional agricultural practices with low organic matter and nitrogen content.

3.2. Effect of organic mulches on wine phenolic composition

There are contradictory findings in existing literature when it comes to the study of the impact of organic mulching on the phenolic content of wine. In addition, all the studies have been based in spectrophotometric analyses instead of using separation techniques based on chromatographic methods. Discrepancies between studies may be attributed to diverse factors such as climatic conditions, soil composition, grape varieties, and the specific type of mulch employed, whether organic or inorganic (Steenwerth & Guerra, 2012). This study entails a four-year experiment conducted in two locations, using UHPLC-QqQ-MS/MS to quantify the detailed phenolic compounds. For this reason, this research offers a novel perspective on the subject.

3.2.1. Effect on wine anthocyanins

The results of the UHPLC analysis of anthocyanins in the wines obtained from the different soil management practices are presented in Table 2. In agreement with previous works on the Tempranillo grape variety (Portu et al., 2023), the most abundant anthocyanin groups were delphinidin, petunidin and, highlighting, malvidin. In Field 1, the wines from the SMC treatment had lower significant amounts of cyanidin (glucoside, acetyl glucoside and coumaroyl glucoside), delphinidin (glucoside, acetyl glucoside and coumaroyl glucoside), petunidin (glucoside, acetyl glucoside and coumaroyl glucoside) and peonidin (glucoside and coumaroyl glucoside) than wine from the HERB treatment. Moreover, SMC treatment also had significantly lower amounts of delphinidin, cyanidin, petunidin, and peonidin glucoside than TILL treatment. Finally, when compared to GPD, the SMC treatment showed lower concentrations of the 3-*O*-glucosides of delphinidin, petunidin, and peonidin, as well as petunidin-3-*O*-acetyl glucoside and the five

Table 2

Average anthocyanin content (mg/L) in wines made from grapevines managed according to five different soil management practices (herbicide (HERB), intra-row tillage (TILL) and organic mulching with straw (STR), grapevine pruning debris (GPD) and spent mushroom compost (SMC)) in two fields (Field 1 and Field 2) during the 4-year study and their field average belongs to the four experimental field years.

	Field 1					Field 2					Field 1	Field 2
	HERB	TILL	STR	GPD	SMC	HERB	TILL	STR	GPD	SMC	Average	Average
Delphinidin-3-glc	67.48a	61.37a	56.67ab	64.54 A	44.28b	45.28ab	52.03 A	39.25b	41.01b	38.34b	58.87 A	43.56B
Cyanidin-3-glc	5.84 A	5.14a	3.98ab	3.90ab	1.93b	4.50	4.17	2.40	2.75	2.37	4.17 A	3.23B
Petunidin-3-glc	82.27a	81.62 A	80.67ab	89.83a	75.75b	73.85ab	81.23a	67.34b	70.11ab	65.51b	82.03 A	71.94B
Peonidin-3-glc	23.36 A	23.86 A	19.59ab	21.29a	14.80b	24.85	24.84	18.43	19.27	17.76	20.58	21.09
Malvidin-3-glc	255.78	266.40	255.18	278.92	251.0	296.09	317.33	290.05	292.67	303.57	261.46	299.05
Delphinidin-3-acglc	6.95a	6.19ab	6.23ab	6.69ab	4.92b	3.65	4.34	3.41	3.55	3.32	6.20 A	3.68B
Cyanidin-3-acglc	2.01a	1.81ab	1.75ab	1.79ab	1.25b	1.07	1.19	0.91	0.91	0.85	1.72 A	0.99B
Petunidin-3-acglc	12.94 A	11.56ab	12.16ab	12.73 A	8.70b	6.54	8.01	6.58	6.44	6.47	11.62 A	6.83B
Peonidin-3-acglc	6.31	6.23	6.13	6.11	4.50	3.39	4.18	3.45	3.17	3.07	5.86 A	3.46B
Malvidin-3-acglc	60.24	59.88	59.82	66.20	55.50	39.47bc	44.53ab	42.09abc	40.46bc	43.94 A	60.33 A	42.46B
Delphinidin-3-cmglc	9.01a	7.46ab	8.09ab	8.48a	5.82b	6.50ab	7.92a	6.60ab	6.06b	6.21ab	7.78	6.67
Cyanidin-3-cmglc	5.95a	5.12ab	5.50a	5.49a	3.17b	4.58ab	5.40a	4.21ab	3.98b	4.14ab	5.05	4.47
Petunidin-3-cmglc	11.37a	9.67ab	10.75ab	11.18a	7.09b	7.98ab	9.62a	8.11ab	7.33b	8.34ab	10.00	8.24
Peonidin-3-cmglc	5.58a	5.21ab	5.16ab	5.60a	3.14b	3.83ab	5.82 A	4.67ab	4.22b	4.52ab	5.08	4.78
Malvidin-3-cmglc	26.26ab	26.06ab	26.79ab	29.77a	23.31b	21.41b	24.72 A	22.54ab	21.17b	23.90ab	26.44	22.72
Malvidin-3-cfglc	1.79	1.47	2.24	2.00	1.75	1.38	1.32	1.44	1.45	1.29	1.85 A	1.39B
Total	583.15	579.04	560.71	614.55	507.61	545.22ab	596.65a	521.49b	524.55b	533.58ab	569.01	544.58
∑ non-acylated	434.73	438.39	416.11	458.50	387.78	444.57	479.60	417.48	425.8	427.54	427.10	438.88
∑ acylated	148.42ab	140.65ab	144.61ab	156.06a	119.83b	100.65b	117.05a	104.00b	98.75b	106.04ab	141.91 A	105.70B
∑ acetylated	88.46ab	85.67ab	86.08ab	93.53a	74.87b	54.11b	62.26a	56.44ab	54.54b	57.64ab	85.72A	57.43B
∑ coumaroylated	58.17ab	53.50ab	56.29ab	60.52a	43.21b	45.16b	53.48a	46.13b	42.77b	47.11ab	53.34	46.88
∑ delfinidins	83.44a	75.02 A	70.99ab	79.71a	55.02b	55.43ab	64.29a	49.26b	50.26b	49.92b	72.84 A	53.90B
∑ cyanidins	13.80a	12.07a	11.23ab	11.19ab	6.39b	10.14ab	10.76a	7.52b	7.64ab	7.40b	10.94A	8.69B
∑ petunidins	106.58ab	102.85ab	103.58ab	113.75a	91.53b	88.37ab	98.86a	82.04b	83.88b	81.93b	103.66 A	87.02B
∑peonidins	35.26a	35.29a	30.89ab	33.00 A	23.11b	32.92ab	34.84a	26.55b	26.66b	25.77b	31.51 A	29.35B
∑ malvidins	344.07	353.81	344.03	376.90	331.55	358.35	387.90	356.12	355.75	369.98	350.07	365.62
Vitisin A	0.81a	0.65ab	0.87a	0.72ab	0.46b	0.69ab	0.73ab	0.82a	0.80a	0.62b	0.70B	0.73 A
Vitisin B	1.14ab	1.49a	0.74b	0.66b	1.02ab	2.45	1.15	1.25	1.15	1.90	1.01B	1.56 A
Vitisins	1.95ab	2.14a	1.61ab	1.38b	1.48ab	3.14	1.88	2.07	1.96	2.52	1.71	2.29

