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SPECIAL ISSUE

Are white wines from disease-resistant hybrid grapes comparable to *Vitis vinifera*? A chemical and sensory analysis from South Tyrol

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ABSTRACT

This study compared white wines from disease-resistant hybrid grape cultivars (DRHGCs) and *Vitis vinifera* L. cultivars in South Tyrol, Italy. Commercial wines from local wineries, including conventional cultivars ('Pinot blanc', 'Pinot gris', 'Chardonnay', 'Gewürztraminer', 'Kerner', and white blends) and DRHGCs ('Souvignier gris', 'Bronner', 'Johanniter', 'Solaris', 'Muscaris', and white blends) were studied. Metabolomic methods (liquid chromatography-mass spectrometry, LC-MS, and two-dimensional gas chromatography with mass spectrometry, GC × GC-MS) were combined with sensory analysis by semi-trained panellists (modified rate-all-that-applies, mRATA, and projective mapping, Napping). The data were subsequently analysed using multiple factor analysis (MFA) and analysis of coinertia. Based on the MFA, neither chemical nor sensory analysis could distinguish satisfactorily between DRHGC and *V. vinifera* wines, suggesting that the two types of wine are not as distinctive as previously thought. However, some significant differences were noted between a small number of specific variables for DRHGC and *V. vinifera* wines, such as the sensory characters olfactory 'honey' and olfactory 'pineapple', as well as in the volatile compounds 1-hexanol and limonene. Several compounds that are suggested to have antimicrobial, antifungal, and/or antiviral properties in the literature were found at significantly higher levels in the studied DRHGC wines than in the studied *V. vinifera* wines and therefore might be relevant to the disease tolerance of these cultivars. The analysis of coinertia showed strong relationships between sensory and chemical properties. These results suggest that the primary barrier to commercial adoption of white DRHGCs for wine production may be consumer and producer unfamiliarity rather than wine quality or the presence of unfamiliar sensory properties.

KEYWORDS: disease-resistant hybrid grape cultivars, sensory analysis, GC × GC-MS, LC-MS, multifactor analysis, oligomeric proanthocyanidins, volatile compounds, Macrowine 2025

INTRODUCTION

This study compared the chemical and sensory profiles of white disease-resistant hybrid grape cultivar (DRHGC) and *Vitis vinifera* L. wines from South Tyrol and builds on our work on red wine (Duley *et al.,* 2025), linking DRHGC chemistry with wine sensory properties. This previous study found red wines produced from DRHGCs to be distinctive in terms of both chemical and sensory properties from red wines produced from *V. vinifera*.

DRHGCs are known to be distinctive from *V. vinifera* in terms of their chemical and sensory properties, but most work to date has concerned red grapes and wines. However, it appears that the chemical and sensory properties of white DRHGCs may be less distinct from those of white *V. vinifera* than for red cultivars (Socha *et al.,* 2015).

One of the few white DRHGCs that has been extensively studied is *Vitis* sp. 'Vidal', given its importance for ice wine production in Canada (Bowen & Reynolds, 2012; Chisholm *et al.,* 1994; Chisholm *et al.,* 1995; Slegers *et al.,* 2017). Chisholm *et al.* (1994) compared the volatile profile of *V. vinifera* 'Riesling' with DRHGCs *Vitis* sp. 'Vidal blanc', 'Seyval blanc', and 'Cayuga White'. The presence of compounds known to be specific to DRHGCs was noted, albeit not in concentrations high enough to have a major impact on wine sensory properties. Methyl anthranilate ('grape' aroma) was noted in all DRHGCs but not in 'Riesling', while o-aminoacetophenone ('animal' aroma) was present in trace amounts in 'Cayuga White' and 'Seyval blanc' but not in 'Riesling' or 'Vidal'. Furaneol ('cotton candy', 'strawberry', or 'caramel' aroma) was tentatively considered to be present in 'Vidal blanc' and 'Cayuga White' but not in 'Sevyal blanc' or 'Riesling', based on acetate extracts (Chisholm *et al.,* 1994).

In contrast, a comparison of *V. vinifera* 'Riesling' and DRHGC 'Vidal blanc' by Bowen and Reynolds (2012) did not detect any of the compounds considered to be characteristic of DRHGCs. However, ethyl 2-methylbutyrate ('fruity' aroma), ethyl valerate ('coffee' aroma), 1-heptanol ('vinyl/plastic' aroma), and isoamyl acetate ('banana' aroma) were detected in 'Vidal blanc' but not in 'Riesling', while 2-phenylethyl acetate ('floral' aroma), ethyl cinnamate ('fruity' aroma), and β-ionone ('floral' aroma) were detected in 'Riesling' but not in 'Vidal'.

Less work has been done to date on the sensory properties of DRHGC white wines. Fuentes-Espinoza *et al.* (2018) looked at consumer response to white wines produced from the Vitis sp. 'Bouquet 3159' DRHGC, compared with three (Aude IGP, standard conventional; Languedoc PDO, premium conventional; and organic Languedoc regional wine) *V. vinifera* white wine. Unlike the present study, Fuentes-Espinoza *et al.* (2018) conducted the test with consumers rather than with trained panellists. Consumers gave higher hedonic ratings to the conventional wines. However, they did not completely reject the DRHGC wine, and the ratings for the standard conventional and organic wine were not significantly different from that of the resistant variety, given the variability in consumer hedonic ratings. This was reflected more strongly in consumer willingness to pay. Providing consumers with information on the environmental impact of wine production (in the form of information about pesticide residue and frequency of pesticide usage) for the DRHGC and organic wine changed this radically, and led to consumers being willing to pay more for the DHRGC and organic wines. This led to it becoming the top-selling wine, suggesting that DRHGC wines could compete well against entry-level *V. vinifera* wines.

Socha *et al.* (2015) compared varietal and blended DRHGC white wines from cold-hardy cultivars with a blended *V. vinifera* white wine from a vineyard in Poland. However, sensory analysis was not undertaken, and only measurements of CIELab colour, phenolic content (total phenolic content and HPLC), and antioxidant activity were obtained. The *V. vinifera* white blend had the highest total phenolic acids. This was particularly true for caffeic acid, which was the only phenolic acid that was significantly different between the DRHGC and *V. vinifera* wines (DRHGC 1.503, *V. vinifera* 10.30, $p = 0.00343$, ANOVA, re-analysed). The paper noted that high levels of caffeic acid were typical of Polish wines due to the cold climate conditions. The *V. vinifera* wine was also higher in (+)-catechin and quercetin than the DHRGC wines, but the difference was not significant ($p > 0.05$, ANOVA, re-analysed). There were no differences in colour between the white DRHGC and *V. vinifera* wines ($p > 0.05$, ANOVA, re-analysed). Consequently, a PCA did not separate the DRHGC and *V. vinifera* white wines.

Norton *et al.* (2023) examined consumer preference for DRHGC wines produced in Iowa, USA, but did not use descriptive analysis or compare DRHGC wines with *V. vinifera* wines. Interestingly, they noted that Midwestern American consumers exhibited a preference for wines with a 'grapey', 'foxy' character indicative of cultivars with *Vitis labrusca* genetic heritage.

Kiefer and Szolnoki (2023) compared several wines made from both DRHGCs and *V. vinifera* using different cultivars and styles, using a panel of consumers who were segmented into different market types based on factors such as wine knowledge. Wine preference differed by market segment, with young wine enthusiasts preferring the macerated *Vitis* sp. 'Sauvignac' wine, where experts preferred the 'premium' 'Sauvignac' wine. A slight preference for the *V. vinifera* 'Sauvignon blanc' wine was noted, however.

Liu *et al.* (2015) examined the chemical and sensory profiles of commercially produced Danish DRHGC white wines from *Vitis* sp. 'Solaris', but no comparison with *V. vinifera* wines was made. The wines were moderate to low in acidity despite the cold climate region, indicating that this cultivar is particularly suited to colder regions and higher altitudes. The wines were defined by esters, particularly ethyl esters of fatty acids, and higher alcohols. The sensory profile of the wines varied but was typically characterised by attributes such as green apple, citrus, elderflower, muscat, peach, and black

pepper, while less successful wines were dominated by wood, chemical, and rooibos/smoke attributes. Similar attributes were also seen in Danish 'Solaris' by Zhang *et al* (2015). Nordmark *et al.* (2016) also used sensory analysis to examine DRHGC white wines from 'Solaris' produced from several vineyards in southern Sweden, also without comparison with *V. vinifera* wines. Swedish 'Solaris' wines were found to differ in sensory properties between vintages and vineyards, with 'citrus', 'green apple', 'floral', and 'elderflower' aromas, and intensity, 'citrus', 'acidic', 'fresh', 'green apple', and 'grapefruit' gustatory character being most important.

