# Sensory Characterisation of Australian Cabernet Sauvignon Wine Typicity

Lira Souza Gonzaga

A thesis submitted for the degree of Doctor of Philosophy

School of Agriculture, Food and Wine

The University of Adelaide

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# Contents

# Contents

# Thesis Summary

Wine is a product with a complex composition that undergoes a diverse number of processes during its production that will eventually impact on the final chemical and sensory profiles. Those processes can and will change depending on the geographical area so that grape growing and winemaking practices can account for unique regional features, such as the biome associated with the vineyard, the logistical and technological inputs at the winery, and the social environment involved with wine commercialisation. Consequently, when a certain wine style is achieved, it will inevitably carry a connection with its provenance that can be expected to be expressed through sensory traits. Conveying unique features that are connected to the wine's place of origin can be defined as wine typicity. Over the years, wine typicity has been increasingly established as a concept to consider in the market and can also be an important factor for the consumer's purchase decision. However, wine typicity is still concept with a broad definition that has been tailored throughout the years to suit different research purposes.

Considering provenance connection and the notion of unique expression, this thesis starts by reviewing the literature that covers the wine typicity concept and the influencing factors around it (Chapter 1). After reviewing the literature around wine typicity, a concept is proposed encompassing aspects that are considered for the purposes of this thesis: "Wine typicity can be defined as a juxtaposition of unique traits that define a class of wines having common aspects of terroir involving biophysical and human dimensions that make the wines recognisable, and in theory, unable to be replicated in another territory.". The literature review also covers consumer perspectives regarding the concept of wine typicity and details previous studies that have reported the importance of typicity for consumer behaviour and purchase decisions.

Similarly, to other nations, wine producing regions in Australia are divided into Geographical Indications (GIs) that relate wine to it geographical production area. Among all the red varieties produced in those GI, Cabernet Sauvignon is the second most important to the Australian industry, and is an internationally renowned variety. Thus, the different research studies reported in this thesis (Chapter 2 to 5) aimed to offer a better understanding of the sensory aspects involved with the typicity of Australian Cabernet Sauvignon wines from different GIs. Notably, different Cabernet Sauvignon producing regions of Australia are included throughout the studies in this thesis, namely Coonawarra, Margaret River, and Yarra Valley.

Additionally, as the birthplace of the Cabernet Sauvignon variety, Bordeaux in France was also included for benchmark purposes.

The first research publication (Chapter 2) used a web-scraping software and content analysis to investigate over 2,500 web-based Cabernet Sauvignon wine reviews from established Australian wine writers, including their tasting notes and overall scores. Sensory analysis was also conducted with a set of 84 Cabernet Sauvignon wines using 11 industry experts, who provided freely chosen descriptors. A sensory lexicon was created using the content analysis software and the frequencies for each term were statistically analysed. Correspondence analysis showed descriptors that were associated with the sensory profiles of the studied regions along with descriptors that were most commonly associated with assigned quality scores. When both data sets were compared, a higher agreement was shown for quality assessments than for regional profiles, whereby wine writers and expert panellists had a better alignment with descriptors that were associated with low and high quality wines.

Using the same expert panel and the set of 84 Cabernet Sauvignon wine samples, the second research publication (Chapter 3) combined a variant of rate-all-that-apply and a sorting task data with a separate descriptive analysis conducted by a panel of 10 trained tasters using a subset (n = 52) of the initially-studied wines. The sorting task data demonstrated that the sample segregation undertaken by the expert panel was mainly based on sensory profiles rather than regionality, although there was a clearer segregation on the Bordeaux wine samples. Both panels (expert and trained panel), however, raised multiple sensory attributes associated with the regional profile of wines from the four wine regions specified earlier. Some of the attributes, such as 'minty', 'cooked vegetables' and 'floral', were in close agreement between the two sensory cohorts.

Understanding what represents sensory regionality (regional typicity) for the Australian Cabernet Sauvignon wines is important, so procedures and environmental characteristics that influence regional typicity can be pinpointed. However, for the commercialisation of the product, comprehending the target market and how consumers behave is also an important tool for the industry. Therefore, the third research publication (Chapter 4) dealt with consumer perspectives around the wine typicity concept and the impact of provenance information when tasting wine. Red wine consumers (n = 112) were recruited to taste a restricted subset of samples (n = 8) drawn from the previous studies. The participants were divided into two groups: one group received origin information of the wine prior tasting and the other tasted the samples blindly. With the chosen experimental design, this study was able to demonstrate that provenance information had a positive impact on consumer hedonic scores even though both groups essentially perceived the sensory profiles of the wines in the same way. A survey conducted with these consumers about the wine typicity concept showed that many were familiar with the typicity term, and for a moderate number, typicity was deemed to be important for their purchase decision.

