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Identification and control of volatile compounds responsible for important sensory attributes



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1. Abstract

This project succeeded in its aim to expand knowledge of several key flavour compounds in wine, including those responsible for 'stone fruit', 'tropical', 'green' and 'jammy' characters. Using a wide range of sensory and analytical methods, compounds responsible for flavour attributes in wine were identified. Relationships between wine composition and sensory properties were investigated, as well as the effect of viticultural and oenological techniques on flavour compound formation. New analytical methods were established for a number of compounds, providing an enhanced ability to understand their sensory significance. This research has given producers new knowledge to help them avoid negative flavours and enhance positive flavours.

2. Executive summary

A good understanding of the relationship between wine composition and wine flavour is important to being able to control grape and wine quality. This research project was carried out to improve knowledge of:

- compounds responsible for key flavours, including the identity of previously unrecognised compounds, especially for the varieties Shiraz and Chardonnay
- the relationships between wine composition and wine sensory properties
- the effect of viticultural and oenological techniques on the formation of compounds.

It also aimed to develop routine analytical methods for flavour compounds that can be applied in research and industry trials.

Compounds responsible for flavour attributes in wine were identified using sensory-guided chemical methods, gas chromatography-mass spectrometry in combination with olfactometry (use of the human nose as a detector), liquid chromatography–mass spectrometry and formal sensory studies.. Analytical methods using isotopically labelled standards were adopted where possible, to ensure accurate, precise and sensitive analyses of compounds at or below ppb levels. Surveys of commercially available wines were used to confirm the importance of compounds, while detailed chemical studies shed light on the formation reactions occurring during winemaking. Use of replicated viticultural and winemaking studies enabled the effects of different production practices to be determined, and formal sensory and consumer preference data were obtained.

Analytical methods were established for a number of key flavour compounds, providing an enhanced ability to measure levels of compounds with context regarding their sensory significance, including flavour contributions. The compounds included those implicated in overripe raisin/jammy flavour, including 1-octen-3-ol, 1-penten-3-ol, 2,4-heptadienal, β-damascenone, 3-methylbutanal, 2-methyl propanal, phenylacetaldeyde, ethyl 3-methylbutanoate, ethyl 2-methylpropanoate, 3-methyl-2,4-nonanedione (MND), 1,5-octadien-3-one, furaneol, homofuraneol, and gamma-nonalactone. A method combining and expanding on the set of monoterpenes and C13-norisoprenoids was developed. The concentration of proline in wines was quantified using a newly developed cost-effective and rapid ^{1}H NMR method.

The sensory interactions of compounds responsible for the 'apricot' flavour in Viognier wine (the monoterpenes, geraniol, linalool and nerol with other aroma compounds) were determined, with lactone compounds enhancing this character. Several esters were shown to contribute to 'peach-like' aroma in Chardonnay.

Several potent thiol compounds were found to be strongly enhanced in white wines made from grapes where the vineyard had been treated with a simple nutrient foliar spray. Optimal applications were found and trialled with industry partners demonstrating the potential of this simple practice.

Regarding 'green' flavour in red wines, stalks in Shiraz and Pinot Noir fermentations were found to give rise to green characters from methoxypyrazines, which were previously thought to be unimportant for these varieties.

Bunch exposure influences were studied in Riesling and Shiraz, with coloured shade cloth found to have a clear effect on aged character in Riesling, and compounds contributing to jammy/raisin characters in Shiraz being identified, together with links of this character to hang-time rather than berry temperature or sun exposure.

A highlight of the project was the recognition of the importance of the previously little-studied amino acids proline and glutamic acid in wine flavour. For proline, there were both direct and interactive effects driving the perception of many positive sensory properties of red wines, notably sweetness, red fruit flavour and viscosity, while diminishing astringency and bitterness. The practical application of this knowledge was demonstrated in a blending study with high- and low-proline wines, showing that wine from warm inland regions can be greatly improved with incorporation of high-proline components. The savoury character in many red wines was shown to involve glutamic acid, which previously had been considered to be at too low a concentration to have a sensory effect in wine.

Rapid and simplified sensory methods were evaluated and found to have utility as substitutes for more complex time-consuming sensory descriptive analytical methods, without sacrificing accuracy or detail. These methods can be used in industry contexts such as evaluating smoke taint or outcomes from viticultural or winemaking trials.

Overall, the results of this research have increased knowledge of the main volatile compounds involved in wine flavour attributes, so that the causative compounds for many of the most important sensory attributes of wines are now established and many of the influences on their formation understood. This research has given producers new knowledge to avoid negative flavours and enhance positive flavours in finished wine.

3. Acknowledgements

This work was supported by Australia's grapegrowers and winemakers through their investment body Wine Australia with matching funds from the Australian Government. The AWRI is a member of the Wine Innovation Cluster in Adelaide, SA.

Research collaborators at Hochschule Geisenheim University in Germany, CSIRO, University of Adelaide, University of South Australia and Metabolomics Australia are thanked for their contributions to this project

4. Background

Three pillars which underpin the growing market share and ongoing success of Australian premium wines are:
(1) the ability to convey to the market the premium nature of Australia's wines
(2) the ability to generate unique, differentiated products that are desirable in the eyes of customers and consumers
(3) the taste of Australian wines in relation to consumer preferences and offerings by Australia's main competitors.

To address (2) and (3) this project expanded the knowledge of key volatile chemical compounds responsible for important sensory attributes in wine. For many winemakers and consumers, these

attributes define a wine's fundamental quality and therefore value in relation to its price; they also provide researchers, grapegrowers and winemakers with quality markers and leads for targeting improvements to vineyard management and winemaking practices. To complement and fast track flavour chemistry research and related studies, this project also assessed alternative, less time-consuming and/or simplified sensory methods for wine characterisation. The aim was to enable faster characterisation under standardised benchmarking conditions of larger numbers of wines from research trials and new product development projects.

Within this project, the formation of, and factors that influence aroma compounds recently found to be responsible for 'stone fruit' (apricot-peach) character, which is common in Chardonnay and Viognier, were investigated, with fermentation and vineyard studies and an exploratory survey of commercial wines of these and other white varieties.

The role of methoxypyrazine in Shiraz and Pinot Noir wines, previously considered not relevant to undesirable green flavour in these varieties, was explored in collaboration with CSIRO, through whole bunch fermentation studies, analysis of stalks and leaves, and determination of the genetic basis of the expression and regulation of this metabolite in stalks.

Jammy/raisin flavour was studied. Overripe jammy/raisin flavour of Shiraz from grapes from warmer regions, and more generally the aroma and flavour compounds negatively influenced by bunch exposure, have not previously been addressed. The lack of knowledge of the compound(s) responsible for this flavour, is a major gap in setting a measurable target in viticultural projects, especially given increases in growing season temperatures and vintage compression, and consequential undesirably extended hang-times.

The role of thiols and other sulfur compounds in red varieties was determined. Foliar nitrogen and sulfur vineyard sprays were investigated, as these have been shown to have the potential to positively affect thiol concentrations in wine..

The effect of blending alternative varieties with Cabernet Sauvignon produced in the Riverland and Murray Valley regions was investigated, to provide enhanced flavour characteristics, acid, colour, and mouth-feel weight to these types of wines. The project also had a component in which off-flavours and taints were identified and studied.

Current practice in sensory evaluation of research wines uses sensory descriptive analysis, and while considered the most powerful and sophisticated method, it requires several weeks of data generation and substantial time for data analysis. In recent years, alternative faster methods have been developed in food science applications. This project evaluated these protocols to determine their utility in wine studies and for wider industry use. The advantages of using untrained consumers compared to trained panellists were also assessed.

5. Project aims

Deliverables and activities for this project are listed in Tables 1 to 5 below.

Table 1. 2017-18 Deliverables and activities

	Deliverables	Activities	Target date
A	Methoxypyrazines in Shiraz: the role of whole bunch fermentations and concentration in stalks.	1. Working with CSIRO, quantify methoxypyrazines in the rachis and berries of at least two sets of Shiraz grapes sampled progressively post-flowering. Provide samples to CSIRO for assessment of gene expression for the biosynthesis of methoxypyrazines. 2. Complete a replicated winemaking study involving whole bunch fermentation of Shiraz grapes with at least five treatments in triplicate, with varied proportion of whole bunches or whole berries.	June 2018
B	Understanding the role of varietal thiols in red varieties.	1. Quantify varietal thiols in at least 100 red commercial wines from the major varieties (including Shiraz, Cabernet Sauvignon, Grenache, Merlot and Pinot Noir).	June 2018
C	Effect of foliar sprays on thiols.	1. Conduct a foliar nitrogen and sulfur application study on vines of two varieties and produce wine from grapes from the plots.	June 2018
D	Improved understanding of how TDN is formed, how it contributes to the perception of 'kerosene' and how to better manage this sensory attribute.	1. Conduct an ageing experiment on wines made from at least six grape lots, from a single vineyard, with varying TDN precursor concentrations, involving sensory and compositional analysis and accelerated ageing at elevated temperature. 2. Produce experimental wines in both Germany and Australia to assess TDN production potential, evaluating winemaking as a potential variable in explaining TDN concentration differences between German and Australian wines. 3. Conduct LC-MS/MS analyses of grape samples to understand the structural identity of TDN precursors.	June 2018
E	Stone fruit compound mechanisms of formation.	1. Analyse a total of at least 100 commercial Australian white wines of several major varieties (e.g. Chardonnay, Riesling, Sauvignon Blanc, Pinot Grigio/Gris and Viognier) for dairy lactone and monoterpenes, previously implicated in the 'stone fruit' attribute. 2. Analyse free and bound monoterpenes in grapes from at least 10 Viognier clones sourced from a single vineyard. 3. Quantify free and bound monoterpenes in at least 15 berry samples from a ripening study of Viognier grapes.	June 2018
F	Comparisons of results from alternative methods with those obtained from sensory descriptive analysis, including assessment of effects of size of panel, degree of panel training and	1. Complete a Pivot© profile sensory study using a set of 15 premium Shiraz wines (purchased through Project 4.4.1) comparing a panel of Australian winemakers and a panel of international sommeliers. Complete a projective mapping task and conventional descriptive analysis on the same wines.	June 2018

	need for replication: assessment of Pivot© profile, projective mapping, and polarised sensory positioning		