The *V. vinifera* cultivars that are most widely grown in South Tyrol are the international cultivars *V. vinifera* 'Pinot Grigio' ('Grauburgunder', 'Pinot gris', 699 ha), 'Chardonnay' (650 ha), 'Gewürztraminer' (634 ha), 'Pinot Bianco' ('Weißburgunder', 'Pinot blanc', 610 ha), 'Sauvignon blanc' (497 ha), 'Kerner' (129 ha), 'Müller-Thurgau' (135 ha), 'Sylvaner' (106 ha), 'Riesling' (105 ha), 'Goldmuskateller' ('Moscato Giallo', 96 ha), 'Grüner Veltliner' (27 ha), and 'Welschriesling' (areas under cultivation from Consorzio Alto Adige Wines (2024b)). A smaller number of producers have planted white DRHGCs, including *Vitis* sp. 'Souvignier gris' (31.6 ha), 'Solaris' (22.9 ha), 'Bronner' (14.1 ha), 'Muscaris' (5.1 ha), 'Johanniter' (3.0 ha), and Diolinoir (0.4 ha) (area under cultivation from Consorzio Alto Adige Wines (2024a)).

This study aimed to compare DRHGC and *V. vinifera* wines produced in South Tyrol. While it is known that there are clear differences in wine chemistry between red DRHGCs and *V. vinifera* cultivars, there is currently little detail in the literature regarding these differences in white wines. Therefore, this study used a combination of sensory and chemical data to characterise and compare DRHGC and *V. vinifera* wines. It was hypothesised that semi-trained panellists would be able to distinguish between DRHGC wines and conventional wines, but would not have a preference between the two.

MATERIALS AND METHODS

1. Samples

Already bottled commercial wines were bought from or donated by local wineries in South Tyrol, northern Italy. Wine samples included wines that were labelled as *V. vinifera* cultivars ('Pinot Bianco', 'Pinot Grigio', 'Chardonnay', 'Gewürztraminer', 'Kerner', and white blends) and DRHGCs ('Souvignier gris', 'Bronner', 'Johanniter', 'Solaris', 'Muscaris', and white blends). However, as is typical, varietally labelled wines can contain up to 15 % of other varieties. This is an unavoidable limitation of using commercially produced wines. The varietal composition was confirmed with the winery, where possible. During the sensory analysis, DRHGC wines were compared exclusively with *V. vinifera* wines of the same style from the same winery. A total of 22 wine samples were used, and a list of the samples used is shown in Table 1.

TABLE 1. Wine samples used in study.

Wine code	Type	Variety
Winery1_Kern	*Vitis vinifera*	'Kerner'
Winery1_PinotG	*Vitis vinifera*	'Pinot gris'
Winery1_DRHGC	DRHGC	White blend
Winery2_DRHGC	DRHGC	White blend
Winery2_CuveeSweet	*Vitis vinifera*	White blend
Winery2_CuveeDry	*Vitis vinifera*	White blend
Winery3_Char	*Vitis vinifera*	'Chardonnay'
Winery3_DRHGC	DRHGC	White blend
Winery4_Gew	*Vitis vinifera*	'Gewürztraminer'
Winery4_SouvGrisMac	DRHGC	'Gewürztraminer' (skin contact)
Winery5_Char	*Vitis vinifera*	'Chardonnay'
Winery5_SouvGris	DRHGC	'Souvignier gris'
Winery6_Bronner	DRHGC	'Bronner'
Winery6_PinotB	*Vitis vinifera*	'Pinot blanc'
Winery6_Solaris	DRHGC	'Solaris'
Winery6_SouvGris	DRHGC	'Souvignier gris'
Winery6_SouvGrisMac	DRHGC	'Souvignier gris' (skin contact)
Winery7_Johanniter	DRHGC	'Johanniter'
Winery7_Muscaris	DRHGC	'Muscaris'
Winery7_Solaris	DRHGC	'Solaris'
Winery7_SouvGris	DRHGC	'Souvignier gris'

2. Sensory analysis

Sensory analyses of DRHGC and *V. vinifera* wines were conducted in a similar method to that used for red wines in our previous paper (Duley *et al.,* 2025), except that the wines were presented over a larger number of sessions, given the larger number of samples. Each session covered one winery, with three replicates of two wines per session. Wineries with more than two wines to be tasted were split over two sessions. As described in the previous paper, both modified rate-all-that-applies (mRATA) and projective mapping (Napping ®) were used.

Briefly, the sensory analysis was conducted in three stages:

1. Round table: definition of visual, olfactory, and gustatory attributes by the panel;
2. Rapid training: one-hour sessions for each type of attribute, with three sessions overall; aroma, aroma and flavour, taste; and
3. Data collection: mRATA and Napping were used to describe the wines.

Cysensy, an SQL binding sensory analysis web software developed in collaboration with the Computer Science faculty of the Free University of Bozen/Bolzano, was used during the training and the mRATA sessions.

Projective mapping was performed using GeoGebra Classic (https://www.geogebra.org/classic). The napping sheets were created by drawing a 52 × 35 cm rectangle on the GeoGebra sheet (an example is provided in Figure S1), as reported previously (Mayhew *et al.,* 2016; Valentin *et al.,* 2018).

To give the panellists insight into the study and into DRHGC and *V. vinifera* wines, the project and the wines to be tasted were introduced to the panellists. This was followed by the round table session. During this session, panellists individually assessed each wine and listed descriptors related to its visual, olfactory, and gustatory characteristics using an interactive web whiteboard (Jamboard, Google, Mountain View, CA, USA). The shared attributes for each wine type were subsequently discussed by the panel leader and panellists, and this was used to compile the final sensory lexicon. Once the final sensory lexicon (Table S1) was defined, panellists were trained for those specific attributes. Panellists were trained with reference standards (Noble *et al.,* 1987) or natural standards if references were not available (Darnal *et al.,* 2023c). The definition of each sensory descriptor is given in Table S1. Training session one covered aroma (olfactory) attributes, while training session two covered gustatory attributes (taste and flavour) and the aroma attributes that had not been recognised (by more than 75 %) during the first training session.

Panellists were provided with detailed definitions of descriptors and instructions on conducting the sensory evaluation (sampling from left to right according to the order proposed) by the panel leader before the start of each sensory session during the data collection phase of the project. Panellists were reminded that the descriptors (Table S1) were related to olfactory evaluation, gustatory evaluation, and overall quality judgement (OQJ) (Dupas de Matos *et al.,* 2020). OQJ was defined as an overall evaluation of three aspects of the sensory analysis (visual, olfactory and gustatory), and should be considered an objective evaluation of the overall quality of the product (Poggesi *et al.,* 2022).

Samples were evaluated using both modified RATA (mRATA) and projective mapping methods. Sensory sessions during the data collection phase of the project were organised on a per-winery basis, with panellists presented with wines from a single, anonymised winery per session. Each session included both DRHGC and *V. vinifera* wines from the same winery. Panellists were presented with 30 mL wine samples, and each wine was sampled in triplicate. Where a single winery had more than three samples, its samples were split over two sessions with a maximum of nine samples (three wines in triplicate) per session. Wines were served in a randomised Latin Square incomplete block design to control for possible carry-over effects in each session (Valentin *et al.,* 2016). The wine samples were labelled with random 3-digit codes, and they were served in ISO glasses (ISO 3591:1977). The bottles were opened 30 min before the session.

For the mRATA, the panellists were asked to rate the intensity of each attribute from 0 to 5, where 0 was "does not apply", 1 was "weak", and 5 was "strong". Additionally, panellists performed projective mapping by positioning each sample on the GeoGebra file (an example is reported in Figure S1), and the X and Y coordinates of each sample were collected to the nearest centimetre from the lower left corner of the rectangle in the GeoGebra sheet. This method was used to achieve a rapid categorisation and characterisation of wines.

The study was conducted following the principles set out in the Declaration of Helsinki (World Medical Association, 2013). There was no cost to participate; refusal to participate did not imply any penalties or loss of benefits, and participants were permitted to withdraw at any time without giving any reason. Panellists were recruited voluntarily and signed an informed consent form in which they were informed about the presence of sulfites in the sample wines. Based on these statements and since the participants were instructed to spit the wine after the analysis and the samples were commercial products available on the market, approval from an ethics committee was not required (Darnal *et al.,* 2023c). The maximum quantity of wine was 30 mL per glass per session (Darnal *et al.,* 2023c). The wines contained approximately 13 % v/v ethanol (3.9 g of ethanol per 30 mL sample).

There were 12 assessors on the panel, of whom six were women and six were men, all aged between 25–35 years old. Water and unsalted crackers were provided for palate cleansing during every sensory session. The training and sensory sessions were conducted in the same room and at the same time for one month, to minimise the impact of location and time on the reproducibility of the sensory analysis.

3. Chemical analysis

Wines were analysed using LC-MS (Darnal *et al.,* 2023a), GC × GC-MS (Poggesi *et al.,* 2022), and a multiparametric analyser (Miura One, ISE Srl, Montecelio, RM, Italy).

3.1. LC-MS analyses

3.1.1. Monomeric polyphenols

Polyphenols were analysed using an LC/TQ 6465 UHPLC-QqQ/MS system (Agilent, Santa Clara, CA, USA), equipped with a 1260 Infinity II UHPLC with a quaternary pump system, a 1260 Infinity II WR PDA detector, and an AJS ESI QqQ mass analyser in series (Darnal *et al.,* 2023a; Darnal *et al.,* 2023b; Poggesi *et al.,* 2022).