Nomenclature abbreviations: glc, glucoside; acglc, acetyl glucoside; cmglc, *trans*-p-coumaroyl glucoside; cfglc, caffeoylglucoside.
The soil management treatments were independently compared within each field, and a separate comparison was made between the average values of the fields. Concerning each parameter, minor letters represent significant differences between treatments, while major letters indicate significant differences between fields (p-value ≤ 0.05). The absence of letters indicates a non-statistical difference.

coumaroyl derivatives. As a result, wines from SMC had the lowest total concentration for all groups of anthocyanins, although the differences were not significant for non-acylated and total anthocyanins. In Field 2, the anthocyanin composition in wines from mulched vines closely resembled that of HERB. However, wines from the treatments exhibited lower concentrations of these compounds compared to TILL. For example, STR and GPD had significantly lower concentrations of total anthocyanins, acylated anthocyanins, coumaroylated derivatives, petunidins, and peonidins. Additionally, STR had a lower concentration of cyanidins, GPD had a lower concentration of acetylated derivatives and total delphinidins, and SMC led to wines with lower concentrations of delphinidins, cyanidins, petunidins, and peonidins. Finally, the most important outcome regarding vitisins composition was found in wines from SMC mulched vines in Field 1, which showed lower concentration of total vitisins when compared to TILL.

The water status of vines, along with soil characteristics such as fertility, can significantly impact the accumulation of phenolic compounds in grapes, leading to notable differences in wine (Poni et al., 2018). Consequently, the greater fertility and water availability in mulched vines may result in reduced anthocyanin levels in wine. For example, SMC significantly increased soil fertility in Field 1, which explains the lower anthocyanin content in wines from this treatment. Conversely, in Field 2, vines subjected to TILL management exhibited lower water availability at −25 cm, potentially explaining why this treatment led to wines with the highest anthocyanin levels.

Few articles have previously evaluated the influence of organic mulching on grape or wine general anthocyanin amount, but none of them analysed wine-detailed anthocyanin composition by UHPLC. Cataldo et al. (2020) reported that STR mulching in cv. Cabernet Sauvignon increased total anthocyanins and extractable anthocyanins in one of the two years of their study compared to TILL. A similar result was observed by Jiang et al. (2022) in the same grape variety, as they found that mulch with organic wood chips, like GPD mulch, increased grape anthocyanins and total phenols more than TILL treatment. In contrast, Buesa et al. (2021) found that GPD mulch decreased total anthocyanins compared with TILL in one of three years of their study with the Bobal grape variety in Eastern Spain, which are more similar climate conditions to our research.

Anthocyanins are the pigments that primarily contribute to the color of young red wines. Recently, their role in other sensory properties has also been under investigation (Allegro et al., 2021). Our study has demonstrated that, in certain instances, organic mulching may lead to lower anthocyanin concentrations in wine compared to traditional management practices. This effect was particularly relevant in the case of acylated anthocyanins, which are more stable than non-acylated forms (Zhang et al., 2021). Also, vitisins, which also contribute to wine color stability (Zhang et al., 2021), were found in general at lower concentrations in wines from mulched vines in Field 1. Therefore, our results suggests that organic mulching may exert a potentially negative impact on wine quality (Parpinello et al., 2009). However, as it can be seen in Table 1, we just found a reduction in color intensity in wines from SMC-mulched vines in Field 1, indicating that wine color is influenced by various factors apart from anthocyanin concentration, as it has been extensively reported (Heras-Roger et al., 2016; Parpinello et al., 2009).

3.2.2. *Effect on wine flavonols*

Table 3 shows the results of the UHPLC analysis of flavonols. As

Table 3

Average flavonol content (mg/L) in wines made from grapevines managed according to five different soil management practices (herbicide (HERB), intra-row tillage (TILL) and organic mulching with straw (STR), grapevine pruning debris (GPD) and spent mushroom compost (SMC)) in two fields (Field 1 and Field 2) during the 4-year study.