Table 2. 2018-19 Deliverables and activities

	Deliverables	Activities	Target date
A	Methoxypyrazines in Shiraz: the role of whole bunch fermentations and concentration in stalks	1. Analyse the wines from the 2018 vintage whole bunch fermentation study for methoxypyrazines and other key volatiles and quantify sensory attributes by sensory descriptive analysis.	June 2019
B	An understanding of the role of varietal thiols in red varieties	1. Summarise the data for dissemination at the 2019 AWITC and/or an industry journal article.	June 2019
C	Effect of foliar sprays on thiols	1. Analyse the 2018 Chardonnay and Shiraz juice/wine samples for thiols, low molecular weight sulfur compounds and amino acids, together with other analytes as determined following sensory evaluation. 2. Conduct a study of foliar nitrogen and sulfur application on vines of two varieties from the 2018-19 season, with the experimental design based on results from the 2018 study.	June 2019
D	Improved understanding of how TDN is formed, how it contributes to the perception of 'kerosene' and how to better manage this sensory attribute	1. Repeat accelerated ageing experiments using the protocol developed from the initial experiment and align results with sensory evaluation of 2016 Riesling wines. 2. Conduct analysis of 2018 shaded grapes and wine for norisoprenoids and monoterpenes, and if applicable provide samples for sensory evaluation. 3. Work with collaborators in Geisenheim to conduct an exposure trial during vintage 2018 in Germany. 4. Review experimental outcomes to date and evaluate best possible trial design for a vintage 2019 vineyard trial in Australia. 5. Characterise structures of potential TDN precursors through applicable techniques (e.g. NMR, MS/MS, high resolution MS).	June 2019
E	Stone fruit compound mechanisms of formation	1. Conduct a winemaking study to assess the effect of clone or grape ripeness on 'stone fruit' characters in Viognier, using at least two clones picked earlier and later, likely at two sites, dependent on results of the previous year. 2. Quantify dairy lactone as well as other flavour active lactones in a range of commercially available sweet botrytis white wines and at least 30 red wines, to better evaluate the contribution of this little-studied compound to wine flavour. 3. Complete a reconstitution experiment to examine the sensory contribution of monoterpenes, lactones and esters in 'peach' aroma in Chardonnay.	June 2019
F	An understanding of the impact of odorants of	1. Review the literature and plan the experiments to be conducted in 2019-2020, considering	June 2019

	premium Shiraz through GC-O/reconstitution models	wines with distinctive sensory properties from Projects 3.3.1 or 4.4.1.	
G	List of compounds related to expression of 'raisin/jammy' flavour	1. Conduct model Maillard reactions to understand the role of amino acid/sugar interactions in the evolution of 'jammy' character. 2. Artificially heat grapes to induce chemical changes that are expected to occur under model Maillard reactions. 3. Source grapes and wine that have 'jammy' character or that have experienced excessive heat during production. Conduct GC analysis to investigate chromatographic regions that change as a result of heating and/or increase hang-time. 4. Complete a comparative GC/O study on commercial maturity versus overripe Shiraz grapes to determine aroma active changes due to late-hanging.	June 2019
H	Data on the utility of alternative methods to sensory descriptive analysis: comparisons of results from alternative methods with those obtained from sensory descriptive analysis	1. Assess projective mapping under the conditions of blind; informed; and informed based on choice/preference; with at least 50 consumers, together with sensory descriptive analysis.	June 2019

Table 3. 2019-20 Deliverables and activities.

	Deliverables	Activities	Target date
A	Understanding of the role of whole bunch fermentations and concentration in stalks on methoxypyrazines in Shiraz; an understanding of the impact of odorants of premium Shiraz through GC-O/reconstitution models; and list of compounds related to expression of 'raisin/jammy' flavour (Year 5 deliverable)	1. Complete data analysis and draft a manuscript of results of the whole bunch fermentation study. 2. Complete a reconstitution/omission sensory study examining the sensory effects of specific compounds in Shiraz, including volatiles and non-volatiles such as tannin. 3. Conduct chemical and sensory analysis of the wines made in vintage 2019 under Project 4.1.1 (vintage compression) for 'jammy/raisin' characters and associated target analytes. 4. Understand the role of Maillard reactions and relevant variables (heat, time etc.) on the evolution of 'jammy' and 'raisin' characters at a laboratory scale. 5. Depending on the outcome of experiments, complete a validated analytical method for accurate quantification of key 'raisin/jammy' compounds. 6. Undertake a winemaking study in vintage 2020 aiming to modulate 'jammy/raisin' characters, with the experimental design to be based on the outcome of previous experiments.	June 2020
B	Stone fruit compound mechanisms of formation	1. Analyse the 2019 vintage wines, juices and grapes from the clone and ripeness study for free and glycosidically bound monoterpenes and complete a sensory study on the wines. 2. Monitor the concentrations of free and glycosidically bound monoterpenes over time in the 2019 vintage wines. 3. Prepare a manuscript for a peer-reviewed journal.	June 2020

		4. If warranted based on prior experimental outcomes, assess effect of fermentation on formation of dairy lactone.	
C	An understanding of the role of varietal thiols in red varieties and effect of foliar sprays on thiols	1. Complete a reconstitution/omission sensory study examining the sensory effects of thiols in red wine, taking into account sensory and chemical results from the foliar spray study and the terroir study. 2. Conduct a laboratory-scale fermentation experiment looking at the role of different nitrogen and sulfur doses on varietal thiol accumulation in Chardonnay. 3. Conduct a large-scale spraying trial in vintage 2020 with experimental design to be based on the outcome of previous trials. 4. Analyse the wines produced in the 2019 vintage experiment, and perform subsequent analyses based on sensory analysis. 5. Publish an industry article on the role of foliar spraying on the accumulation of varietal thiols.	June 2020
D	Improved understanding of how TDN is formed, how it contributes to the perception of 'kerosene' and how to better manage this sensory attribute	1. Complete analysis of grapes and wine from the 2019 Australian vintage and the 2018 German vintage, including assessment of TDN-related glycosides. 2. Conduct experiments that highlight the significance of TDN in the generation of aged character in Australian and German Riesling.	June 2020
E	Data on the utility of alternative methods to sensory descriptive analysis: comparisons of results from alternative methods with those obtained from sensory descriptive analysis	1. Assess 'check all that apply', 'polarised sensory positioning' and 'rate all that apply' methods.	June 2020
F	Identification of taints and off-flavours (as required). (Year 5 deliverable)	1. Evaluate and summarise data from Project 2.2.1 (AWRI helpdesk) investigations of indole incidence in sparkling wine and depending on the results complete a targeted sensory/compositional study or precursor fermentation investigation. 2. Quantify mousy compounds in a set of red and white wines to confirm the contribution of specific target compounds to the taint.	June 2020

Table 4. 2020-21 Deliverables and activities

	Deliverables	Activities	Target date
A	Blending options involving alternative varieties for managing flavour deficiencies	1. Prepare samples for a sensory and compositional study on Cabernet Sauvignon from a warm inland region blended with varied small amounts of other variety wine, using a formal experimental design approach with two varieties as blending components at less than 15% v/v. 2. Investigate the role of foliar spraying in conjunction with other enhancing treatments in producing a high thiol Chardonnay wine. 3. Select commercial Chardonnay wines targeting 'peach' character and undertake a confirmatory sensory and compositional study.	June 2021

B	List of compounds related to expression of 'raisin/jammy' flavour	1. Undertake a bench tasting and chemical analysis on 2019 bottled wines. 2. Undertake GC-O and grape berry sensory evaluation on material obtained during vintage 2020. 3. Prepare a manuscript on the initial experiments and associated analytical methods. 4. Based on the outcomes of 2019 and 2020 experiments, plan and perform a winemaking experiment for vintage 2021.	June 2021
C	Improved understanding of the aroma and flavour compounds influenced by bunch exposure	1. Compare free and glycosidically bound monoterpenes in sun-exposed and canopy-shaded Viognier grapes, of two clones from two regions. 2. Compile experimental information to date on vineyard and winemaking practices that contribute to the evolution of aged character associated with TDN, or other important aroma compounds. 3. Develop an understanding of key norisoprenoid precursors in grapes, and improve existing analytical methods for glycosidically bound compounds including monoterpenes.	June 2021
D	Evaluation of procedures for assessing product-context appropriateness	1. Assess the effect of a natural consumption setting compared to a laboratory test on consumer liking scores for a red wine data set.	June 2021
E	Identification of taints and off-flavours (as required).	1. Conduct investigations into the chemical identity of taint compounds and their formation/origin, as required.	June 2021
F	Practical advice and extension materials for winemakers	1. Prepare AWRI roadshow presentations and 'how-to' material on rapid sensory methods. 2. Prepare AWRI roadshow presentation and/or webinar on foliar spraying outcomes. 3. Work closely with Project 2.1.1 to identify likely early adopters and effective pathways to facilitate industry uptake.	June 2021