Separation was achieved using a Poroshell 120 SB-C18 column (2.1 mm × 100 mm, 2.7 µm, Agilent) maintained at 30 °C. The mobile phases used were A: 0.1 % v/v formic acid in Millipore water, and B: 0.1 % v/v formic acid in LC-MS grade acetonitrile. The gradient programme started with 1 % B from 0 to 1.5 min, increased to 30 % B from 1.5 to 19 min, then to 99 % B from 19 to 20 min, held at 99 % B until 24 min, followed by a return to 1 % B from 24 to 25 min, with the run concluding at 30 min. The injection volume was 5 µL. The PDA detector captured absorbance in the 200–700 nm range, with a 4 s response time (1.25 Hz), 4 nm slit width, and 1 nm spectrum steps.

Mass spectrometry was performed in negative ionisation mode with the following parameters: mass range *m/z* 200–750, scan time 500 ms, step size 0.1 amu, fragmentor potential 135 V, cell acceleration 5 V, nitrogen gas temperature 340 °C, nitrogen flow rate 13 L min^{-1}, nebuliser pressure 50 psi, sheath gas heater 350 °C, sheath gas flow 12 L min^{-1}, capillary voltage −3500 V, and nozzle voltage −500 V.

The tentative identification of compounds was based on full-scan mass spectrometry and PDA λmax assignment for classification. For compounds that could not be fully identified, classification was made to the phenolic class level. Targeted MS/MS fragmentation (product ion monitoring, PRM) was performed on selected ions with the same source parameters as the MS1 analysis. The acquisition mass range was from *m/z* 25 to *m/z* +10 from the selected precursor ion, scan time was 125 ms, fragmentor potential 135 V, collision energy 25 V, and cell accelerator 5 V.

3.1.2. Oligomeric proanthocyanidins (PAC)

Oligomeric proanthocyanidins (PAC) were analysed separately using the same UHPLC-QqQ/MS system (Agilent LC/TQ 6465) (Darnal *et al.,* 2023a; Darnal *et al.,* 2023b; Poggesi *et al.,* 2022).

Chromatographic separation was performed on a Vertex Plus Eurospher II column (KNAUER, Berlin, Germany) with dimensions of 4.6 mm × 250 mm × 5 µm, along with a precolumn, maintained at 30 °C. The flow rate for separation was 0.7 mL min^{-1}. The mobile phases were: A, 0.1 % [v/v] formic acid in Millipore water, and B, 0.1 % [v/v] formic acid in LC-MS grade acetonitrile. The gradient programme included 1 % B from 0 to 2.5 min, increasing to 25 % B from 2.5 to 50 min, then 25 % to 99 % B from 50 to 51 min, maintained at 99 % B from 51 to 55 min, with a return to 1 % B from 55 to 56 min, and a final hold at 1 % B until 62 min. The injection volume was 5 µL.

The mass spectrometer operated in positive electrospray ionisation mode (ESI+), and the detection of proanthocyanidins was carried out in single-ion monitoring mode. The acquisition parameters for all wine samples are detailed in Table S2. The key parameters for MS detection were as follows: fragmentor potential 135 V, cell acceleration 5 V, nitrogen gas temperature 230 °C, nitrogen gas flow rate 8 L min^{-1}, nebuliser pressure 20 psi, sheath gas heater 300 °C, sheath gas flow rate 10 L min^{-1}, capillary voltage 3000 V, and nozzle voltage 2000 V. Feature selection, based on retention time and *m/z* ratio, was done through direct inspection of the acquired data. The selected features were used to extract peak intensities using MzMine3 software, resulting in a peak table. The retention times and tentative identifications of the compounds were compared to the findings of Darnal *et al.* (2023a); Darnal *et al.* (2023b) and Poggesi *et al.* (2022). The results are reported in Table S3.

In addition, percentage ratios (%) of cyclic tetrameric procyanidin (%C-4), cyclic tetrameric prodelphinidin with one (epi)gallocatechin, three (epi)catechins (%C-4-OH), and cyclic pentameric procyanidin (%C-5) were calculated as concentration-normalised parameters (Darnal *et al.,* 2023a). This is suggested in the literature as an indicator of wine authenticity and wine origin (Darnal *et al.,* 2023c; Poggesi *et al.,* 2022).

3.2. HS-SPME-GC × GC-ToF/MS analysis of volatile compounds

The volatile compound analysis was carried out as follows (Poggesi *et al.,* 2022). All samples were analysed simultaneously, immediately after the bottles were opened, to minimise sampling error and oxidation. Sample preparation involved adding 0.5 g of sodium chloride, 4 mL of wine, and 10 µL of 2-methyl-3-pentanol as an internal standard (from a 1/50 stock solution in ethanol) into a 10 mL solid-phase microextraction (SPME) glass vial. The vial was sealed with a perforable screwcap equipped with a silicon septum for automated SPME. SPME was performed using an LPAL3 GC autosampler (LECO Corporation, St Joseph, MI, USA) with a Peltier stack, keeping samples at 4 °C until analysis. A Stableflex SPME fibre (50/30 µm DVB/CAR/PDMS, 23 Ga needle size, Supelco, Bellefonte, PA, USA) was used. The SPME sample extraction was carried out as follows:

1. Sample incubation at 40 °C for 15 min with agitation at 300 rpm (5 s agitation, 2 s pause);
2. Sample extraction for 30 min (fibre penetration depth of 25 mm into the vial); and
3. Sample injection with a 6-minute desorption time in the GC split/splitless inlet (fibre penetration depth of 40 mm).

Before each analysis, the SPME fibre was preconditioned at 240 °C for 6 min. Separation was performed by comprehensive GC × GC using an Agilent 7890B GC system (Agilent, Santa Clara, CA, USA) coupled with a Pegasus BT 4D time-of-flight mass spectrometer (LECO), equipped with a Flux flow modulator (LECO). The separation was achieved using helium as the carrier gas at a flow rate of 1 mL min^{-1} in splitless mode, with a septum purge flow of 2 mL min^{-1} and an inlet purge flow of 6 mL min^{-1}. The inlet temperature was set at 240 °C. In GC × GC mode, separation was conducted using a polar cross-bond PEG-phase MEGA-Wax Spirit column (0.30 µm × 0.18 mm × 40 m, Mega S.r.l., Legnano, MI, Italy) as the first dimension, and a Rxi-17 Sil column (0.10 µm × 0.10 mm × (0.7 + 0.31) mm, Restek, Bellefonte, PA, USA) as the second dimension. The two columns were connected using a Flux modulator (LECO) with a 15.92 psi auxiliary helium flow. The secondary column was housed in a secondary oven, thermally isolated from the primary oven.

The primary oven temperature programme was as follows: hold at 40 °C for 6 min, then ramp up to 180 °C at 3 °C min^{-1}, followed by an increase to 240 °C at 10 °C min^{-1}, and hold at 240 °C for 1 min. The secondary oven was maintained at 5 °C higher than the primary oven, with the temperature programme adjusted in sync with the primary oven.

The GC × GC system was connected to the mass spectrometer via a transfer line set at 250 °C. The mass spectrometer operated with the following conditions: 0 s acquisition delay, 70 eV filament electron energy, 250 °C ion source temperature, 150 spectra s^{-1} acquisition rate, 32 kHz extraction frequency, and an acquisition mass range of *m/z* 35–530. The mass spectrometer was tuned before starting each new analysis sequence.

After each run, GC × GC chromatograms were reconstructed into 2D colour maps by deconvolution using ChromaTOF® software (LECO, version 2021). Automatic compound identification was performed by comparison with the NIST 2017 (NIST MS Search 2.3) database. Linear retention indices were calculated from first-dimension retention times using a series of injected linear fatty ethyl esters (C4–C24, even carbon-saturated, Merck, Darmstadt, Germany). The collected data underwent automatic alignment using ChromaTOF® (LECO, version 2021) software, and the resulting table was inspected and refined before statistical analysis. The volatile compounds identified, along with the codes assigned for statistical analysis, are shown in Table S4.

3.3. Basic oenological parameters

Basic oenological parameters were determined using a Miura One automatic analyser (Exacta+Optech Labcenter SpA, San Prospero, MO, Italy) for the following compounds: L-tartaric acid, L-malic acid, L-lactic acid, glucose, fructose, total sulfur dioxide, free sulfur dioxide, and total polyphenols. The reagent kits used for analysis were purchased from Exacta+Optech Labcenter SpA, and each parameter was calibrated using the corresponding reference standard provided by the supplier. pH measurements were conducted with an XS pH 60 VioLab benchtop pH metre (XS Instruments, Carpi, MO, Italy), which was calibrated using pH 7.0 and 4.0 buffer solutions (Darnal *et al.,* 2023a; Darnal *et al.,* 2023b; Poggesi *et al.,* 2022).

4. CIELab colorimetry

Measurements were made using a CR-400 colorimeter (Konica Minolta, Chiyoda-ku, Tokyo, Japan) according to the manufacturer's instructions using the CIE76 colourspace. For each sample, 20 mL of wine was measured.

In CIELab, parameter L* indicates lightness (L* 0 = black, L* 100 = diffuse white), parameter a* indicates green-magenta colours (negative values indicate green, positive values indicate magenta), and parameter b* indicates blue-yellow colours (negative values indicate blue, positive values indicate yellow) (Bakker *et al.,* 1986; Duley, 2021; Liang *et al.,* 2011).

Further derived parameters are h* and C*. Of these, h* indicates hue angle (degrees) and is calculated from h* = arctan b*/a*, while C* indicates chroma (saturation) and is calculated from $[(a^*)^2 + (b^*)^2]^{0.5}$ (Bakker *et al.,* 1986; Liang *et al.,* 2011).