	Field 1					Field 2					Field 1	Field 2
	HERB	TILL	STR	GPD	SMC	HERB	TILL	STR	GPD	SMC	Average	Average
Myricetin-3-gal	0.14a	0.12ab	0.13a	0.13ab	0.07b	0.14b	0.19a	0.16ab	0.15ab	0.16ab	0.12B	0.16 A
Myricetin-3-glc	2.80a	2.56 A	2.75a	2.84a	1.96b	1.89b	2.31 A	1.92ab	2.00ab	1.96ab	2.26	2.02
Myricetin-3-glcU	6.41a	5.42ab	6.61 A	6.19a	3.71b	5.01b	6.34a	5.40ab	5.23b	5.26ab	5.67	5.47
Myricetin	1.83	1.52	1.62	1.45	1.18	1.49ab	1.84a	1.61ab	1.31b	1.81a	1.52B	1.61A
∑ myricetins	11.18a	9.62ab	11.11 A	10.6a	6.93b	8.53b	10.67a	9.08ab	8.68b	9.18ab	9.89	9.26
Quercetin-3-gal	1.14a	0.94ab	1.31 A	1.01a	0.54b	1.54	1.88	1.66	1.54	1.61	1.0B	1.64 A
Quercetin-3-glc	4.78a	3.91ab	5.90a	5.02 A	2.14b	3.78	4.48	4.29	4.16	4.74	4.35	4.23
Quercetin-3-glcU	10.90ab	9.11ab	11.02a	9.77ab	6.14b	8.32b	10.36 A	9.63ab	9.18ab	9.07ab	9.39	9.37
Quercetin-3-rut	0.20	0.19	0.33	0.29	0.26	0.19	0.27	0.32	0.39	0.38	0.25B	0.31A
Quercetin	0.51a	0.44ab	0.56 A	0.45ab	0.29b	0.48ab	0.63a	0.44ab	0.37ab	0.36b	0.47	0.45
∑ quercetins	17.53a	14.59ab	19.11 A	16.61a	9.37b	14.31b	17.61a	16.34ab	15.64ab	16.17ab	15.44	16.0
Laricitrin −3-gal	0.03	0.03	0.03	0.04	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.03
Laricitrin-3-glc	2.88a	2.67ab	2.99a	2.96a	2.22b	2.24	2.52	2.24	2.26	2.38	2.74	2.32
Laricitrin	0.06	0.05	0.06	0.06	0.06	0.06	0.07	0.07	0.06	0.07	0.06	0.06
∑ laricitrins	3.00 A	2.75ab	3.08a	3.06a	2.31b	2.32	2.62	2.34	2.34	2.47	2.83	2.42
Kaempferol-3-gal	0.33 A	0.28ab	0.38a	0.33ab	0.16b	0.51	0.61	0.59	0.56	0.56	0.30B	0.56A
Kaempferol-3-glc	0.85ab	0.66ab	1.11a	0.88ab	0.24b	0.96	1.18	1.20	1.11	0.81	0.75B	1.04 A
Kaempferol-3-glcU	0.30a	0.26ab	0.31a	0.27ab	0.16b	0.34	0.40	0.37	0.37	0.30	0.26B	0.36A
Kaempferol-3-rut	0.02a	0.02ab	0.02ab	0.02ab	0.01b	0.02a	0.02ab	0.01ab	0.01ab	0.01b	0.02	0.01
Kaempferol	0.03 A	0.03ab	0.03 A	0.02ab	0.01b	0.04	0.04	0.03	0.02	0.02	0.02B	0.03 A
∑ kaempferols	1.54 A	1.24ab	1.85a	1.53a	0.59b	1.86	2.25	2.22	2.08	1.70	1.35B	2.0 A
Isorhamnetin-3-gal	0.03	0.03	0.04	0.03	0.02	0.05	0.06	0.06	0.05	0.05	0.03B	0.05A
Isorhamnetin-3-glc	0.75a	0.63ab	0.84a	0.76a	0.42b	0.64	0.78	0.73	0.70	0.52	0.68	0.67
Isorhamnetin-3-glcU	0.02a	0.02ab	0.03 A	0.02a	0.01b	0.03ab	0.03 A	0.03ab	0.03ab	0.02b	0.02B	0.03A
Isorhamnetin-3-rut	1.03a	0.90ab	1.01a	1.03a	0.70b	0.99ab	1.09 A	0.87ab	0.87ab	0.79b	0.93	0.91
∑ isorhamnetins	1.84a	1.58ab	1.92a	1.85a	1.16b	1.71ab	1.96a	1.69ab	1.65ab	1.38b	1.67	1.66
Syringetin-3-glc	2.63	2.27	2.37	2.35	2.16	2.07	2.25	2.17	2.09	2.16	2.36	2.14
Syringetin	0.11	0.11	0.12	0.14	0.14	0.11	0.12	0.13	0.12	0.15	0.13	0.13
∑ syringetins	2.74	2.39	2.49	2.50	2.30	2.18	2.38	2.31	2.21	2.32	2.48	2.27
Total flavonols	37.80a	32.18ab	39.57a	36.14a	22.66b	30.92b	37.49a	33.97ab	32.60ab	33.22ab	33.67	33.61

Nomenclature abbreviations: glcU, glucuronide; gal, galactoside; glc, glucoside.

The soil management treatments were independently compared within each field, and a separate comparison was made between the average values of the fields. Concerning each parameter, minor letters represent significant differences between treatments, while major letters indicate significant differences between fields (p-value ≤ 0.05). The absence of letters indicates a non-statistical difference.

expected from previous studies with cv. Tempranillo, myricetin and quercetin-type flavonols were the most predominant compounds (Portu et al., 2023). The most abundant glycoside was the glucosylated form, accounting for 41% of the flavonols. As stated previously for the wine physiochemical parameters and anthocyanins (Tables 1 and 2), there were more significant differences in Field 1 than in Field 2. In this regard, wines made from SMC mulch had lower flavonol concentrations, especially with respect to HERB, STR and GPD treatments. HERB, STR and GPD treatments had more concentration than SMC of myricetins, quercetins, laricitins, kaempferol, isorhamnetins, and the total flavonol amount. In Field 2, TILL treatment led to the highest concentration of these compounds, but differences in the total amount per type of flavonol were significant just in the following cases: total myricetins and quercetins compared to HERB; total myricetins compared to GPD; and total isorhamnetins compared to SMC soil management. Moreover, the TILL treatment had significantly more total flavonol content than the HERB treatment.

No previous studies have evaluated the influence of organic mulches on wine detailed composition on flavonol compounds, despite being a very important class of phenolic compounds. Actually, flavonols are found abundantly in grapes and wine and their significance in winemaking extends beyond their well-known antioxidant properties as they contribute significantly to both the technological and sensory characteristics of wine. For instance, recent research has elucidated that flavonols can influence several key technological aspects during wine production. Regarding wine stability, studies such as Gambuti et al. (2020) have revealed that high concentration of flavonols may lead to the formation of insoluble complexes and precipitation that causes the presence of turbidity in bottle. In wines, these compounds are also relevant regarding wine organoleptic properties, as they contribute to various sensory aspects like color, bitterness, and astringency. For example, previous studies indicate they interact with salivary proteins, increasing perceptions of astringency and bitterness (Ferrer-Gallego et al., 2016). In addition, it is well established that flavonols play a key role in red young wine color stability, as they are very effective copigments in copigmentations reactions with anthocyanins (Zhang et al., 2021).

This group of phenols share most of their biosynthetic pathway with anthocyanins (both flavonoids), so it seems reasonable that the results are related. Flavonols play an essential role in the color stabilisation of young red wines through the copigmentation interaction with anthocyanidins, so this could also partly explain the less color intensity observed in SMC wines in Field 1. Moreover, flavonol biosynthesis is sensitive to solar radiation and they are synthesised to protect berries from ultraviolet radiation. Burg et al. (2022) described an increase of plant vegetative growth applying a nutrient-rich organic mulch, like the SMC, which may reduce cluster light interception and decrease wine flavonoid accumulation (Wang et al., 2021). Therefore, our hypothesis is that increased water and nutrient availability in mulched vines, particularly for SMC at Field 1, may increase vine vigor and, consequently, decrease flavonol accumulation. This result could contribute to explaining why SMC wines in Field 1 had higher L* and lower color intensity.

3.2.3. *Effect on wine flavanols and non-flavonoid compounds*

Table 4 summarises the wines' flavanol, phenolic acid (hydroxybenzoic acid and hydroxycinnamic acids), and stilbene composition.