Table 5. 2021-22 Deliverables and activities

	Deliverables	Activities	Target date
A	Blending options involving alternative varieties for managing flavour deficiencies	1. Complete a sensory and compositional study on Cabernet Sauvignon from a warm inland region blended with varied small amounts of other variety wine, in cooperation with Project 3.1.4. Summarise the results from the blending study in a manuscript. 2. Complete sensory and compositional analysis on wines from the foliar spray study, quantifying the effects of S- and N- sprays on Adelaide Hills Chardonnay wine, and analyse Chardonnay and Sauvignon Blanc juices or wines made by industry collaborators. Prepare a manuscript and commence preparing extension materials. 3. Conduct a winemaking study to assess the effect of different levels of solids (very low, medium and high NTU) in Chardonnay using two high- and two low-ester-producing yeast strains in order to optimise the expression of 'peach'	June 2022

		character and to obtain wine for tasting with winemakers.	
B	List of compounds related to expression of 'raisin/jammy' flavour	1. Undertake compositional and sensory analysis of 2021 Shiraz grapes and/or wine, looking at the impact of vineyard-applied heat treatments on volatile and non-volatile composition. 2. Aggregate all data to date and prepare extension material for the 18th AWITC in 2022. 3. Depending on the outcome of vineyard-derived work, initiate an experiment in vintage 2022 looking at modulation of 'jammy' or 'raisin' characters.	June 2022
C	Improved understanding of the aroma and flavour compounds influenced by bunch exposure	1. Summarise data for dissemination at the 18th AWITC and/or in an industry journal article.	June 2022
D	Evaluation of procedures for assessing product-context appropriateness	1. Prepare an industry article on the context study.	June 2022
E	Identification of taints and off-flavours (as required).	1. Conduct investigations into the chemical identity of taint compounds and their formation/origin, as required.	June 2022
F	Practical advice and extension materials for winemakers	1. Prepare AWRI roadshow presentation and extension materials on 'jammy'/'raisin' flavour in grapes. 2. Prepare a manuscript and commence preparing extension materials on effects of foliar sprays. 3. Prepare industry journal article and extension materials on light exposure and winemaking effects on TDN outcomes. 4. Prepare extension materials for the 18th AWITC on rapid practical sensory methods. 5. Support Projects 2.1.1 (Extension) and 2.1.2 (Communication and awareness-raising activities) through identifying topics and preparing materials for awareness-raising and practice change activities.	June 2022

6. Methods

6.1 Compound elucidation and quantitative analytical methods

Sensory-guided chemical analysis was used to identify key compounds, with gas chromatography-mass spectrometry (GC-MS)-olfactometry, semipreparative fractionation using HPLC and GC-PFC-olfactometry, sensory-based aroma detection threshold measures and preliminary bench-style sensory assessments applied to identify probable compounds responsible for key sensory attributes of wines (Capone et al. 2022, Siebert et al. 2021). The identity of the volatile compounds responsible for aroma attributes in wine was established through purchase and synthesis of compounds for use as analytical standards, and through GC-MS studies and formal statistical experimental design addition sensory studies, to confirm the identity and the importance of the compounds (Espinase Nandorfy et al. 2021), and their interactions with other compounds.

Volatile compounds were targeted and quantified by GC or LC stable isotope dilution analyses (SIDA) using previously reported methods, as described in Siebert et al. (2018a). A method combining and expanding on the set of monoterpenes and C13-norisoprenoids was developed (Pisaniello et al.

2022). This method was also used for a white wine survey comparing aged white wines (131 wines of 1 to 20 years old). A new method was optimised for compounds implicated in overripe raisin/jammy flavour, including 1-octen-3-ol, 1-penten-3-ol, 2,4-heptadienal, β-damascenone, 3-methylbutanal, 2-methyl propanal, phenylacetaldeyde, ethyl 3-methylbutanoate, ethyl 2-methylpropanoate, 3-methyl-2,4-nonanedione (MND), 1,5-octadien-3-one, furaneol, homofuraneol, and gamma-nonalactone, based on the method from Mayr et al. (2015).

These quantitative analysis methods were used to survey commercial wines (e.g. Espinase-Nandorfy et al. 2021), with the number of wines where a compound was above the sensory detection threshold providing evidence that the compound was of importance to wine.

The formation of compounds was established through kinetic and mechanistic studies and ways of adjusting their levels through viticultural and winemaking practices were assessed (Grebneva et al. 2019). The project team worked closely with multiple industry partners to assess commercial options for adjusting levels of aroma compounds in the vineyard or winery.

Glycosidically bound monoterpenes were measured by LC-MS as per Siebert et al. (2018a).

The concentration of proline in wines was quantified using ^{1}H NMR with analysis performed on a Bruker Avance Neo instrument operating at 400 MHz. Samples were prepared as follows: wine was added to a commercial buffer then automatically titrated with 1.0 M HCl or NaOH to pH 3.1 using a microtitrator (Bruker, Sydney, Australia). A 1D NOESY spectrum was acquired using a 600 µL aliquot of the sample where water and ethanol were suppressed to accurately quantify underlying metabolites. Proline was then quantified, where the area under the curve (AUC) was obtained and regressed against concentrations of spiked samples to obtain a linear function of concentration against AUC.

6.2 Sensory evaluation methods

For many compounds, their sensory significance was determined through collection of quantitative sensory descriptive (Espinase Nandorfy et al. 2022a), with rapid sensory methods also applied (Espinase Nandorfy et al. 2022a, Pearson et al. 2020). Partial least squares regression and principal component analysis were commonly applied to assess the multivariate datasets obtained (Siebert et al. 2018b).

7. Results and discussion

7.1 Methoxypyrazines in Shiraz and Pinot Noir

Although the berries of grape varieties such as Pinot Noir and Shiraz do not contain methoxypyrazines (the volatile compound that imparts ‘green capsicum’ and ‘herbaceous’ notes to wine), it has been previously established that the rachis (stalks, stems) of some varieties can contain high levels of this compound. There is therefore the potential for winemaking practices such as whole bunch fermentation to impart ‘green’ notes to Shiraz or Pinot Noir wines. The inclusion of varying proportions of crushed whole bunches in Shiraz and Pinot Noir fermentations gave enhanced concentrations of ‘green’ methoxypyrazine compounds, notably isobutyl methoxypyrazine (IBMP), as well as higher tannin, and led to changes in colour and ‘green’ and ‘fruity’ wine sensory attributes (Day et al. 2020). In other words, the inclusion of as little as 25% of whole bunches can give undesirable ‘green capsicum’/‘stalky’ wine flavour. For both varieties, the sensory scores for ‘green capsicum’ and the concentration of IBMP (the methoxypyrazine compound most responsible for ‘green capsicum’ aroma) were highly correlated with the proportion of whole bunches in the ferment (Figures 1 and 2). For Shiraz, the concentration of tannin and the perception of astringency were also highly correlated with the proportion of whole bunches. Differences in red/brown hue were also observed.

This study showed clearly that inclusion of the rachis in Shiraz and Pinot Noir fermentation can result in chemically detectable and sensorially significant methoxypyrazine concentrations, and winemakers need to consider the trade-off between the generation of potentially undesirable 'green' characters against enhancement of wine colour, desirable flavour changes and increased tannin when adding whole bunches to their ferments.