5. Statistical analysis

Statistical analysis was conducted using GNU R (R Core Team, 2024) and 'tidyverse' (Wickham *et al.,* 2019) under Microsoft Windows 10. The datasets included 22 wine samples of ten different cultivars (plus white blends) from seven wineries (see Table 1). The basic oenological parameters dataset contained eight variables: mRATA, 24; Napping, 32; polyphenols (LC-MS), 238; PAC (LC-MS, 27; PAC percentage ratios, two; (GC × GC-MS), 81; and CIELab, five variables.

For all analyses, ANOVA was conducted to determine significance ($p \leq 0.05$) using the base R 'aov' function from the 'stats' package (R Core Team, 2024). The 'TukeyHSD' function ($\alpha = 0.05$) from the 'stats' package (R Core Team, 2024) or the 'HSD.test' function from the 'agricolae' package (de Mendiburu, 2023) were used to perform Tukey's Honestly Significant Difference (HSD) analysis for multiple comparisons. Significance was represented by groups and indicated by alphabetical letters, determined using the 'HSD.test' function from the 'agricolae' package. Stars indicating significance levels were determined using 'stars.pval' function from the 'gtools' package (Warnes *et al.,* 2023). For CIELab colorimetry, the ΔE* was calculated using R by comparing the average CIELab values for all DRHGC wines *vs* that for all *V. vinifera* wines.

Multiple factor analysis (MFA) was used to analyse a combined data set (sensory, chemical, and colorimetry). MFA was conducted using the 'FactoMineR' (Lê *et al.,* 2008) and 'factoextra' (Kassambara & Mundt, 2020) packages. The dataset used in the MFA can be seen in Table S5. Statistical significance (ANOVA) of the variables is shown in Table S6. MFA Cos^2 values can be seen in Table S7. Figures were compiled using the 'ggpubr' (Kassambara, 2023) package.

An analysis of coinertia was undertaken to examine the relationships between the sensory and chemistry datasets (Duley *et al.,* 2021) using the 'dudi.pca' and 'coinertia' functions of the 'ade4' package (Bougeard & Dray, 2018; Chessel *et al.,* 2004; Dray *et al.,* 2007; Dray & Dufour, 2007; Thioulouse *et al.,* 2018) and the adegraphics package (Siberchicot *et al.,* 2004; Thioulouse *et al.,* 2018). Pearson's correlation coefficients and their associated *p* values were determined using the 'rcorr' function of the 'Hmisc' package (Harrell Jr, 2023), and values can be seen in Tables S8 and S9. Figures were compiled using the 'ggpubr' (Kassambara, 2023) package.

Spider graphs for sensory analysis were drawn using R with the 'ggplot2' (Wickham, 2016) and 'reshape2' (Wickham, 2007) packages. Figures were compiled using the 'ggpubr' (Kassambara, 2023) package.

RESULTS AND DISCUSSION

1. Combined analyses

The MFA (Figure 1) shows that the chemical and sensory profiles of DRHGC and *V. vinifera* wines were similar. The first dimension represented 14.7 % of the variance, the second dimension was 9.95 %, and the third dimension represented 6.89 % of the variance; eight dimensions were required to explain more than 50 % of the variance (53.1 %). The low numbers seen are likely the result of the heterogeneity of the wine samples and the complexity of the dataset, hence, variation is spread across many dimensions rather than concentrated in the first few. Polyphenols represented 24.1 % of the first dimension, 12.9 % of the second dimension, and 10.1 % of the third dimension; CIELab represented 21.4 % of the first dimension, 5.40 % of the second dimension, and 6.47 % of the third dimension; Miura (basic oenological parameters) represented 18.2 % of the first dimension, 10.9 % of the second dimension, and 4.19 % of the third dimension; mRATA represented 14.5 % of the first dimension, 25.2 % of the second dimension, and 9.42 % of the third dimension. The partial axes can be seen in Figure 1B.

The graph of individuals (Figure 1A) shows that there is considerable overlap between the two groups, with few obvious patterns visible. The one sweet white wine (Winery2_CuveeSweet) and the macerated white wines were separated from the rest of the wines. The macerated wines (DRHGC 'Souvignier gris') were defined by pH (higher pH), olfactory 'honey', and the following compounds: x_280, x_105, x_319, pentamer_1, c_OH_tetramer, c_pentamer_1, isopropyl alcohol (LIV), and 2-methylpentanal (pentanal, 2-methyl-, LXXVII).

The effect of skin contact on pH is unsurprising, given that extended skin contact increases potassium levels and thus decreases wine acidity (Boulton, 1980; Kemp *et al.,* 2022; Sokolowsky *et al.,* 2015). This was also observed in the present study, with skin-contact wines having significantly higher pH than conventional wines (skin-contact wines pH 3.71, conventional wines pH 3.33, $p = 7.905 \times 10^{-9}$, ANOVA).

A previous study also found an increase in 'honey' character in skin-contact white wines but suggested this might be due to colour-driven bias (Sokolowsky *et al.,* 2015). A similar association was seen here (skin-contact wines 1.706, conventional wines 1.118, $p = 0.000227$, ANOVA), and the same effect was likely seen in the present study. This seems likely given that wine colour was significantly associated with skin-contact wines, which were perceived to be more yellow and less green than conventional wines (colour green: skin-contact wines 0.0685, conventional wines 0.9965, $p = 1.74 \times 10^{-13}$; colour yellow: skin-contact wines 4.639, conventional wines 2.252, $p = 0.13 \times 10^{-12}$, ANOVA).

Interestingly, bitterness was not strongly associated with skin-contact white wines in the MFA in contrast to previous findings (Kemp *et al.,* 2022; Sokolowsky *et al.,* 2015), but ANOVA showed a significant difference in bitterness between skin-contact and conventional wines (skin-contact wines 1.5, conventional wines 0.86, $p = 4.06 \times 10^{-6}$, ANOVA). This suggests that, while there was a significant difference between skin contact and conventional wines in terms of bitterness based on an ANOVA comparing the two groups directly, it was not important for the overall MFA. The panellists also perceived significant differences in astringency between skin-contact and conventional wines (skin-contact wines 1.6, conventional wines 1.1, $p = 0.000681$, ANOVA).

The sweet wine (*V. vinifera*, Winery2_CuveeSweet) was defined by residual sugars (fructose + glucose), but also by 'peach' flavour and aroma, 'rose' flavour and aroma, and trimer_OH_2. Although the varietal composition of the wine was not declared by the winery, 'peach' and 'rose' are typical sensory characteristics found in wines made from aromatic cultivars such as 'Moscato Giallo' and 'Gewürztraminer' (Chigo-Hernandez *et al.,* 2022).

No specific variables could be said to define either DRHGC or *V. vinifera* wines. This suggests that white DRHGC wines are not distinctive from white *V. vinifera* wines and are closer in chemical and sensory properties than previously considered. Volatile compounds with high cos^2 values (Table S7) included 4-ethyl-phenol (cos^2 0.592, LXXVII), isoamyl lactate (cos^2 0.418, LXXXI), benzyl alcohol (cos^2 0.409, XXXVII), and trans-β-damascenone (cos^2 0.381, 2-Buten-1-one, 1-(2,6,6-trimethyl-1,3-cyclohexadien-1-yl)-, (E)-, XI), indicating their importance to the analysis. However, these were not inevitably statistically significantly different between DRHGC and *V. vinifera* wines for all compounds (4-ethyl-phenol: DRHGCs 1108000, *V. vinifera* 442700, $p = 0.0396$; isoamyl lactate: DRHGCs 6554000, *V. vinifera* 5385000, $p = 0.591$; benzyl alcohol: DRHGCs 3594000, *V. vinifera* 1647000, $p = 0.0457$; trans-β-damascenone: DRHGCs 3300000, *V. vinifera* 1245000, $p = 0.0436$; ANOVA), underscoring that the MFA did not reliably distinguish between the two groups.