Flavanols mainly exist as monomers, oligomers and polymers and contribute to wine color stabilisation, astringency, and bitterness perception (Gutiérrez-Escobar et al., 2021). Their contribution to wine mouthfeel properties and wine color is extensively referenced (Waterhouse et al., 2016). In contrast, flavan-3-ol monomers are considered

Table 4

Average flavanol and non-flavonoid content (mg/L) in wines made from grapevines managed according to five different soil management practices (herbicide (HERB), intra-row tillage (TILL) and organic mulching with straw (STR), grapevine pruning debris (GPD) and spent mushroom compost (SMC)) in two fields (Field 1 and Field 2) during the 4-year study.

	Field 1					Field 2					Field 1	Field 2
	HERB	TILL	STR	GPD	SMC	HERB	TILL	STR	GPD	SMC	Average	Average
Flavanols												
Catechin	13.11	12.30	12.11	12.18	10.72	9.98	10.43	10.20	10.12	9.90	12.09 A	10.07B
Epicatechin	4.83ab	4.62ab	3.67b	4.56ab	5.01a	3.60	3.57	3.54	3.65	3.66	4.54 A	3.60B
Epicatechin gallate	0.37ab	0.44a	0.42 A	0.33ab	0.11b	0.58ab	0.67a	0.50ab	0.44b	0.57ab	0.33B	0.54 A
Gallocatechin	2.77a	2.75a	2.80a	2.74a	2.30b	2.86	3.17	3.03	2.86	3.24	2.67B	3.02A
Epigallocatechin	1.88	1.97	1.80	2.16	2.17	2.08	2.26	2.07	1.99	2.21	2.00	2.14
Procyanidin B1	11.43 A	10.82ab	11.20a	10.22ab	8.55b	12.17ab	12.78b	12.24ab	11.81ab	11.48a	10.45	12.09
Procyanidin B2	2.78a	2.45ab	1.95b	2.32ab	2.64ab	2.54	2.25	2.13	2.37	2.46	2.43A	2.33B
Procyanidin B3	1.53a	1.46ab	1.46ab	1.40ab	1.14b	1.73	1.80	1.67	1.70	1.80	1.40	1.73
Procyanidin C1	0.12ab	0.11ab	0.09b	0.12ab	0.14a	0.12	0.13	0.12	0.13	0.13	0.12	0.13
Total	38.83	36.90	35.50	36.03	32.78	35.65	37.06	35.51	35.09	35.45	36.00A	35.64B
Hydroxycinnamic acids												
Caffeic acid	0.27b	0.27b	0.26b	0.27b	0.33 A	0.45ab	0.42b	0.43ab	0.44ab	0.50a	0.28B	0.45 A
Caftaric acid	48.00a	42.98ab	45.62a	45.83a	34.00b	40.81ab	43.35a	41.10ab	36.62b	42.90ab	43.29	40.85
p-Coumaric acid	0.45b	1.64b	1.55b	1.75b	2.58a	1.59b	1.67b	1.79ab	1.75ab	2.16a	1.79B	1.82A
Coutaric acid	43.71a	35.25ab	37.42ab	38.43ab	26.85b	19.27	19.85	19.26	18.52	18.03	36.33 A	19.33B
Ferulic acid	0.20	0.20	0.20	0.20	0.20	0.18b	0.19ab	0.19ab	0.19ab	0.20a	0.20	0.19
Fertaric acid	6.59	6.28	6.09	6.41	6.02	5.57	5.78	5.63	5.32	5.60	6.28 A	5.59B
Total	100.25a	86.62ab	91.15ab	92.88a	69.97b	67.86ab	71.27a	68.39ab	62.84b	69.40ab	88.17 A	68.23B
Hydroxybenzoic acid												
Gallic acid	16.34ab	15.52ab	12.66b	14.78ab	16.73a	8.87	8.96	8.21	9.03	9.06	15.21 A	8.90B
Stilbenes												
trans + *cis*-Resveratrol	0.29ab	0.38ab	0.26b	0.30ab	0.44a	1.25	1.41	1.25	1.18	1.63	0.33B	1.33 A
trans + *cis*-Piceid	2.52	2.54	2.02	2.43	2.45	10.16	10.20	8.51	8.03	7.79	2.39B	8.97 A
ε-Viniferin	0.03ab	0.03ab	0.02b	0.03ab	0.04a	0.11	0.10	0.08	0.09	0.09	0.04B	0.09 A
Ω-Viniferin	0.04ab	0.05a	0.03b	0.04ab	0.05a	0.11	0.12	0.09	0.09	0.09	0.04B	0.10A
trans + *cis*-Piceatannol	0.06	0.07	0.06	0.07	0.08	0.12	0.12	0.11	0.10	0.12	0.07B	0.11A
trans + *cis*-Astringin	0.19	0.22	0.18	0.20	0.21	0.45	0.49	0.39	0.39	0.37	0.20B	0.42 A
Total	3.13	3.28	2.58	3.06	3.27	12.19	12.44	10.43	9.89	10.08	3.06B	11.03A

The soil management treatments were independently compared within each field, and a separate comparison was made between the average values of the fields. Concerning each parameter, minor letters represent significant differences between treatments, while major letters indicate significant differences between fields (*p*-value ≤ 0.05). The absence of letters indicates a non-statistical difference.

poor copigments, except for epicatechin, despite being present in higher amounts than flavonols in young red wine (Gutiérrez et al., 2005). Phenolic acids, especially caffeic acid, take part in copigmentation reactions with anthocyanins, they are associated with browning processes, and they can act as precursors of volatile phenolic compounds (Gutiérrez-Escobar et al., 2021). Stilbenes are phytoalexins which are synthesised in response to biotic and abiotic stresses (Flamini et al., 2013).

Overall, no discernible trend between soil management treatments was observed, as there were numerous differences across different compounds and fields, which limits the conclusions that can be drawn from the study. Specifically, when comparing to control treatments (HERB and TILL), the SMC treatment showed lower concentrations of flavanol monomers and dimmers (such as epicatechin gallate, gallocatechin, and procyanidins B1 and B3), as well as hydroxycinnamic acids (including caftaric and coutaric acids). No significant differences were observed in total flavanols and stilbenes, while a notable decrease in total hydroxycinnamic acid concentration was observed in this treatment compared to HERB and GPD treatments.