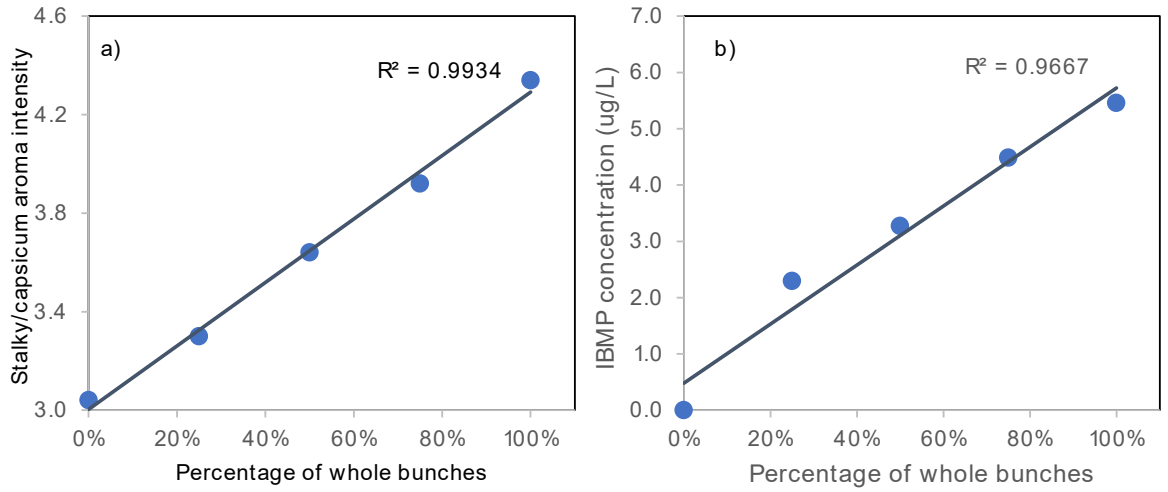


Figure 1. Relationship between the percentage of whole bunches included in a Shiraz fermentation and a) stalky/capsicum aroma intensity and b) isobutyl methoxypyrazine concentration in the wines

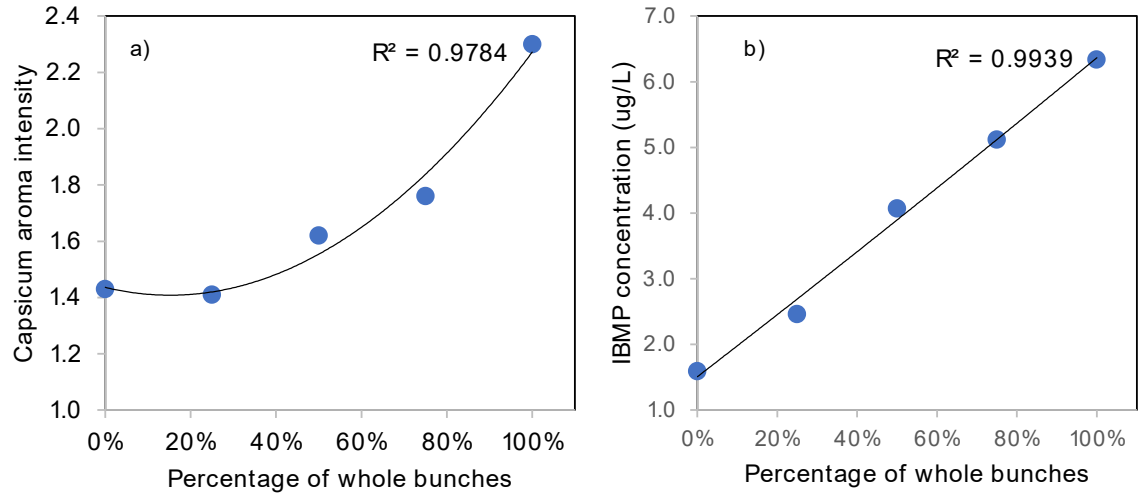


Figure 2. Relationship between the percentage of whole bunches included in a Pinot Noir fermentation and a) capsicum aroma intensity and b) isobutyl methoxypyrazine concentration in the wines

Further studies completed in collaboration with CSIRO researchers showed that Shiraz grapevines grafted on Ramsey and Dog Ridge rootstocks gave wines higher in 'green' sensory characters and IBMP, and it was confirmed that IBMP was not detected in grape berries but was at a significantly higher concentration in the rachis of the Ramsey rootstock compared to vines on own roots (Capone et al. 2022). The precursor to methoxypyrazines was also higher in the Ramsey rachis when sampled early in the season, although the expression of methyltransferase genes related to methoxypyrazine was not linked to methoxypyrazine concentration in the rachis, requiring further study to determine why methoxypyrazines accumulate in the rachis of Shiraz.

7.2 Stone fruit characters in white wines

Data from a large set of commercially produced white wines analysed for the dairy lactone compound implicated in 'apricot' character showed only a small number of wines had concentrations exceeding its sensory threshold of 100 ng/L (Siebert et al. 2018c), with the highest concentrations found in Riesling and Viognier wines.

A reconstitution sensory study investigating the interaction of lactones with monoterpenes in a model base confirmed earlier work that the monoterpenes are of importance to the perception of 'apricot' while several lactones at wine-like concentration enhanced the intensity of 'apricot' aroma (Figure 3, Espinase Nandorfy et al 2022a).

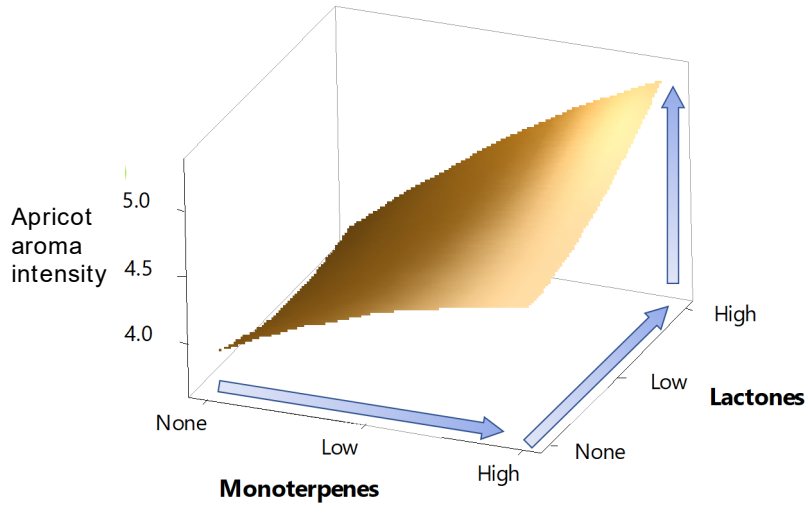


Figure 3. Response surface illustrating the enhancement of apricot aroma intensity with increasing concentrations of monoterpenes added to a model wine, with a secondary effect of lactones acting as enhancers

In work investigating 'peach' aroma in white wines, following a sensory-directed sorting exercise, a set of five Chardonnay wines considered to have either high or negligible 'peach' aroma was analysed for a suite of aroma compounds. Using these quantitative data, a 'peach' reconstitution sensory study was completed. The results showed the important influence of several fermentation-derived fatty acid ethyl esters, notably ethyl octanoate and ethyl hexanoate, on this aroma attribute (Figure 4, Espinase Nandorfy et al. 2022a). This study should allow winemakers to adjust the level of this character through simple fermentation practices such as use of anerobic conditions and enhanced lipid concentration (e.g. through decreased juice clarification, yeast selection and lees contact), which are known to affect these compounds.

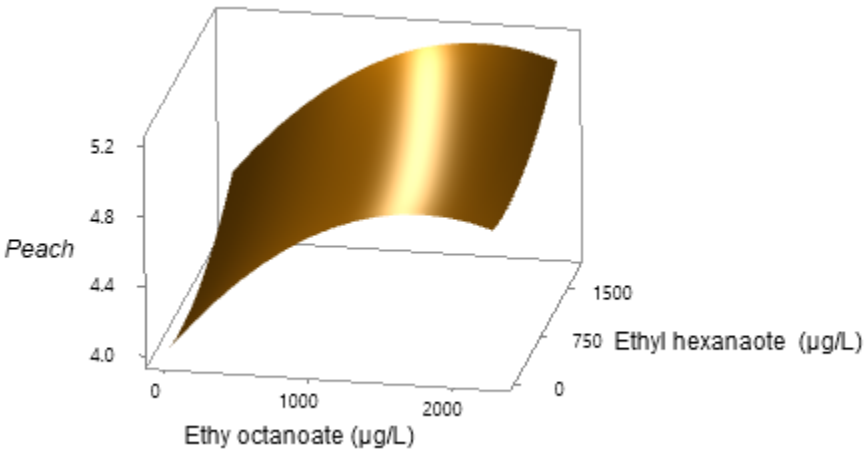


Figure 4. Response surface illustrating the directing of peach aroma intensity with increasing ethyl octanoate and ethyl hexanoate added to a model wine (adapted from Espinase Nandorfy 2022a).

A study assessing aroma compounds in sweet, *Botrytis*-affected white wines and dry white wines found that some lactones were generally at much higher concentration in the sweet wines, especially those from Riesling, suggesting that these compounds may be important to the desirable apricot flavour often found in this wine style (Figure 5). A survey of 37 commercially produced red wines from multiple varieties indicated that these compounds were not at a concentration likely to direct flavour, being well below aroma detection thresholds (data not shown).

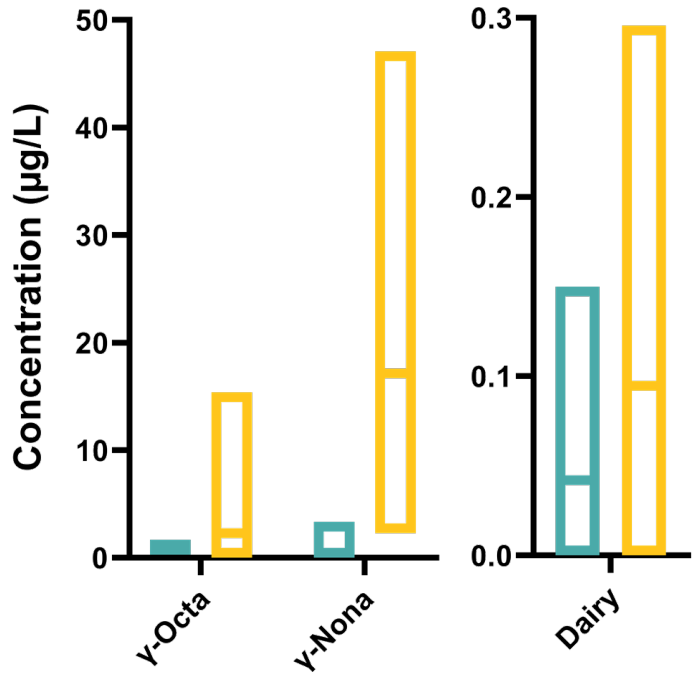


Figure 5. Concentration ranges of three lactones (gamma-octalactone, gamma-nonalactone, and dairy lactone) of a set of commercially produced dry Riesling wines (blue) compared to that of 39 sweet *Botrytis*-affected white wines (yellow). The box indicates the interquartile range, with the median value indicated.