Similar trends can be seen in the analysis of coinertia (Figure 2). Analysis of coinertia is a two-table ordination method that uses a covariance matrix to show whether the variables from one dataset can be explained by another dataset (Dolédec

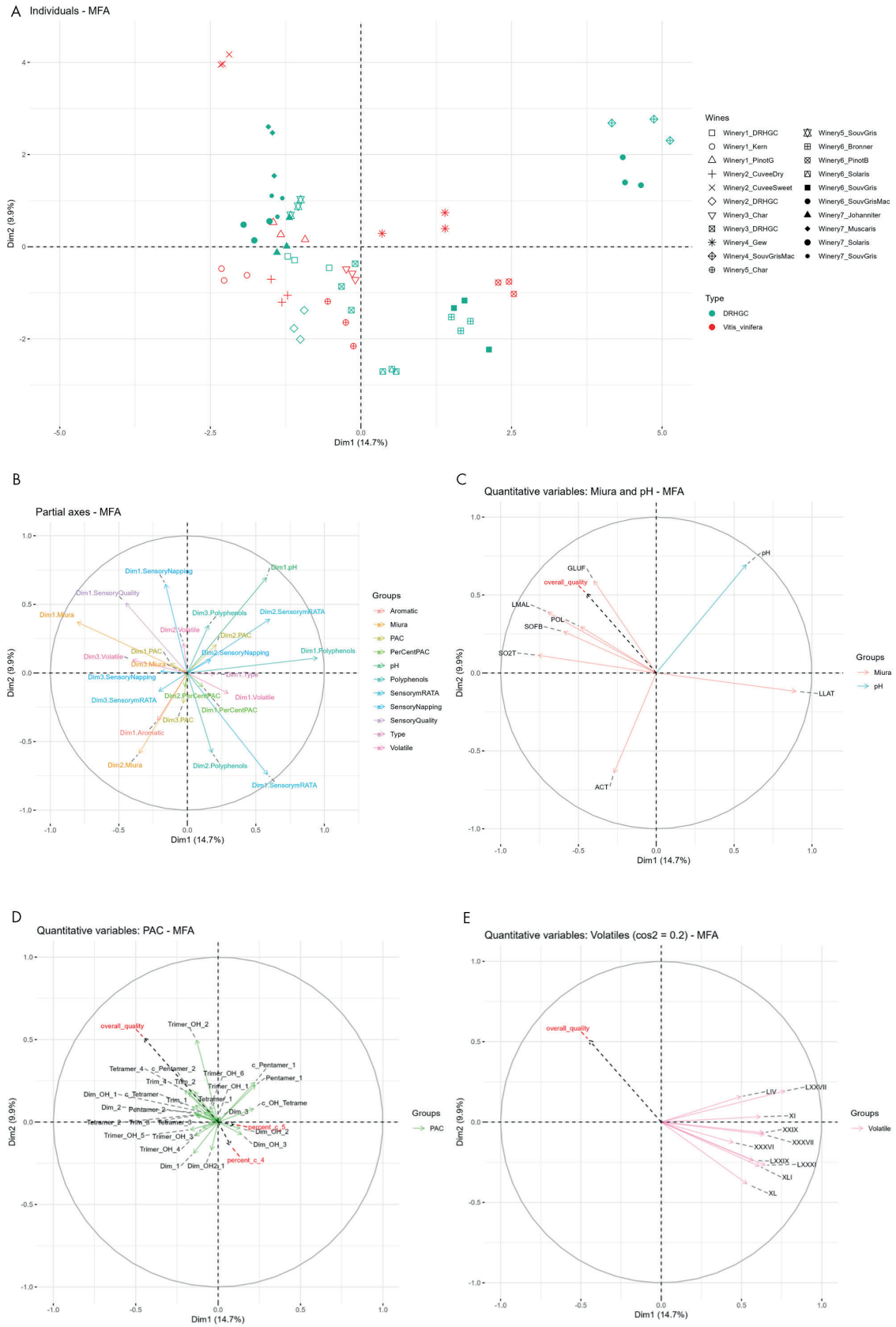


FIGURE 1. MFA of white wine data. (part 1/2)

A) MFA of the complete dataset (HPLC, GMCS, CIELab, basic oenological parameters, mRATA, and Napping), individuals; B) MFA partial axes; C) MFA quantitative variables for basic oenological parameters (Miura and pH); D) MFA quantitative variables for PAC parameters; E) MFA quantitative variables for GC × GC-MS parameters (volatile compounds), filtered with cos2 = 0.2; F) MFA quantitative variables for polyphenol parameters, filtered with cos2 = 0.5; G) MFA quantitative variables for CIELab colour; H) MFA quantitative variables for mRATA sensory analysis; and I) MFA quantitative variables for napping sensory analysis.

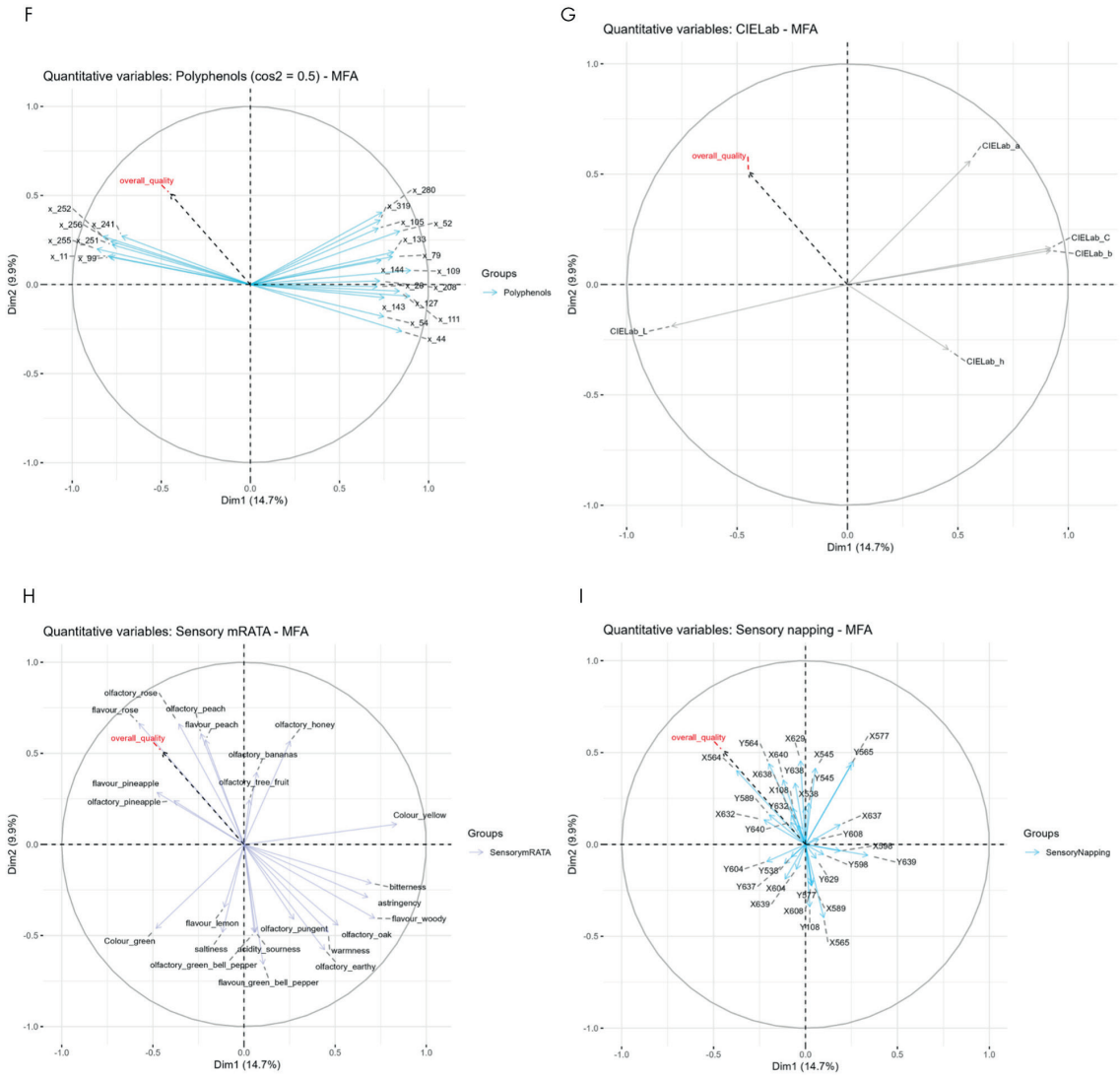


FIGURE 1. MFA of white wine data. (part 2/2)

A) MFA of the complete dataset (HPLC, GMCS, CIELab, basic oenological parameters, mRATA, and Napping), individuals; B) MFA partial axes; C) MFA quantitative variables for basic oenological parameters (Miura and pH); D) MFA quantitative variables for PAC parameters; E) MFA quantitative variables for GC × GC-MS parameters (volatile compounds), filtered with cos2 = 0.2; F) MFA quantitative variables for polyphenol parameters, filtered with cos2 = 0.5; G) MFA quantitative variables for CIELab colour; H) MFA quantitative variables for mRATA sensory analysis; and I) MFA quantitative variables for napping sensory analysis.

& Chessel, 1994; Dray *et al.,* 2003; Duley *et al.,* 2021). The majority of the co-structure between sensory and chemical variables was captured in the first two axes, and the first axis explained 57.2 % of the data and the second 19.2 % (Figure 2C). These two axes together accounted for a cumulative projected inertia of 76.5 %. An RV coefficient of 0.533 indicates a moderately strong relationship between the chemical and sensory data, and the simulated *p*-value of 0.001 (Monte-Carlo, based on 999 permutations) suggests that this relationship is significant. This suggests that the chemical dataset can help to explain the sensory dataset.

As in the MFA, the DRHGC and *V. vinifera* wines did not separate neatly, and the wines clustered into groups for sweet, macerated, and other wines (Figure 2D).Such associations can help link the sensory characteristics of the wines perceived by the panellists with metabolomic results.