The different profile in flavanol composition may have sensorial implications. For example, besides their implication in mouthfeel properties (Waterhouse et al., 2016), there are differences in their effectiveness as copigments (Rivero et al., 2020). Additionally, dimer and trimer procyanidins have been found to negatively impact the intraoral release of esters, showing stronger negative correlations compared to monomeric flavanols such as catechin and epicatechin (Esteban-Fernández et al., 2018).

Regarding the composition of hydroxycinnamic acids in wine, it is noteworthy that SMC led to a lower concentration of tartaric acid esters but a higher concentration of simple hydroxycinnamic acids compared to the other treatments. This suggests differences during the fermentation process that have resulted in increased hydrolysis of tartaric acid esters, possibly due to a higher pH and potential increased activity of lactic acid bacteria (Virdis et al., 2021). However, this is only a hypothesis, as no microbial determinations were performed.

However, these differences were not consistently observed in Field 2, where only a few significant differences were found. Notably, wines from GPD mulched vines exhibited lower amounts of total hydroxycinnamic acids than those from TILL, likely due to a lower concentration of caftaric acid. Additionally, it was also observed higher hydrolysis tartaric acid esters in SMC mulched wines with respect to control treatments.

Considering all the obtained results, our study shows the influence of organic mulching on the phenolic composition of cv. Tempranillo wine when compared to traditional soil management practices was scarce and could depend on the mulching type and the vineyard conditions. In this respect, the intra-row mulching with SMC led to wine with lower significant concentrations of acylated anthocyanins, flavonols and hydroxycinnamic acids, but only in Field 1. In contrast, in Field 2, STR and GPD led to wines with lower concentration of total anthocyanins with minor differences on the rest of compounds. Apart from differences in climatic conditions, in the years before the trial, Field 1 had been managed according to conventional practices, while Field 2 had been handled according to ecological practices. Therefore, due to the drastic change in vineyard management, organic mulches probably had a more noticeable effect on the accumulation of phenolic compounds in grape berries in Field 1 than in Field 2. In this regard, organic mulches promoted more water retention and nutrient availability in the soil (Pou et al., 2021), which could lead to increased cluster growth and size. This could reduce the relative proportion between skin and pulp and consequently decrease the phenolic content in these treatments due to a dilution effect (Gil et al., 2018).

3.3. *Canonical discriminant analysis on wine phenolic composition*

Principal component analysis (PCA) plots were performed on each field, analysing the effect of the main phenolic groups on the soil management treatments (see Fig. A1 in the appendix). However, the graphs did not discriminate between the soil treatments analysed. For this reason, a canonical discriminant analysis (CDA) was performed (Fig. 1) showing the maximum differences between wines from different soil management treatments according to their phenolic composition.

Function 1 explained 54.2% of the variability, and function 2 explained 24.2%. Thus, the cumulative explained variance was 78.4%. Function 1 separated conventional soil management practices (HERB and TILL) from mulching treatments (STR, GPD and SMC). In addition, Function 2 allowed distinguishing SMC soil management from STR and GPD. The multivariate CDA analysis focuses on finding linear combinations that maximise soil treatment separation and minimise variability. In this sense, it is essential to analyze the data deeply to identify the most influential variables in each case. This analysis does not consider the concentration of the compounds examined, so their influence on wine phenolic content could be minimal. The conventional soil management treatments (TILL and HERB) outperformed the organic mulches (GPD, STR and SMC) by 92% phenols with an average amount of <0.1 mg/L. Syringetin, ferulic acid, procyanidin C1, and kaempferol glucuronide were the most concentrated influenced compounds, with a total cumulative influence of 4% in Function 1.

Function 2 distinguished the organic mulch treatments (SMC of GPD and STR). This function was mainly influenced (96%) by low-concentrated compounds. Among the most abundant molecules, ferulic acid, myricetin galactoside, caffeic acid, procyanidin C1 and syringetin were the most influencing polyphenols in graph distribution (2.5%). Overall, data clustering was determined (92%) by low-concentrated compounds (< 0.1 mg/L) on the phenolic profile of the wine. The same analysis without considering minor compounds (data not shown) indicated no differences between the treatments analysed. Therefore, although the analyses theoretically found differences in the phenolic profile between the different soil management practices, their perception of the wines is questionable due to the slight influence of these phenolic compounds at low concentrations.

3.4. *Sensory analysis*

Fig. 2 shows the sensory evaluation of the wine samples, including overall organoleptic assessment (reverse scoring) (Fig. 2a) and aromatic

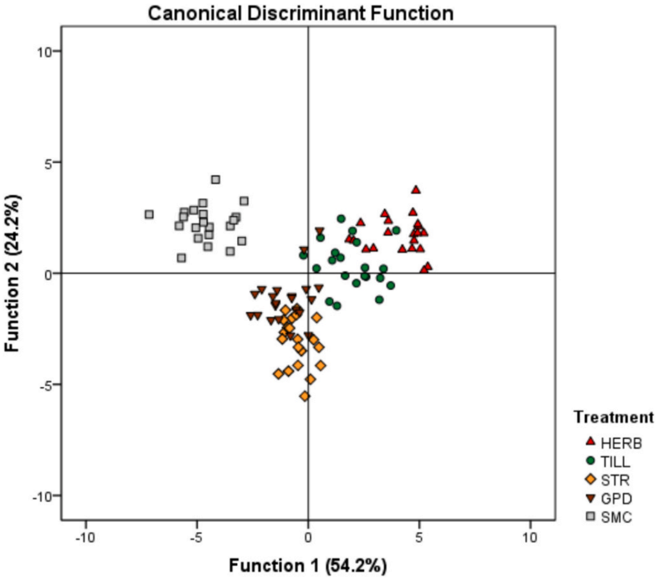


Fig. 1. Canonical discriminant distribution of wine samples made from different intra-row soil management practices (herbicide (HERB), intra-row tillage (TILL) and mulches of straw (STR), grapevine pruning debris (GPD) and spent mushroom compost (SMC)) based on their phenolic composition.