Investigations into sweet Sauternes wines and dry Viognier wines used a newly developed technique of GC-preparative fraction collection following HPLC semi-preparative isolation. This study confirmed the role of several monoterpenes in apricot aroma in Viognier (Siebert et al. 2021).

A sensory and compositional study of the relative effects of region of origin, harvest date and grapevine clone was used to probe 'apricot' flavour and the monoterpenes related to this aroma in Viognier. Two regions, the warm inland irrigated Riverland and cooler climate Eden Valley, were studied, with two commonly planted clones, Entav 1042 and Montpellier 1968. Region of origin was found to be the most important factor influencing monoterpene concentrations, but clone and harvest date were also significant, with one clone giving a much higher level of monoterpenes. Higher concentrations of bound monoterpenes were present in the Viognier grapes at commercial harvest compared to early harvest for both clones at the Riverland site, but no clonal effect was observed. Changes over time were also observed. For Eden Valley wines, a minimal effect of ripeness was seen, but a clonal difference effect was evident.

Most of the quantified free and glycosidically bound monoterpenes increased in concentration from racking to bottling (nine months), and sensory timepoints (11 months). After a further 15 months in bottle, the changes in free and glycosidically bound monoterpenes varied across the sites and clones. In Eden Valley, the Entav 1042 clone wines increased significantly in both the early harvest (e.g. linalool and geraniol were 2.5-fold higher) and commercial harvest dates. While linalool and geraniol concentrations in the Eden Valley Montpellier 1968 clone wines decreased by half for both harvest dates, in Riverland wines both clones decreased at a similar rate to each other for each of the two harvest dates. After the sensory time point, the glycosidically bound monoterpenes decreased for all wines.

Using the same sites and clones as above, free and glycosidically bound monoterpenes were measured by GC-MS and LC-MS in frozen samples of Entav 1042 and Montpellier 1968 clones of Viognier grapes from sun-exposed and canopy-shaded positions at the warmer climate site (Riverland) and the cooler climate site (Eden Valley). Overall, the effect of sun exposure in increasing grape monoterpenes in Viognier grapes was more evident in the Riverland than in Eden Valley. This might have been due to the more substantial canopy on the Riverland vines and/or the later ripening and harvest of Eden Valley fruit during heatwave conditions.

The targeted study of 'peach' in Chardonnay wines was combined with the targeted 'struck flint' study (see Project 3.4.2). Seventy-one white wines (mostly Chardonnay) were assessed by an expert panel during four informal tasting sessions. A subset of 24 wines with varied levels of 'peach' and/or 'struck flint' characters was selected for comprehensive sensory and chemical compositional analysis. Quantitative analyses of volatile compounds and standard wine parameters in the selected wines were conducted and sensory descriptive analysis was completed. The sensory data showed good separation and scaling of target aromas, 'peach' and 'flint' by the external descriptive panel. Strong evidence of the simple linear effects of ethyl esters to fruity aromas was not confirmed, instead a few wines with the highest concentrations of ethyl esters as well as low concentrations of potent thiols were rated highest for 'peach' aroma, highlighting the complex interactions among odorants. However, from the ensuing consumer preference test of six wines ranging from 'peachy' to high 'struck flint', two thirds of consumers preferred 'fruity' wines high in 'peach' aroma, 'sweetness' and 'viscous mouthfeel' and lower in 'flint/struck match' aroma. A follow-up spiking study of the associated 'flinty' compounds PMT and 2FMT, identified from the QDA study, revealed the importance of both compounds to this mineral-like aroma as well as their making effects on fruit aromas. Surprisingly, the effect of 2FMT was 20 times larger than the influence of PMT on 'flinty' aroma intensity (see Project 3.4.2).

A winemaking study is underway to assess peach-related compounds in Chardonnay wines, with two yeast strains (one low- and one high-ester producing strain), three levels of solids (very low, medium and high NTU) and Chardonnay grapes from two sites (McLaren Vale, warmer region, and Adelaide Hills, cooler region). Sufficient volume of the wines has been made for presentation in industry workshops.

7.3 Thiols from foliar sprays and in red wines

Foliar sprays, including basic nitrogen and sulfur formulations, applied in Chardonnay or Shiraz vineyards were found to have a major influence on potent thiol compounds in finished wines over several seasons. Chardonnay wines made from treated vineyards showed more desirable sensory properties than Shiraz wines (Hixson et al. 2020). Wines were also made from a trial assessing a single foliar spray in a Chardonnay vineyard, which may be more practical for growers to adopt compared to previous treatments which required multiple spray applications.

Sensory analysis of the Chardonnay wines showed a significant increase in 'passionfruit'/'tropical fruit' descriptors with an increased foliar spraying rate. This aligns with chemical data for varietal thiols, which showed significant increases in 3-mercaptohexanol (3SH) in particular in the wines made from the treated vineyards. Importantly, analysis for low molecular weight sulfur compounds (usually associated with off-flavours) showed no increase with treatment. The increase in 3-mercaptohexyl acetate (3SHA) in Chardonnay wines was not mirrored in Shiraz.

A further practical vintage study assessed the relative effect of foliar sprays in a commercial Adelaide Hills vineyard compared to fermentation with a high thiol-producing yeast strain. The magnitude of effects was similar, with the highest thiol concentration arising from the combination of treatments (Maxi yeast with sprayed vines, Figure 6). The sprays have been trialled at several commercially operated Sauvignon Blanc and Chardonnay vineyards, with positive feedback obtained.

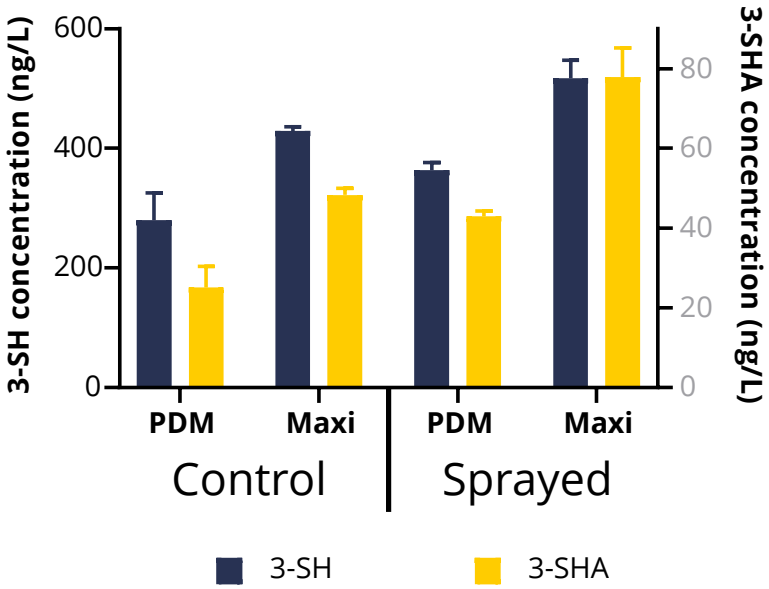


Figure 6. Concentration of varietal thiol compounds in Chardonnay wine from a study comparing treatments with and without foliar sprays in the vineyard and comparing the effects of two yeast strains, PDM (a general-purpose yeast) and Maxi (a strain known to release thiols from precursors)

An analytical survey of 110 commercially produced red wines of several varieties provided data on varietal thiol concentrations (Siebert et al. 2019). Only 3MH was detected in the wines. Similar concentration ranges (100-450 ng/L) and median concentrations (280 ng/L) were found in all varieties examined except for Pinot Noir wines, which were higher (up to 760 ng/L). These concentrations are much higher than the reported aroma detection threshold for 3MH in model wine (60 ng/L). To assess the role of these thiols in red wine flavour, an addition sensory study was completed with the compounds added singly or in combination to a base Pinot Noir wine. Little sensory effect was observed, except when the compound 3MHA was added at a high concentration, where it gave a 'sweaty' flavour. The study provided evidence that these thiols have only a limited role in red wine flavour.

7.4 TDN in Riesling

The compound TDN has been known for some time to be a key flavour compound in Riesling, playing an important role in bottle-aged flavour, and can be considered undesirable if at too high a concentration early in a wine's development.

A viticultural experiment involving shade cloth of different colours found that the concentration of TDN was diminished by the influence of shade cloth, with black and green shade cloth giving a greater reduction of TDN than red shade cloth, with few other sensory effects. This provides a practical means of limiting the contribution of this compound in wine made from grapes grown under hotter climates.