Strong relationships can be seen between sensory and chemical properties in the analysis of coinertia (particularly by comparing Figures 2E and 2F). These relationships were also reinforced by Pearson's correlations (Table S8). For example, earthy aroma and diethyl butanedioate (XL; Pearson's correlation 0.624, $p = 4.71 \times 10^{-8}$), 3-methylbuthyl ester pentadecanoic acid (LXXI; Pearson's correlation 0.580, $p = 6.13 \times 10^{-7}$), x_230 (Pearson's correlation 0.738, $p = 5.10 \times 10^{-12}$), x_179 (Pearson's correlation 0.726, $p = 1.59 \times 10^{-11}$), and x_44 (Pearson's correlation 0.653, $p = 6.82 \times 10^{-9}$); between rose flavour and x_320 (Pearson's correlation 0.694, $p = 2.86 \times 10^{-10}$), residual sugars (Pearson's correlation 0.549, $p = 3.12 \times 10^{-6}$, presumably due

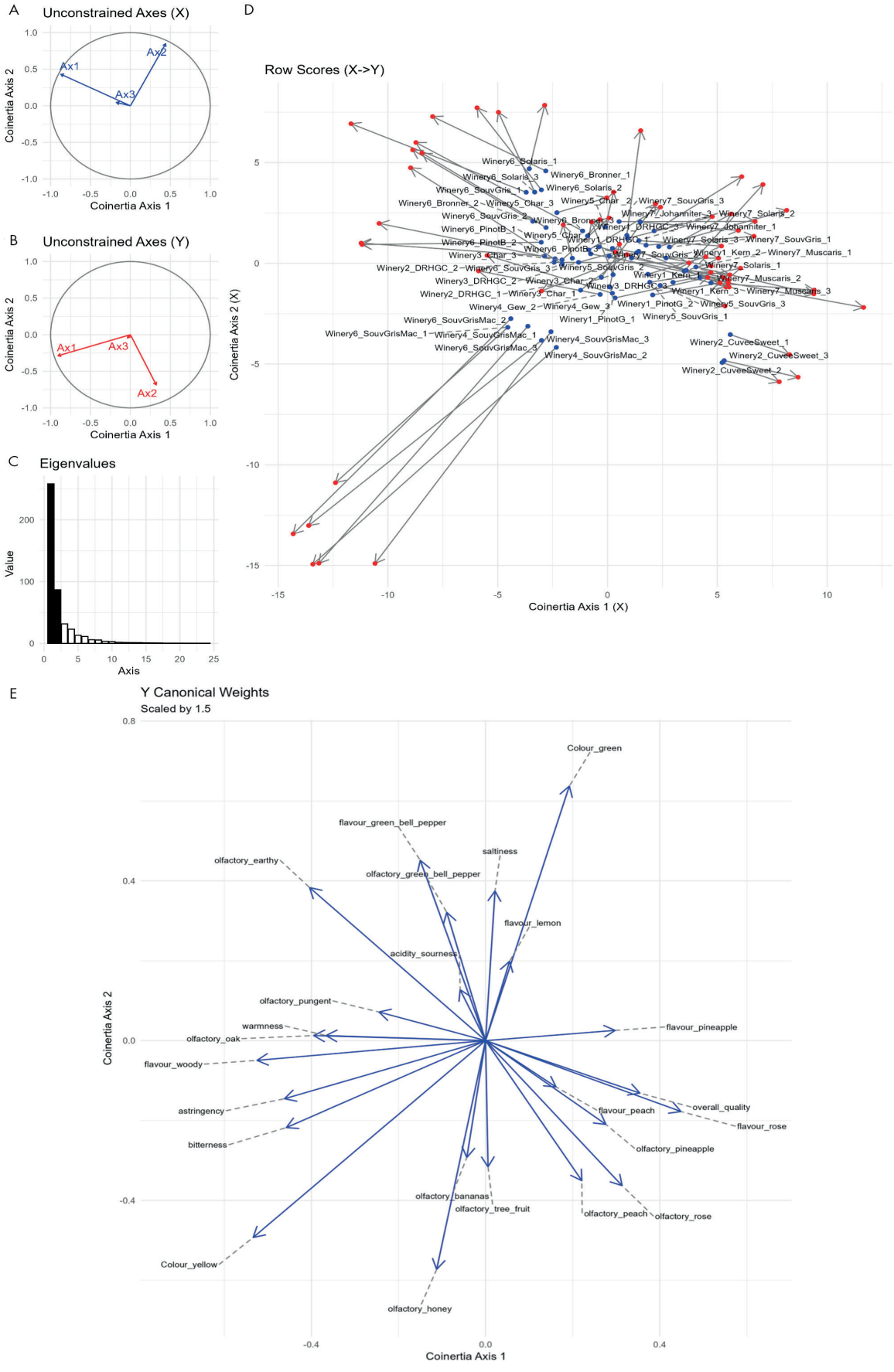


FIGURE 2. Analysis of coinertia. (part 1/2)

A) Unconstrained axes (X); B) Unconstrained axes (Y); C) Eigenvalues; D) Row scores; E) Y canonical weights, F) X canonical weights.



FIGURE 2. Analysis of coinertia. (part 2/2)

A) Unconstrained axes (X); B) Unconstrained axes (Y); C) Eigenvalues; D) Row scores; E) Y canonical weights, F) X canonical weights.

to the rose flavours present in the sweet wine), and x_252 (Pearson's correlation 0.636, $p = 2.16 \times 10^{-8}$); and between pineapple flavour and x_233 (Pearson's correlation 0.568, $p = 1.18 \times 10^{-6}$), residual sugars (Pearson's correlation 0.548, $p = 3.12 \times 10^{-6}$), and x_286 (Pearson's correlation 0.520, $p = 1.22 \times 10^{-5}$). However, while this suggested that these variables were likely influenced by a common factor, it is difficult to interpret any potential causative relationship. For example, a Pearson's correlation of 0.614 ($p = 8.60 \times 10^{-8}$) for woody flavours and CIELab b* does not suggest that woody flavours influence wine colour (or vice versa), but rather that oak ageing can cause both woody flavours and changes in wine colour.

2. Volatile profile

While the overall MFA (Results section 1.) suggests that it is not possible to distinguish between DRHGC and *V. vinifera* wines based on their chemical and sensory profiles, significant differences (ANOVA, $p \leq 0.05$) were observed in a small subset of the volatile compounds. These included 1-hexanol (DRHGC 54120000, *V. vinifera* 28370000, $p = 0.00366$, ANOVA), acetaldehyde (DRHGC 1137000, *V. vinifera* 398500, $p = 0.0148$, ANOVA), limonene (DRHGC 581500, *V. vinifera* 79980, $p = 0.0182$, ANOVA), and nerolidol (DRHGC 613200, *V. vinifera* 243700, $p = 0.0197$, ANOVA). Based on the literature, some of these compounds are considered to have antimicrobial, antifungal, and/or antiviral properties (Bonikowski *et al.,* 2015; Cai *et al.,* 2019; Gupta *et al.,* 2021; Han *et al.,* 2021; Kyoui *et al.,* 2023), and all were found at significantly higher levels in the studied DRHGC wines than in the studied *V. vinifera* wines and therefore might be relevant to the disease tolerance of these cultivars. However, despite these differences, it was not possible to distinguish between DRHGC and *V. vinifera* wines based on GC × GC-MS data, as shown in the overall MFA (section 3.1.).

1-Hexanol is described as having 'green' and 'floral' as aroma descriptors (Niu *et al.,* 2011). It may also have an antimicrobial effect on gram-negative bacteria, but further studies are needed (Kyoui *et al.,* 2023). At low concentrations, acetaldehyde can impart fruity notes to wine, but as the concentration increases, it begins to evoke 'nutty' aromas (Waterhouse *et al.,* 2024). At even higher levels, it produces undesirable 'green', 'grassy', or 'apple'-like off-flavours (Liu & Pilone, 2000; Waterhouse *et al.,* 2024). At such concentrations, it is typically referred to using the term 'acetaldehyde' in classical wine aroma terminology, often described with the general descriptor 'oxidised' (Noble *et al.,* 1987) or as the molecule responsible for a 'flat' character in wine.

Limonene is enantiomeric and the aroma character differs between enantiomers. S-(–)-limonene is known

to have a threshold of 500 µg L^{-1} and is characterised by a 'turpentine'-like aroma, whereas R-(+)-limonene has a threshold of 200 µg L^{-1} and is characterised by an 'orange' aroma. This monoterpene is known to be found in 'Pinot gris' (Chigo-Hernandez & Tomasino, 2023). 'Pinot gris' is an aromatic colour mutation of 'Pinot noir' that likely occurred at different times and places in Bourgogne, France, and Rheinland-Pfalz and Baden-Württemberg, Germany, but which is now grown globally, including in South Tyrol as 'Pinot Grigio' (Robinson *et al.,* 2012). It is typically noted for its 'honey' and 'apricot' aromas (Chigo-Hernandez & Tomasino, 2023). Limonene is also known to have antimicrobial, antiviral, and antifungal properties (Cai *et al.,* 2019; Gupta *et al.,* 2021; Han *et al.,* 2021).

Nerolidol has been reported to give a floral green aroma (Bonikowski *et al.,* 2015; Septiana *et al.,* 2020). It is also known to have antimicrobial and antifungal properties (Bonikowski *et al.,* 2015).