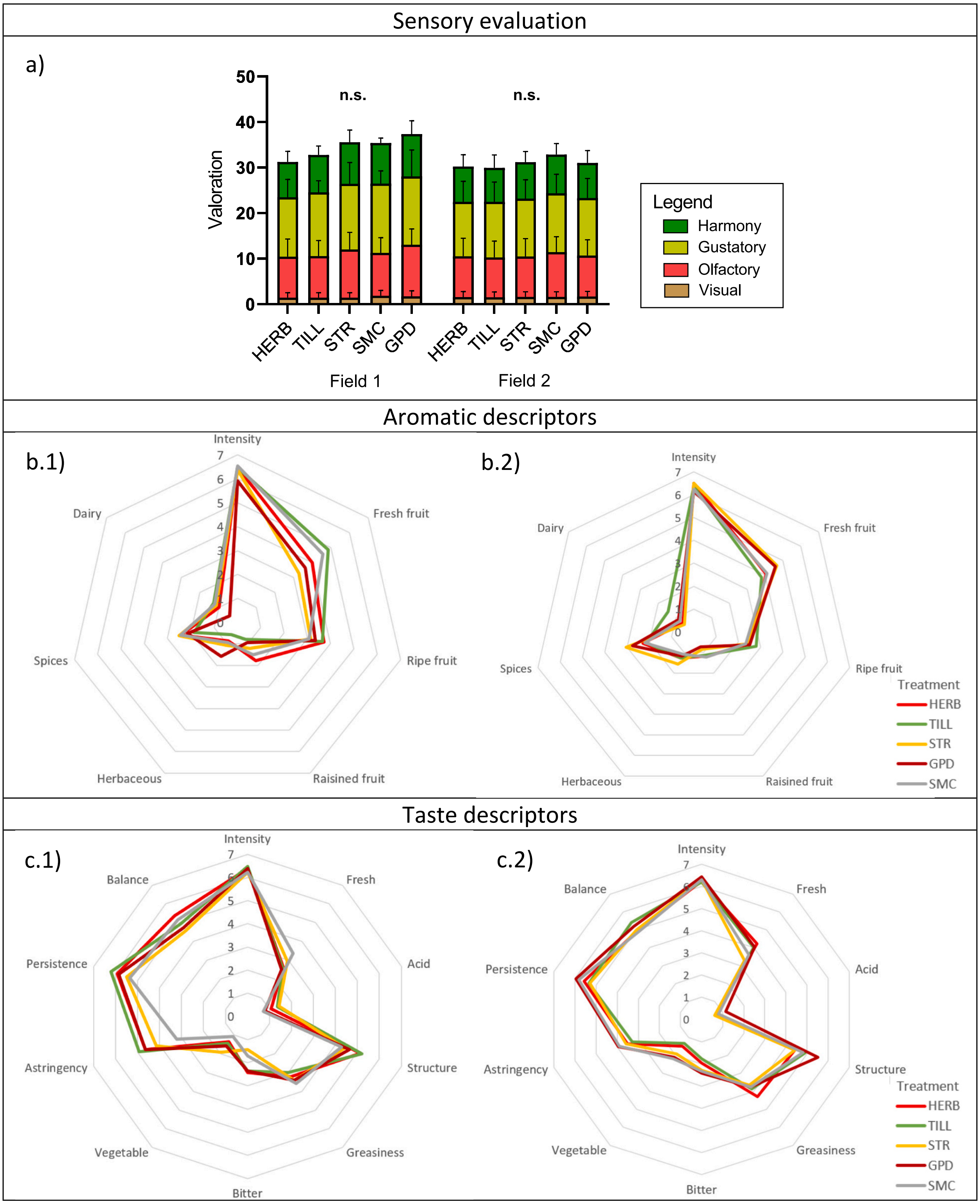


Fig. 2. Sensory average evaluation (a), aromatic (b) and taste (c) descriptors of wines with different soil treatments (herbicide (HERB), intra-row tillage (TILL) and using mulching of straw (STR), grapevine pruning debris (GPD) and spent mushroom compost (SMC)) in Field 1 (1) and Field 2 (2). n.s. = non-significance.

and taste descriptors (Fig. 2b and c, respectively). No previous studies examined the organoleptic properties of wines made from intra-row organic mulches, so our research is the first to investigate the influence of this practice on wine organoleptic evaluation.

As shown in Fig. 2a, no significant differences were found among wines made from the soil management treatments in any of the two fields. Therefore, despite the significant differences in physical-chemical and phenolic parameters (Tables 1–4), organic mulching did not affect the organoleptic evaluation of these red wines according to our tasting panel. Despite differences in certain chemical parameters, the lack of significant sensory differences between soil management treatments may be attributed to their negligible effect on organoleptic properties. It is important to note that the sensory perception of wine is influenced by a multitude of factors beyond just its chemical composition, including structural characteristics and complex interactions between volatile and non-volatile compounds (Yang & Lee, 2020). Nevertheless, these findings should be approached with caution, despite being derived from a multi-year study conducted across different locations, which lends robustness to the data. It is important to acknowledge a significant limitation: the relatively small number of tasters involved in the tasting panel. Despite the study's replication in two separate locations and four years, this aspect may impact the generalizability of the results. In addition, it is important to acknowledge that this sensory evaluation was conducted immediately after wine production. Differences in sensory attributes are expected to evolve over time due to factors such as oxidation and flavor stabilisation during aging, which unfortunately were not analysed in this experiment. In light of these considerations, future research could explore sensory evaluations of aged wines to capture potential differences in sensory perception that may emerge over time.

4. Conclusions

This study was the first to assess intra-row organic mulches' influence on wine's detailed phenolic composition and sensory properties by conducting a 4-year experiment replicated in two different locations. Mulching application can increase nutrient and water availability leading to wines with specific characteristics when compared to traditional soil treatments. In our study, mulched vines resulted in wines with higher pH, potassium, lactic acid, and hue values, and lower tartaric acid content. These results suggest that mulching may have a negative impact on wine quality. However, only minor differences were found in wine color determinations such as color intensity, total polyphenol index, or CIELaB parameters. Regarding the effect of organic mulches on wine phenolic composition, we observed great differences between the results obtained from the two fields, suggesting that soil and climate properties could have a significant impact on the final effect of organic mulches on wine quality. In this sense, vines mulched with SMC in Field 1 resulted in wines with lower concentrations of anthocyanins, flavonols, and hydroxycinnamic acids. However, except for anthocyanins, we observed minor variations in Field 2, probably because this field had already a great fertility prior to the beginning of the experiment. Moreover, wines from the different treatments were grouped according to their phenolic composition, although the compounds which contributed most to this separation were presented at very low concentrations. Finally, the tasting panel was not able to identify significant differences between wines. For this reason, we suggest using organic mulching in cv. Tempranillo grapes to make viticulture more environmentally sustainable and adaptable to current and future climate restrictions with minimal impact on young wine quality. However, more studies should be performed to study the evolution of wine composition and sensory properties through aging, as wines from mulching treatments may have negative characteristics in traits like pH, tartaric acid, or hue, which could made them less suitable for aging.

Declaration of generative AI in scientific writing

During the preparation of this work, the author Andreu Mairata, used the tools "ChatGPT" and "Grammarly" to improve the grammar and syntax of the text. After using this tool, all the authors reviewed and edited the content as needed and took full responsibility for the content of the publications.