Sensory data have been collected on Australian and German commercial Rieslings over the past two years. Specifically, analysis of wines under screw cap with differing oxygen ingress properties has shown changes in TDN accumulation, as well as 'scalping' effects by cork closures. This work suggests that an oxidative exit from the TDN pathway may exist. An in-depth analysis of the mechanism of formation of TDN on a chemical and computational level has been conducted. This mechanistic study has given insight into the implications of both pH and temperature on accelerated ageing and acid-catalysed 'bound' TDN analysis. Viticultural treatment trials in both Germany and South Australia have provided detailed information regarding sunlight and fruit exposure effects on the development of TDN precursors.

As part of this work, a 'total TDN' hydrolytic assay for Riesling wine, was developed, intended not to interfere with yeast-derived formation pathways. The new assay (75°C, pH 1.7, and 60 min) was used to determine the influence of industry-relevant commercial yeasts as well as novel hybrid yeast strains on total TDN concentrations in young Riesling wines. While significant differences were observed among some yeasts, the impact of defoliation as a viticultural intervention outweighed yeast effects, suggesting that elevated TDN concentrations in wine are likely due to grape growing conditions and cannot be readily reduced or compensated for in the winery (Grebneva et al. 2019).

7.5 'Jammy' characters in Shiraz

Studies of overripe raisin or jam-like sensory attributes of Shiraz wines and grape berries have provided insight into several compounds that are related to this character, including some that are also implicated in oxidative flavour in wines. Shiraz grapes from the Barossa Valley were sampled at different time points from commercial maturity onwards, and from each side of an east-west aligned row. Thermal imaging of the grape bunches showed a significant temperature difference between north-side and south-side bunches. Sensory analysis of berry homogenates showed differences in the 'jammy' characters present, with this more closely associated with hang-time than sun exposure/berry temperature from the different sides of the vine.

Subsequently, Shiraz grapes were harvested at two timepoints and the grape parcels manually separated to give under- and over-representations of shrivel. Wines were made from this fruit and putative compounds quantified. Flavour extracts of these grapes were analysed using analytical methodologies in collaborative work at the University of Bordeaux, France, which showed high concentrations of a known 'prune' compound 3-methyl-2,4-nonadione (MND). Gas chromatography-olfactometry using an aroma extract dilution analysis approach was also completed, implicating several key compounds. Analytical methods for these compounds were developed and applied. The differences in chemical composition were found to be driven more by shrivel than harvest timepoint. Furthermore, the extent of compositional changes in shrivelled berries far exceeded the concentration effect of berry dehydration. This suggests that eliminating shrivelled berries would be a more effective strategy than water addition for avoiding over-ripe characters.

Additional vintage trials conducted included:

- the assessment of long hang-time on berry sensory characteristics, which showed significant increases in 'sweetness', 'jammy/cooked fruit flavour' and 'dried fruit flavour' with increasing hang-time and shrivel extent
- the use of open-top vine heating chambers to investigate the role of increased bunch-zone temperature on target compounds
- a berry compositional survey from regions with different climates to determine the prevalence of the key compounds.

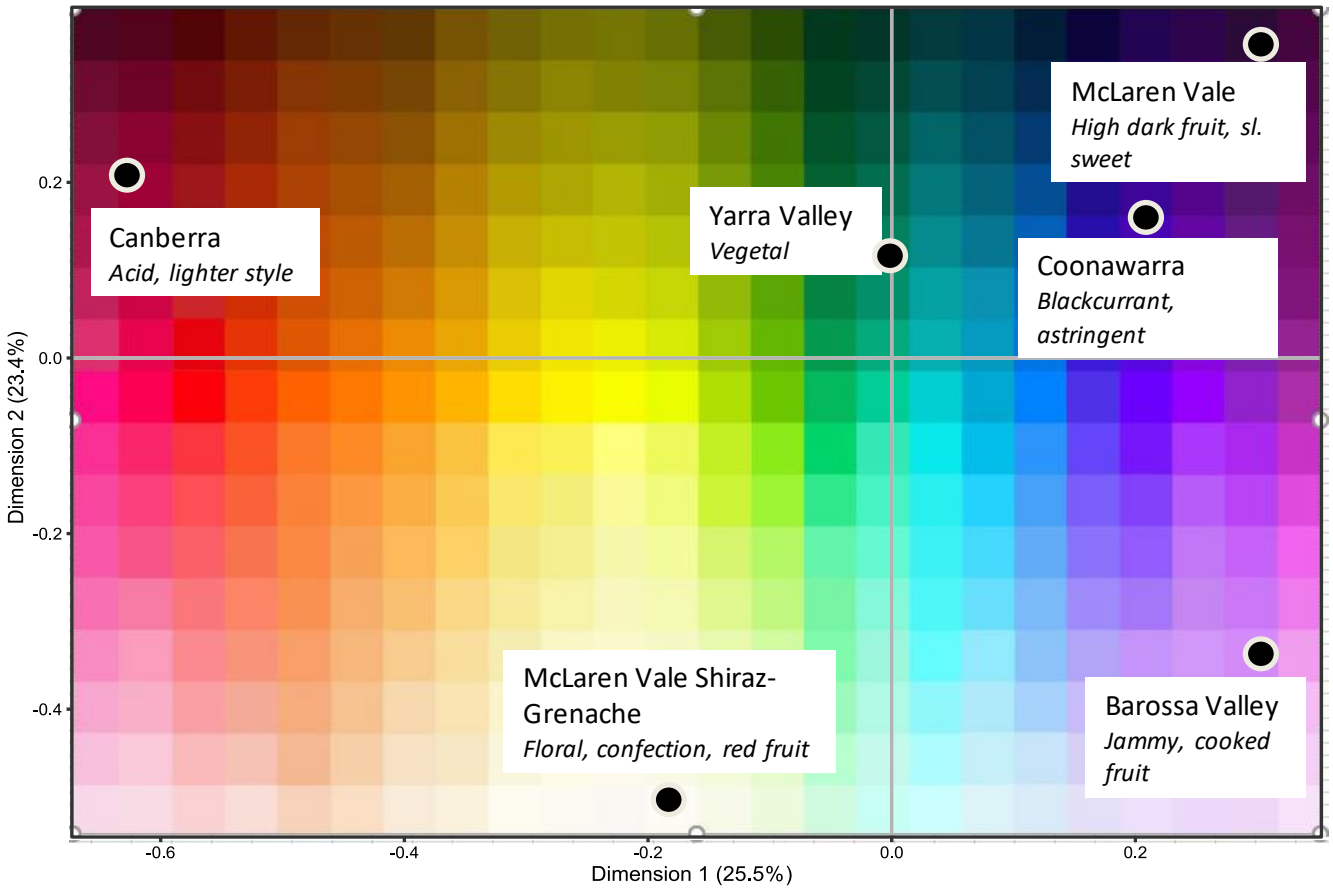
7.6 Alternative sensory methods

To assess alternative sensory analysis methods, including methods suited for industry application, several rapid, relatively simple methods were evaluated in comparison to the accurate and detailed (but lengthy) quantitative descriptive analysis (QDA) method. 'Pivot© Profile' and 'Napping' were both compared to QDA and these methods were found to be valuable rapid approaches, in particular for use with assessors who are able to use a common vocabulary, such as winemakers. A sensory study comparing several different methods was completed using a set of 15 premium Shiraz wines with a panel of Australian winemakers and a separate panel of international sommeliers. The 'rate all that apply' (RATA) method, when completed in a single session with 35 semi-trained assessors, gave similar results to the standard QDA method. The 'polarised sensory positioning' (PSP) method, which also requires little time to collect data, showed great promise as a sensitive means to determine whether several wines differ in their sensory properties, using a relatively small panel.

The RATA method showed the greatest promise as a rapid alternative to QDA, being more amenable to conventional, shorter statistical analysis and giving the most detailed results. The PSP method showed promise as a sensitive means to assess overall sensory differences, with less information gained about the attributes that differed.

Projective mapping with choice was also examined in a study with consumers. A set of alternative red varieties was assessed using this method compared to a Shiraz wine, with some of the varieties included relatively well-known to consumers and others more obscure. Varieties included Tempranillo, Lagrein, Saperavi, Sangiovese, Nero d'Avola, Graciano and Montepulciano. The method provided valuable insight into consumer attitudes and preferences, including appropriate occasions and attitudes. Lagrein showed potential as a variety as it was well-liked blind and with knowledge of variety, with the results indicating that this variety, as well as Saperavi, is of interest to consumers and suited for consumption at restaurants and with friends. Overall, while valuable insight into consumer perception of both sensory preference and consumption occasion could be obtained using this method, the ability to make clear conclusions about the observed differences between tested wines was relatively limited.

As part of an 'artist in residence' program, a sensory projective mapping procedure was completed with six commercially produced Shiraz wines to assess associations of wine flavour with colours and shapes, with a view to aligning environmental cues to match wines to enhance the tasting experience. While all wines were Shiraz, the colours associated with the wines when tasted in black



glasses were surprisingly distinct (Figure 7).

Figure 7. A representation of the colours associated with the flavour of six young commercially produced Shiraz wines (including one blend) by a group of 62 individuals, tasting the wines in black glasses. The set of descriptors associated with each wine is taken from the sensory descriptive analysis study undertaken on the same set of wines.