3. CIELab analyses

Significant differences (ANOVA, $p \leq 0.05$) were observed between DRHGC and conventional wines for CIELab colour (Figure 3). In particular, L* (DRHGC 51.8, *V. vinifera* 52.5, $p = 3.88 \times 10^{-7}$, ANOVA), a* (DRHGC 0.324, *V. vinifera* 0.211, $p = 0.0147$, ANOVA), b* (DRHGC 2.56, *V. vinifera* 1.34, $p = 5.74 \times 10^{-5}$, ANOVA), and C* (DRHGC 2.61, *V. vinifera* 1.37, $p = 4.17 \times 10^{-5}$, ANOVA) were significant, while h* (DRHGC 77.5, *V. vinifera* 75.4, $p = 0.265$, ANOVA) was not. Boxplots can be seen in Figure 3. DRHGCs were significantly lighter (higher L*), more orange (higher a* and b*, thus higher red and yellow), and more saturated (higher C* chroma) than *V. vinifera* wines. These differences were likely not noticeable to an observer, given a ΔE* of 1.48. A ΔE* of 2.3 is normally considered to be the 'just noticeable difference' level, with ΔE* below this considered likely not noticeable (Mahy *et al.,* 1994).

Correlations between CIELab colour and chemical data were also observed (Table S9). Unsurprisingly, there were strong correlations between CIELab colour and pH (a*: Pearson's correlation 0.681, $p = 8.03 \times 10^{-10}$; b*: Pearson's correlation 0.553, $p = 2.55 \times 10^{-6}$; C*: Pearson's correlation 0.562, $p = 1.66 \times 10^{-6}$), lactic acid (L*: Pearson's correlation –0.621, $p = 5.63 \times 10^{-8}$; b*: Pearson's correlation 0.755, $p = 8.64 \times 10^{-13}$; C*: Pearson's correlation 0.751, $p = 1.33 \times 10^{-12}$; h*: Pearson's correlation 0.514, $p = 1.65 \times 10^{-5}$), malic acid (b*: Pearson's correlation –0.563, $p = 1.53 \times 10^{-6}$; C*: Pearson's correlation –0.556, $p = 2.28 \times 10^{-6}$; h*: Pearson's correlation –0.512, $p = 1.79 \times 10^{-5}$), and total sulfur dioxide (L*: Pearson's correlation 0.644, $p = 1.20 \times 10^{-8}$; b*: Pearson's correlation –0.632, $p = 2.75 \times 10^{-8}$; C*: Pearson's correlation –0.633, $p = 2.56 \times 10^{-8}$). Sulfur dioxide has a known bleaching effect, and oxidative browning is pH-dependent.

Correlations were also seen between CIELab colour and a number of volatile compounds such as (E)-β-Damascenone (XI; b*: Pearson's correlation 0.569, $p = 1.16 \times 10^{-6}$; C*: Pearson's correlation 0.570, $p = 1.09 \times 10^{-6}$) and 4-ethylguaiacol (LXXVII; L*: Pearson's correlation –0.676, $p = 1.26 \times 10^{-9}$; a*: Pearson's correlation 0.644, $p = 1.24 \times 10^{-8}$; b*: Pearson's correlation 0.762, $p = 4.03 \times 10^{-13}$; C*: Pearson's correlation 0.767, $p = 2.37 \times 10^{-13}$). Correlations were also found between colour parameters and phenolic compounds, but further work is required to determine the links between phenolic compounds, volatile compounds, and white wine colour.

In contrast to the differences noted between DRHGC and *V. vinifera* wines, there were significant differences between skin-contact and conventional wines (L*: skin-contact wines 49.54, conventional wines 52. 34, $p = 4.64 \times 10^{-15}$; a*: skin-contact wines 1.12, conventional wines 0.193, $p = 9.19 \times 10^{-21}$; b*: skin-contact wines 7.59, conventional wines 1.52, $p = 1.07 \times 10^{-20}$; C*: skin-contact wines 7.68, conventional wines 1.55, $p = 8.75 \times 10^{-63}$; h*: skin-contact wines 81.3, conventional wines 76.2, $p = 0.118$; ANOVA) and these were reflected in the higher ΔE* of 6.66, which is above the 'just noticeable difference' level (2.3). This suggests that the winemaking technique can influence wine colour to a greater extent than any differences between DRHGCs and *V. vinifera*.

4. Sensory analysis

Sensory analysis using both mRATA and Napping revealed that DRHGC and *V. vinifera* wines clustered together closely, indicating that they cannot be reliably distinguished through sensory analysis alone.

Again, just a small subset of attributes had significant differences. The sensory attributes that were significantly different between DRHGC and *V. vinifera* wines were olfactory 'honey' (DRHGC 1.087, *V. vinifera* 1.315, $p = 0.022$, ANOVA), olfactory 'pineapple' (DRHGC 0.8186, *V. vinifera* 1.115, $p = 0.0012$, ANOVA), olfactory 'banana' (DRHGC 0.8752, *V. vinifera* 1.180, $p = 0.0003$, ANOVA), and gustatory 'pineapple' (DRHGC 0.7745, *V. vinifera* 1.008, $p = 0.0059$, ANOVA). Notably, panellists did not rate DRHGC wines as significantly different in terms of overall quality from *V. vinifera* wines (DRHGC 2.751, *V. vinifera* 2.929, $p = 0.07$, ANOVA). In addition, there were no correlations (Pearson's correlation of > 0.5 or < -0.5 with $p \leq 0.05$) between sensory characters and wine type. This suggests that, despite a small subset of characters differing significantly, wine type did not correlate with sensory characteristics.

This can be seen both in the sensory MFA (Figures 4A, 4B and 4C) and the spider graph (Figure 4D). For this reason, the first dimension of the MFA only showed 14.4 % of variance, the second 7.73 %, and the third 6.95 %. mRATA contributed 50.5 % to the first dimension and 31.0 % to the second; the napping dataset contributed 49.5 % to the first dimension and 69.0 % to the second. Of the individual variables, gustatory 'rose' contributed 5.13 % to the first dimension and 0.844 % to the second, gustatory 'peach' contributed 4.84 % to the first dimension and 0.147 % to the second, napping Y564 (a coordinate along the Y axis of the napping analysis) contributed 4.59 % to the first dimension and 0.694 % to the second, and napping X629 (a coordinate along the X axis of the napping analysis) contributed 4.32 % to the first dimension and 9.29 % to the second.

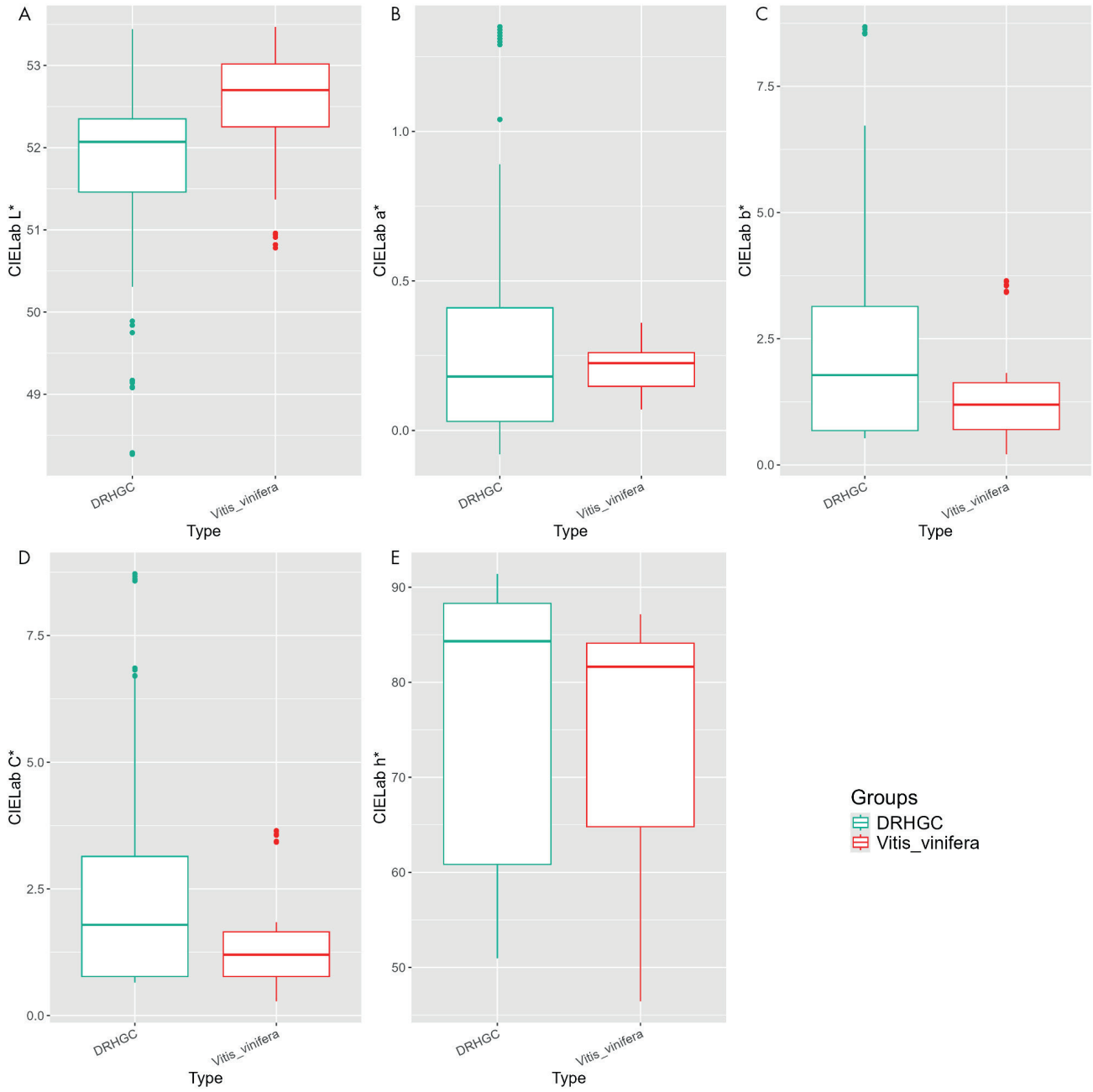


FIGURE 3. Boxplots of CIELab parameters.