CRediT authorship contribution statement

Andreu Mairata: Writing – original draft, Investigation, Data curation, Conceptualization. **Alicia Pou:** Supervision, Funding acquisition, Conceptualization. **Juana Martínez:** Investigation. **Miguel Puelles:** Investigation. **David Labarga:** Investigation. **Javier Portu:** Supervision, Investigation, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no financial interests or personal relationships that could influence the work reported in this article.

Data availability

Data will be made available on request.

Acknowledgements

The authors thank Pernod Ricard and D. Mateos for sharing their vineyards. This research was supported by the European Regional Development Fund (ERDR) and Ministerio de Ciencia e Innovación (MCIN) (RTI2018-095748-R-I00). A.M. thanks ERDR/MCIN for his predoctoral fellowship (PRE2019-089110). MP and DL thank Gobierno de La Rioja for their FPI research grants. The authors would like to thank Miguel Ángel Fernández-Recio, technical staff at the ICVV, for his UHPLC-QqQ(MS/MS) technical support and analysis performance in the anthocyanin and phenol analysis. We authors would like to remark that the UHPLC-QqQ (MS/MS) method used for the performance of the analysis was developed at the ICVV Instrumental Analysis Research Service.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodchem.2024.140045.

References

Agnew, R. H., Mundy, D. C., Spiers, T. M., & Greven, M. M. (2005). Waste stream utilisation for sustainable viticulture. *Water Science and Technology, 51*(1), 1–8. https://doi.org/10.2166/wst.2005.0001

Allegro, G., Pastore, C., Valentini, G., & Filippetti, I. (2021). The evolution of phenolic compounds in *vitis vinifera* l. red berries during ripening: Analysis and role on wine sensory—A review. *Agronomy, 11*(5), 999. https://doi.org/10.3390/agronomy11050999

Artero, A., Artero, A., Tarín, J. J., & Cano, A. (2015). The impact of moderate wine consumption on health. *Maturitas, 80*(1), 3–13. https://doi.org/10.1016/J.MATURITAS.2014.09.007

Benito, S. (2018). The impacts of *Lachancea thermotolerans* yeast strains on winemaking. *Applied Microbiology and Biotechnology, 102*, 6775–6790. https://doi.org/10.1007/s00253-018-9117-z

Blanco-Pérez, R., Vicente-Díez, I., Pou, A., Pérez-Moreno, I., Marco-Mancebón, V. S., & Campos-Herrera, R. (2022). Organic mulching modulated native populations of entomopathogenic nematode in vineyard soils differently depending on its potential to control outgrowth of their natural enemies. *Journal of Invertebrate Pathology, 192*, Article 107781. https://doi.org/10.1016/j.jip.2022.107781

Buesa, I., Mirás-Avalos, J. M., De Paz, J. M., Visconti, F., Sanz, F., Yeves, A., … Intrigliolo, D. S. (2021). Soil management in semi-arid vineyards: Combined effects of organic mulching and no-tillage under different water regimes. *European Journal of Agronomy, 123*, Article 126198. https://doi.org/10.1016/j.eja.2020.126198

Burg, P., Čížková, A., Mašán, V., Sedlar, A., Matwijczuk, A., & Souček, J. (2022). The effect of mulch materials on selected soil properties, yield and grape quality in vineyards under central European conditions. *Agronomy, 12*(8), 1862. https://doi.org/10.3390/agronomy12081862

Caruso, G., Carputo, D., Conti, S., Borrelli, C., Maddaluno, P., & Frusciante, L. (2013). Effect of mulching and plant density on out-of-season organic potato growth, yield and quality. *Advances in Horticultural Science, 27*(3), 115–121.

Cataldo, E., Salvi, L., Sbraci, S., Storchi, P., & Mattii, G. B. (2020). Sustainable viticulture: Effects of soil management in Vitis vinifera. *Agronomy, 10*(12). https://doi.org/10.3390/agronomy10121949

Chan, K. Y., & Fahey, D. J. (2011). Effect of composted mulch application on soil and wine grape potassium status. *Soil Research, 49*(5), 455–461. https://doi.org/10.1071/SR11084

Chan, K. Y., Fahey, D. J., Newell, M., & Barchia, I. (2010). Using composted mulch in vineyards—Effects on grape yield and quality. *International Journal of Fruit Science, 10*(4), 441–453. https://doi.org/10.1080/15538362.2010.530135

Esteban-Fernández, A., Muñoz-González, C., Jiménez-Girón, A., Pérez-Jiménez, M., & Pozo-Bayón, M.Á. (2018). Aroma release in the oral cavity after wine intake is influenced by wine matrix composition. *Food Chemistry, 243*, 125–133. https://doi.org/10.1016/j.foodchem.2017.09.101

Flamini, R., Mattivi, F., De Rosso, M., Arapitsas, P., & Bavaresco, L. (2013). Advanced knowledge of three important classes of grape phenolics: Anthocyanins, stilbenes and flavonols. *International Journal of Molecular Sciences, 14*(10), 19651–19669. https://doi.org/10.3390/ijms141019651

Gambuti, A., Picariello, L., Rinaldi, A., Forino, M., Blaiotta, G., Moine, V., & Moio, L. (2020). New insights into the formation of precipitates of quercetin in Sangiovese wines. *Journal of Food Science and Technology, 57*(7), 2602–2611. https://doi.org/10.1007/s13197-020-04296-7

Gil, P. M., Lobos, P., Durán, K., Olguín, J., Cea, D., & Schaffer, B. (2018). Partial root-zone drying irrigation, shading, or mulching effects on water savings, productivity and quality of "Syrah" grapevines. *Scientia Horticulturae, 240*, 478–483. https://doi.org/10.1016/J.SCIENTA.2018.06.050

Gutiérrez, I. H., Lorenzo, E. S.-P., & Espinosa, A. V. (2005). Phenolic composition and magnitude of copigmentation in young and shortly aged red wines made from the cultivars, cabernet sauvignon, Cencibel, and Syrah. *Food Chemistry, 92*(2), 269–283. https://doi.org/10.1016/j.foodchem.2004.07.023

Gutiérrez-Escobar, R., Aliaño-González, M. J., & Cantos-Villar, E. (2021). Wine polyphenol content and its influence on wine quality and properties: A review. *Molecules, 26*(3), 718. https://doi.org/10.3390/molecules26030718

Gutiérrez-Gamboa, G., Zheng, W., & Martínez de Toda, F. (2021). Current viticultural techniques to mitigate the effects of global warming on grape and wine quality: A comprehensive review. *Food Research International, 139*, Article 109946. https://doi.org/10.1016/j.foodres.2020.109946

Heras-Roger, J., Alonso-Alonso, O., Gallo-Montesdeoca, A., Díaz-Romero, C., & Darias-Martín, J. (2016). *Journal of Food Science and Technology, 53*(6), 2540–2547. https://doi.org/10.1007/s13197-016-2210-3

Jiang, P., Sun, Q., Zhang, J., & Wang, R. (2022). Effect of various mulches on soil chemical properties and rhizosphere Bacteria of wine grape (*Vitis vinifera*). *International Journal of Agriculture and Biology, 27*(2), 165–174. https://doi.org/10.17957/IJAB/15.1913

Lipka, Z., & Tanner, H. (1974). Une nouvelle méthode de dosage du acide tartarique dans les moûts, les vins et autres boissons (selon Rebelein). In *Revue Suisse de Viticulture Arboriculture et Horticulture* (6th, pp. 5–10).