A preference study (n=38 assessors) was conducted with three of the wines assessed under three different conditions. The conditions involved a conventional white sensory booth, and the booth decorated to give two more 'natural' settings, one with a 'yellow-red' graphic that was associated with one of the wines, and another with a 'purple-red' graphic that was associated with another of the wines. There was no significant difference in liking scores of the wines across the three conditions. There was a suggestion that the liking responses for a small number of the consumers tested (21% of the total) were influenced by the setting, with the 'natural' decorated booth settings resulting in higher liking scores, but the pattern of responses across the wines was similar; that is, the most liked and least liked wines were consistent. There was a trend that the 'yellow-red' graphic had a greater effect on liking scores. Overall, this study indicates that a 'natural', setting from a visual point of view does not influence test outcomes, and a 'clinical' sensory test booth setting will not result in false conclusions.

7.7 Influence and interactions involving amino acids in red wine

Investigations into the sensory effect of volatile flavour compounds in combination with non-volatile compounds in a Shiraz model system showed that flavour is a multisensory system, with the volatile compounds giving the greatest contribution to sensory properties such as body or viscosity, while tannin/anthocyanin had little effect. The addition of several amino acids, previously largely unrecognised as being important to wine flavour, led to greater sweetness and a suppression of bitter taste, and the study showed that amino acids, notably proline, can be considered to be contributors to the desirable 'fruit sweetness' character of dry red wines. A further reconstitution sensory study showed that proline concentration was significantly positively related to perception of viscosity, sweetness and 'red fruit' flavour, while being negatively related to astringency and bitterness, showing a suppressive effect. Glutamic acid was linked to 'umami'/'savoury' taste (Figure 8. Espinase Nandorfy et al. 2022b). Assessing several recently conducted sensory studies with sets of Shiraz wines, proline concentration in the wines was also found to be correlated with sensory ratings for viscosity.

The identification of proline as a positive contributor to desirable red wine flavour attributes opens up a potentially new area of control for wine producers, as proline is known to be responsive to deficit irrigation practices, and is not metabolised by yeast during fermentation.

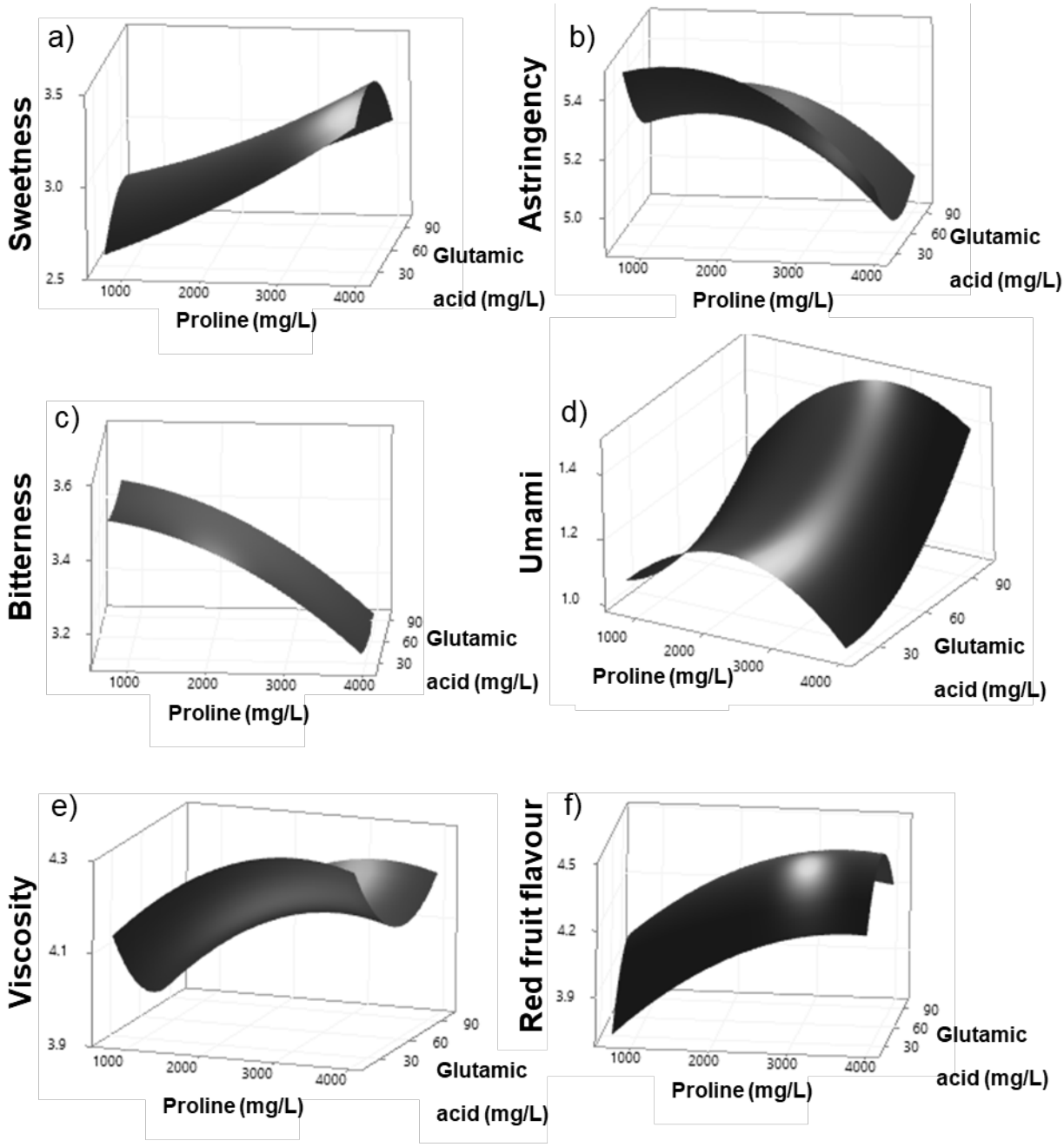


Figure 8. Response surface models of in-mouth sensory attributes influenced by amino acid addition to a Shiraz wine low in amino acids L-proline and L-glutamic acid (Figure reproduced from Espinase Nandorfy 2022b under Creative Commons licence CC-BY-NC-ND).

7.8 Red wine blending

Informed by the causal experiments published in Espinase Nandorfy et al. (2022b), which demonstrated the effects of amino acids on red wine flavour, a practical study attempting to exploit these findings through blending commercial wine was planned with industry input. After a preliminary assessment of 18 candidate wines, covering sensory properties, basic chemical composition, proline concentration and tannin concentration, three wines were selected for the blending study. A high-proline Riverland Cabernet Sauvignon and a high tannin, colour and flavour Limestone Coast Lagrein were blended in different proportions with a low-proline, relatively 'thin', and 'green' flavoured Riverland Cabernet Sauvignon, to produce 14 wines, using a ternary statistical design. Compositional chemical analysis was completed for time-point zero, while sensory analysis, consumer preference testing and repeated chemical analysis were carried out after six months of bottle ageing. Proline-rich blends displayed increased sweetness, viscosity and flavour, lower astringency and bitterness, and were most liked by consumers (Figure 9). Wines with overt

astringency, 'green' aromas and pronounced bitterness were poorly liked. A synergistic blend mainly composed of the flavour-deficient Cabernet Sauvignon with a small proportion of the high-proline wine was identified using this scientific approach.

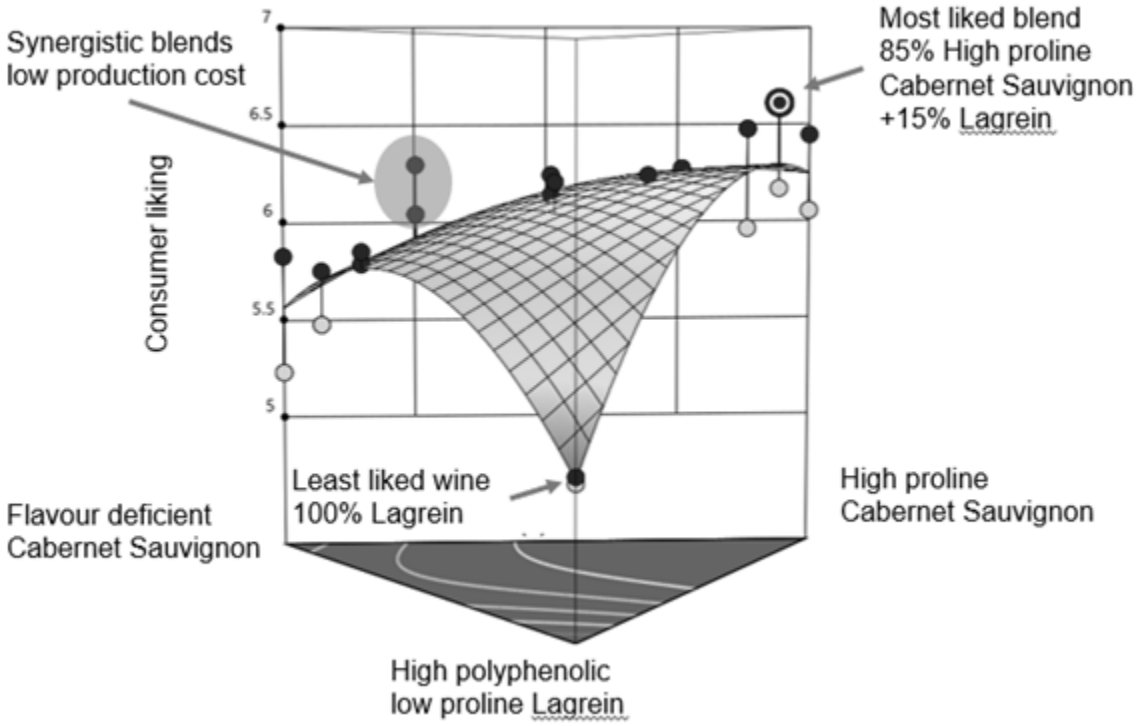


Figure 9. Response surface model of consumer liking scores of Cabernet Sauvignon blends aimed at correcting a warm inland flavour-deficient wine with varying proline and polyphenolic levels

8. Outcome and conclusion

The project has advanced knowledge of volatile and other compounds that give rise to important flavour in varieties of commercial importance to the Australian wine industry.