A) CIELab L*; B) a*; C) b*; D) C*; E) h*.

That panellists could neither distinguish nor express a preference between DRHGC and *V. vinifera* wines is interesting. This result is in contrast to a previous study by the authors, which contrasted red DRHGC and *V. vinifera* wines from South Tyrol, Italy (Duley *et al.,* 2025). With a few exceptions, previous studies contrasting DRHGC and *V. vinifera* wines have examined only red wines (Biasoto *et al.,* 2014; Forino *et al.,* 2022), and most studies on the sensory properties of red DRHGC wines do not directly contrast them with *V. vinifera* wines (de Castilhos *et al.,* 2013; de Castilhos *et al.,* 2016; de Castilhos *et al.,* 2017; de Castilhos *et al.,* 2020; González-Centeno *et al.,* 2019; Socha *et al.,* 2015).

One exception is Kiefer and Szolnoki (2023) (also discussed in section 1.), where white DRHGC and *V. vinifera* wines were found to be distinct based on a consumer study, but preference differed between consumer sectors, with young wine enthusiasts preferring the Sauvignac 'Maceration' (skin-contact) wine. However, the present study examined a larger number of wine cultivars from a larger number of wineries. It is suggested that sensory analysis can distinguish between individual wines but cannot reliably distinguish between DRHGC and *V. vinifera* wines. Another such study is Socha *et al.* (2015), whose results (discussed in section 1.) are not dissimilar to the present study.

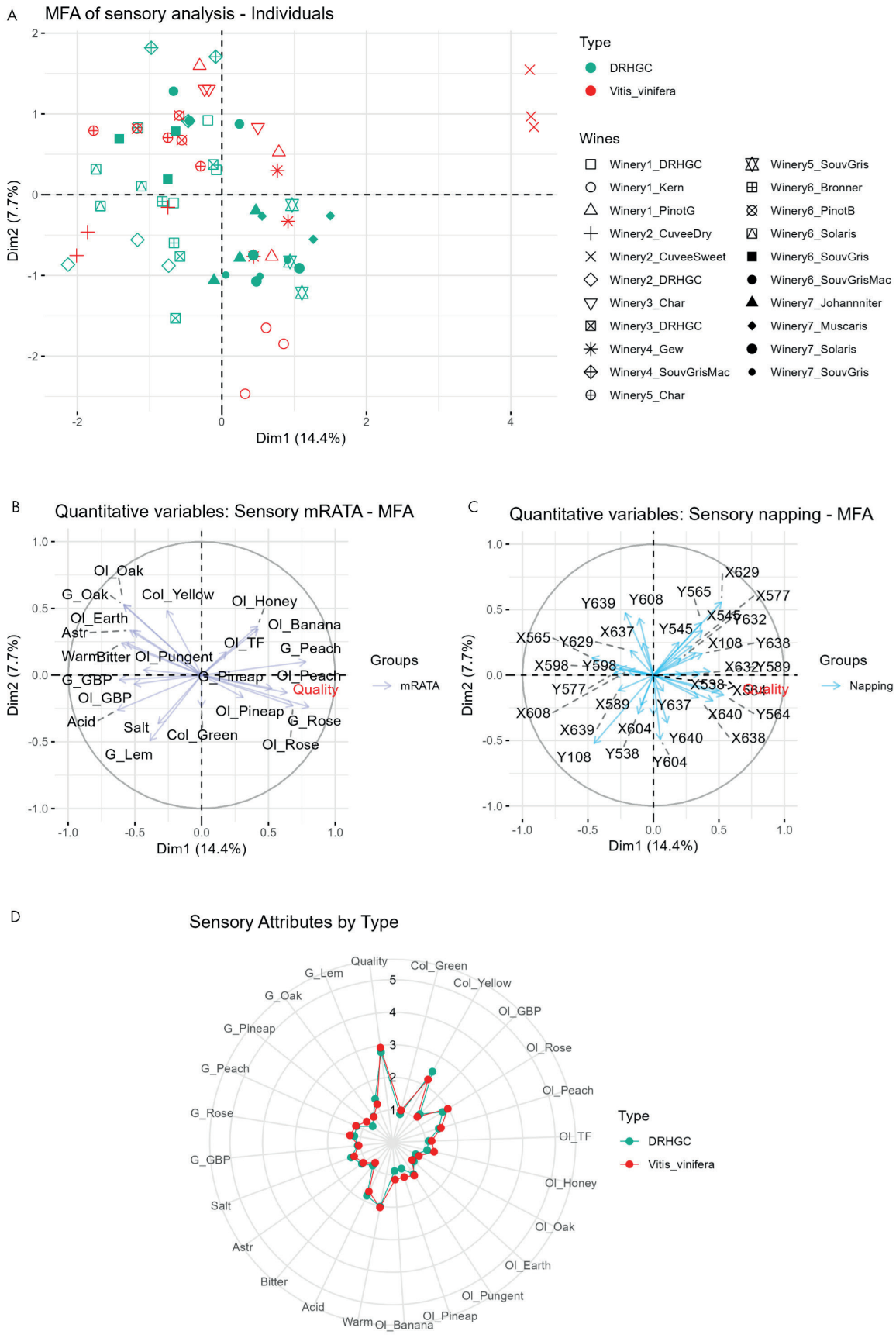


FIGURE 4. MFA and spider graphs of sensory analysis.

A) MFA of sensory analyses (mRATA and Napping), individuals; B) MFA quantitative variables for mRATA; C) MFA quantitative variables for Napping; D) Spider plot of sensory characters contrasting DRHGC and *V. vinifera* wines.

That panellists did not prefer *V. vinifera* wines over DRHGC wines, and that the MFA did not differentiate between the two types of wine is interesting. While the relationship between sensory analysis by trained and semi-trained panellists and by consumers is complex, previous studies have shown that although trained and semi-trained panellists are more reliable at consistently identifying and applying sensory attributes, the results of these two types of studies can show similar patterns and preferences (Hersleth *et al.,* 2005; McMahon *et al.,* 2017; Park *et al.,* 2019). If consumers respond similarly to trained panellists, this suggests that the primary barrier to marketing white DRHGC wines will be consumer familiarity rather than consumer preference. However, further work needs to be done to determine consumer responses, preferably in a number of potential market countries. Determining correlations between mRATA sensory attributes and consumer acceptance could also be of interest (McMahon *et al.,* 2017).

This suggests that consumer education is critical for the successful commercialisation of DRHGC white wines. Fuentes-Espinoza *et al.* (2018) and Kiefer and Szolnoki (2023) emphasised the need to educate consumers on the environmental benefits of DRHGC wines, while Kiefer and Szolnoki (2023) noted the importance of avoiding phrases consumers might not understand or might find off-putting (*e.g.*, 'fungal diseases' or 'cross-breeding') and to emphasise phrases such as 'gentle, sustainable cultivation through substantial pesticide reduction'. The specific requirements for education and marketing will likely differ between markets, and further work is required to determine this, too.

CONCLUSIONS

Panellists were unable to distinguish between DRHGC and *V. vinifera* wines, suggesting that white DRHGC wines are less distinct from white *V. vinifera* wines than is the case for red wines. Consequently, panellists did not express a preference for either type of wine. This is partially in agreement with our initial hypothesis.

Some significant differences were noted between several variables for DRHGC and *V. vinifera* wines, such as olfactory 'honey' (DRHGC 1.087, *V. vinifera* 1.315, $p = 0.022$, ANOVA) and olfactory 'pineapple' (DRHGC 0.8186, *V. vinifera* 1.115, $p = 0.0012$, ANOVA) in the sensory analysis and 1-hexanol (DRHGC 54120000, *V. vinifera* 28370000, $p = 0.00366$, ANOVA) and limonene (DRHGC, 581500, *V. vinifera* 79980, $p = 0.0182$, ANOVA) in the chemical analyses. Many, though not all, of the volatile compounds that differed significantly, were compounds that have been noted to have antimicrobial, antibacterial, or antiviral effects in the literature and thus might be associated with disease resistance in grape vines. These were not sufficient to allow the two types of wine to be readily distinguished, however.

The analysis of coinertia confirmed that there is a moderately strong relationship between the sensory and chemical datasets. This analysis also highlighted some interesting relationships between sensory and chemical characters, such as between earthy aroma and 4-ethyl-phenol, or between pineapple flavour and hexyl acetate.

These results suggest that the primary barrier to market adoption of white DRHGCs is consumer and producer unfamiliarity, rather than anything intrinsic to the wine itself. Further work is required to determine optimal methods for consumer information and education to familiarise consumers with DRHGC wines, but previous studies suggest that emphasising the environmental benefits of DRHGCs might be key.

ACKNOWLEDGEMENTS

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