Mairata, A., Labarga, D., Puelles, M., Huete, J., Portu, J., Rivacoba, L., & Pou, A. (2023). The organic mulches in vineyards exerted an influence on spontaneous weed cover and plant biodiversity. *European Journal of Agronomy, 151*, Article 126997. https://doi.org/10.1016/j.eja.2023.126997

Mpelasoka, B. S., Schachtman, D. P., Treeby, M. T., & Thomas, M. R. (2003). A review of potassium nutrition in grapevines with special emphasis on berry accumulation. *Australian Journal of Grape and Wine Research, 9*(3), 154–168. https://doi.org/10.1111/j.1755-0238.2003.tb00265.x

Mundy, D. C., & Agnew, R. H. (2002). Effects of mulching with vineyard and winery waste on soil fungi and botrytis bunch rot in Marlborough vineyards. *New Zealand Plant Protection, 55*, 135–138. https://doi.org/10.30843/nzpp.2002.55.3942

OIV, (International Organisation of Vine and Wine). (2022). *Compendium Of International Methods Of Wine And Must Analysis*.

Parpinello, G. P., Versari, A., Chinnici, F., & Galassi, S. (2009). Relationship among sensory descriptors, consumer preference and color parameters of Italian Novello red wines. *Food Research International, 42*(10), 1389–1395. https://doi.org/10.1016/j.foodres.2009.07.005

Pérez-Jiménez, M., Esteban-Fernández, A., Muñoz-González, C., & Pozo-Bayón, M. A. (2020). Interactions among odorants, phenolic compounds, and oral components and their effects on wine aroma volatility. *Molecules, 25*(7), 25071701. https://doi.org/10.3390/molecules25071701

Poni, S., Gatti, M., Palliotti, A., Dai, Z., Duchêne, E., Truong, T.-T., Ferrara, G., Matarrese, A. M. S., Gallotta, A., Bellincontro, A., Mencarelli, F., & Tombesi, S. (2018). Grapevine quality: A multiple choice issue. *Scientia Horticulturae, 234*, 445–462. https://doi.org/10.1016/j.scienta.2017.12.035

Portu, J., Rosa Gutiérrez-Viguera, A., González-Arenzana, L., & Santamaría, P. (2023). Characterization of the color parameters and monomeric phenolic composition of 'Tempranillo' and 'Graciano' wines made by carbonic maceration. *Food Chemistry, 406*. https://doi.org/10.1016/j.foodchem.2022.134327

Pou, A., Mairata, A., Rodrigo, E., Labarga, D., García-Escudero, E., Huete, J., & Martínez-Vidaurre, J. M. (2021). Effects of organic mulches on the soil temperature, humidity and CO_2 emissions. *International Journal of Environmental Sciences & natural Resources, 29*(3). https://doi.org/10.19080/IJESNR.2021.29.556265

Rivero, F. J., González-Miret, M. L., Jara-Palacios, M. J., García-Estévez, I., Escribano-Bailón, M. T., Heredia, F. J., & Gordillo, B. (2020). Copigmentation potential of overripe seeds from sun-dried white grapes on anthocyanins colour and stability by differential colorimetry. *International Journal of Food Science and Technology, 55*, 389–396.

ROU. (2003). *Recycled organics products in intensive agriculture. A review of recycled organics products application field trials in intensive agriculture in Australia. 1*.

de Souza, C. R., da Mota, R. V., Silva, C. P. C., Raimundo, R. H. P., Fernandes, F. P., & Peregrino, I. (2019). Row orientation effects on Syrah grapevine performance during winter growing season. *0Revista Ceres, 66*(3), 184–190. https://doi.org/10.1590/0034-737X201966030004

Steenwerth, K., & Guerra, B. (2012). Influence of floor management technique on grapevine growth, disease pressure, and juice and wine composition: A review. *American Journal of Enology and Viticulture, 63*(2), 149–164. https://doi.org/10.5344/ajev.2011.10001

Varga, P., & Májer, J. (2004). The use of organic wastes for soil-covering of vineyards. *Acta Horticulturae, 652*, 191–197. https://doi.org/10.17660/ActaHortic.2004.652.23

Virdis, C., Sumby, K., Bartowsky, E., & Jiranek, V. (2021). Lactic acid Bacteria in wine: Technological advances and evaluation of their functional role. *Frontiers in Microbiology, 11*, Article 612118. https://doi.org/10.3389/fmicb.2020.612118

Waterhouse, A. L., Sacks, G. L., & Jeffery, D. W. (2016). *Understanding wine chemistry* (1st ed.). John Wiley & Sons, Ltd.

Yang, J., & Lee, J. (2020). Current research related to wine sensory perception since 2010. *Beverages, 6*(3), 1–18. https://doi.org/10.3390/beverages6030047

Zhang, B., Wang, X.-Q., Yang, B., Li, N.-N., Niu, J.-M., Shi, X., & Han, S.-Y. (2021). Copigmentation evidence of phenolic compound: The effect of caffeic and rosmarinic acids addition on the chromatic quality and phenolic composition of cabernet sauvignon red wine from the Hexi corridor region (China). *Journal of Food Composition and Analysis, 102*, Article 104037. https://doi.org/10.1016/j.jfca.2021.104037

Zhang, Q. L., Chen, Y., Song, B. Z., Wang, Z., Lu, Y. F., Zhang, J., … Yao, Y. C. (2014). Influence of a pre-harvest reflective orchard mulching film on lipid peroxidation and anti-oxidant activity in apple fruit during post-harvest storage. *Journal of Horticultural Science and Biotechnology, 89*(5), 557–563. https://doi.org/10.1080/14620316.2014.11513123