The knowledge that the rachis of Shiraz and Pinot Noir grape bunches can provide a major source of 'green' methoxypyrazines during fermentation, together with experiments including differing proportions of rachis during fermentation, will allow producers to make informed decisions regarding the sensory benefits and risks when determining the proportion of whole bunches in fermentations, especially in cooler climate regions.

Trials on the effect of foliar nitrogen and sulfur sprays on white grapes have resulted in practical outcomes for producers. Results from studies with Chardonnay over several seasons show the utility of this simple approach in enhancing fruit flavour, especially in light of a changing climate, and the work has been applied to other varieties, notably Sauvignon Blanc. Several companies have trialled the approach and it will form one of the practice change priorities for the extension project in the next AWRI-Wine Australia investment agreement.

Based on the studies of 'stone fruit' character in white wine, notably Chardonnay and Viognier, wine producers can now adjust the levels of 'peach' character in their wines through simple changes to fermentation practices. Knowledge that 'apricot' flavour is mainly related to monoterpenes, has provided tools of clonal selection, harvest date, nitrogen status and canopy management practices, all of which affect these compounds. Knowledge of the importance of monoterpenes in Viognier provides the ability to understand the impact of different planting material and viticultural options on the attractive varietal flavour of this variety. A major Viognier producer has taken steps to use this information in their production systems.

Sensory methodology development work has allowed cost-effective and rapid methods to be available for industry use, where the Pivot© Profile method has been applied in several regional projects, and has also been used for studies for suppliers. Modified sensory methods have been delivered to companies and regional associations, for use in smoke taint assessment in micro-ferments and wines from the 2019-2020 season, with training and support provided.

The novel identification of interactive and direct effects of the amino acids proline and glutamic acid on multiple sensory properties of red wine, was a major advance. A scientific approach to blending identified synergistic flavours and consumer preferences, providing evidence of key compositional markers of sensory significance. Blending high-proline and high colour/tannin alternative variety components greatly improved a 'thin' red wine, providing opportunities to increase the value of the large volume of bulk wine produced in warm inland irrigated areas.

The influence of bunch exposure, the use of appropriate shade cloth and other viticultural approaches, highlighted the practical ability to adjust bottle-age flavour in Riesling, especially when this character might develop earlier than expected, allowing producers to mitigate effects of climate changes on early development of TDN from precursors.

The overripe jammy/raisin flavour in Shiraz was linked to specific volatiles and found to be related to time of harvest rather than sun exposure or berry temperature. The analytical method developed can be applied to future studies and used by producers for trials.

9. Recommendations

It is recommended that the following lines of research stemming from this project should be pursued:

- The mechanism of formation of benzyl mercaptan should be identified, as it is likely formed from a yeast-derived compound with further transformation during barrel fermentation and ageing in oak.

- Variables that affect 'green' aroma and flavour from whole bunch fermentation should be further examined, given that this technique is widely practised in red wine production.

- The role of specific volatiles in other key sensory attributes that are not well understood should be determined, with attributes previously shown to be important in influencing consumer response including 'chocolate' and 'caramel' aroma and compounds other than rotundone that contribute to 'spicy' flavour in red wine. The compounds wine lactone and (E)-1-(2,3,6-Trimethylphenyl)buta-1,3-diene (TPB) are highly potent and little studied, and have been indicated as important to bottle aged character in white wines, notably Semillon.

- The influence of proline and glutamate in wine flavour should be further studied, with additional knowledge required on the concentration of these amino acids occurring in different cultivars, as well as control options for these compounds. The interactions among volatiles and non-volatiles should be an area of increased focus, to mitigate climate change effects and better target alternative varieties with desirable attributes.

10. Appendix 1: Communication

Work describing the effect of inclusion of the rachis in Pinot Noir and Shiraz fermentations received two poster prizes at 17th AWITC, July 2019: Best poster and People's choice. Similarly, in the 18th AWITC, the work on proline and blending received two awards for best poster and best presentation. There have been extensive communications though industry presentations, roadshows, podcasts, webinars, industry journal and AWRI Technical Review articles, and refereed scientific publications as listed in the References section.

Technical notes, *AWRI Technical Review*

Siebert, T. E., Francis, I. L., Pisaniello, L., Melzer, S., Bey, L., Watson, F., Espinase Nandorfy, D., Cordente, T. 2019. Do varietal thiols matter in red wine? *AWRI Tech. Rev.* (243): 10-15.

AWRI webinars + YouTube videos

The flavour of bottle-aged Riesling – predicting and controlling future chemistry, September 2018

Why does this wine smell like apricots?, October 2018

Influencing tropical thiol concentration in white wine by combining foliar sprays, September 2022

Industry presentations

- What are the key Chardonnay volatile compounds (and how can we improve on the Tassie standard)? Launceston, October 2018
- Existing sensory methods and practical issues, AWITC workshop July 2019
- Projective mapping/napping, AWITC workshop July 2019
- Pivot© Profile, AWITC workshop July 2019
- What chemical measures relate to regional sensory differences? AWITC workshop July 2019
- Sensory effects of 'positive' thiols as fruit enhancers or tropical impact aromas AWITC workshop July 2019
- Trial design and effective use of sensory evaluation techniques, AWITC workshop July 2019
- Are tropical thiols varietal? AWITC workshop July 2019
- 'Apricot' aroma in white wine: contributors and influences AWITC workshop July 2019
- Whole bunch fermentation of Shiraz and Pinot Noir: influence on 'green' characters and astringency, 17th AWITC plenary program, July 2018
- Modulating tropical character in the vineyard, October 2019
- The perception of mouthfeel in wine: a sensory perspective and clues from neurophysiology, ASVO seminar October 2020
- Did someone light a match? Struck match/struck flint and other fun sulfur compounds in Chardonnay, Hobart, November 2020
- Smoke taint sensory evaluation: considerations to improve rigour and aid decision-making, Hahndorf, May 2021

Roadshow seminar presentations

- Complexity, texture and flavour ... or green, hard and herbal? Incorporation of stems and leaves in cool climate Shiraz fermentation, Mt Barker WA, November 2018
- Struck match and tropical fruit: the role of varietal thiols in Australian Chardonnay Mt Barker WA, November 2018
- Struck match and tropical fruit: the role of varietal thiols in Australian Chardonnay, Margaret River, November 2018

- The voice of the consumers: why should we listen? Margaret River, November 2018
- Struck match and tropical fruit: the role of varietal thiols in Australian Chardonnay, Swan Valley, November 2018
- What makes a red wine green?, 28 November 2018
- The flavour of bottle-aged Riesling – predicting and controlling future chemistry, Barossa, 12 November 2019
- The flavour of bottle-aged Riesling – predicting and controlling future chemistry, Clare, 13 November 2019

11. Appendix 2: Intellectual property

Program IP has been communicated through presentations and publications and resides in the public domain. Copyright in any reports, posters or presentations is held by the AWRI. Copyright in publications remains with the publisher. No inventions or patentable discoveries have been identified from the work. No Program IP has been commercialised or identified for commercialisation at the time of writing this report.

12. Appendix 3: References

Capone, D.L., Barker, A., Pearson, W., Francis, I.L. 2021. Influence of inclusion of grapevine leaves, rachis and peduncles during fermentation on the flavour and volatile composition of *Vitis vinifera* cv. Shiraz wine. *Aust. J. Grape Wine Res*. 27(3): 348-359.

Capone, D.L., Francis, I.L., Clingeleffer, P.R., Maffei, S.M., Boss, P.K. 2022. Evidence that methoxypyrazine accumulation is elevated in Shiraz rachis grown on Ramsey rootstock, increasing 'green' flavour in wine. *Aust. J. Grape Wine Res.* 28: 304-315.

Day, M.P., Capone, D.L., Kassara, S., Bilogrevic, E.O., Nandorfy, D.E., Watson, F.T., Francis, I.L., Bindon, K.A. 2020. Whole bunch fermentation of Shiraz and Pinot Noir: influence on 'green' characters and astringency. Beames, K.S., Robinson, E.M.C., Dry, P.R., Johnson, D.L. (eds.) *17th Australian Wine Industry Technical Conference*, Adelaide, South Australia: The Australian Wine Industry Technical Conference Inc. 94-96.

Espinase Nandorfy, D., Bilogrevic, E., Williamson, P., Francis, L. 2021. Smoke taint decision-making: simple steps for reliable sensory testing. *AWRI Tech. Rev.* (252): 5-12.

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13. Appendix 4: Staff

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14. Appendix 5: Other supporting material

Not applicable