The last manuscript (Chapter 5) aimed to verify if the sensory traits found in Chapters 2, 3, and 4 were important for Coonawarra typicity. Additionally, this manuscript explored the possible association between spectrofluorometric analysis, as a highly selective and sensitive methodology, and sensory traits of Coonawarra Cabernet Sauvignon wines. Thus, commercially-produced but unfinished Cabernet Sauvignon wines from different vineyards of the Coonawarra GI were evaluated through rate-all-that-apply (RATA) sensory testing (n = 60), along with basic chemistry, and spectrofluorometric analysis. The sample set was clustered into five distinctive sensory profiles through agglomerative hierarchical clustering (AHC) analysis that were modelled against fluorescence data with extreme gradient boosting discriminant analysis (XGBDA), a machine learning technique. This enabled classification of the wines according to their sensory clustering with 100% accuracy using excitation and emission matrices (EEMs) from spectrofluorometric analysis. Four main fluorophores characterising the sample set were tentatively identified through parallel factor analysis (PARAFAC) and associated with classes of phenolic compounds commonly present in red wine. Even though it is likely to be an indirect association, the EEMs of those four fluorophores were tentatively associated with the sensory descriptors found through the RATA assessment. The sensory panel ratings for perceived astringency mouthfeel were also predicted (68.1% of confidence) through a partial least squares regression model that explained 84.8% of the variance in the results. Considering the optimistic nature of the task described in this manuscript promising results was found, showing that fluorescence analysis might be the key to predict sensory traits from a small number of wine compositional factors.

# Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint award of this degree.

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__ _ Date: 12 May 2021

Lira Souza Gonzaga

# Publications

This doctoral thesis includes a collection of three papers that were published in peer-reviewed scientific journals during the candidature (Chapter 1 to 5).

**Chapter 1**

**Souza Gonzaga, L.**, Capone, D. L., Bastian, S. E. P., & Jeffery, D. W. (2021). Defining wine typicity: Sensory characterisation and consumer perspectives. *Australian Journal of Grape and Wine Research*, 27(2), 246-256. https://doi.org/10.1111/ajgw.12474.

**Chapter 2**

**Souza Gonzaga, L.**, Capone, D. L., Bastian, S. E. P., Danner, L., & Jeffery, D. W. (2019). Using content analysis to characterise the sensory typicity and quality judgements of Australian Cabernet Sauvignon wines. *Foods*, 8(12), 691. https://doi.org/10.3390/foods8120691.

**Chapter 3**

**Souza Gonzaga, L.**, Capone, D. L., Bastian, S. E. P., Danner, L., & Jeffery, D. W. (2020). Sensory typicity of regional Australian Cabernet Sauvignon wines according to expert evaluations and descriptive analysis. *Food Research International*, 138, Part A, 109760. https://doi.org/10.1016/j.foodres.2020.109760.

**Chapter 4**

**Souza Gonzaga, L.**, Bastian, S. E. P., Capone, D. L., Danner, L., & Jeffery, D. W. (2021). Exploring consumer knowledge of wine typicity and the impact of region of origin information when tasting Cabernet Sauvignon wines. *Food Research International, 110719.* https://doi.org/10.1016/j.foodres.2021.110719.

**Chapter 5**

**Souza Gonzaga, L.**, Bastian, S. E. P., Capone, D. L., Ranaweera K. R. Ranaweera, & Jeffery, D. W. (2021). Modelling Cabernet Sauvignon wine sensory traits with spectrofluorometric data. *Oeno One*, *55 (4), 19-33.* https://doi.org/10.20870/oeno-one.2021.55.4.4805

Ancillary publications included in the Appendix section were also produced during the period of candidature:

**Appendix A** Ranaweera, R. K. R., **Souza Gonzaga, L.**, Capone, D. L., Bastian, S. E. P., & Jeffery, D. W. (2021). 3.33 - Authenticity and Traceability in the Wine Industry: From Analytical Chemistry to Consumer Perceptions. In A. Cifuentes (Ed.), Comprehensive Foodomics (452-480). Oxford: Elsevier. https://doi.org/10.1016/B978-0-08-100596-5.22876-X

**Appendix B** **Souza Gonzaga, L.**, & Capone, D. L., Bastian, S. E. P., & Jeffery, D. W. (2020, 17-18 November). Sensory characterisation and consumer perspectives of Australian Cabernet Sauvignon wine typicity in IVES Conference Series, XIIIth International Terroir Congress, Adelaide, Australia. https://ives-openscience.eu/wp-content/uploads/2021/03/Souza-Gonzaga-et-al_ITC2020_FO.pdf

**Appendix C** Capone, D. L., Boss, P., **Souza Gonzaga, L.**, Bastian, S. E. P., & Jeffery, D. W. (2020, 17-18 November). Characterising the chemical typicity of regional Cabernet Sauvignon wines in IVES Conference Series, XIIIth International Terroir Congress, Adelaide, Australia. https://ives-openscience.eu/wp-content/uploads/2021/03/Capone-et-al_ITC2020_SO.pdf

# Conferences

1 **17th Australian Wine Industry Technical Conference (AWITC)**, Adelaide, Australia, 21-24 July 2019.

Poster presentation: "Exploring the typicity of Australian Cabernet Sauvignon wines".

2 **School of Agriculture, Food & Wine Annual Postgraduate Symposium**, Adelaide, Australia, 24 – 25 September 2019.

Oral Presentation: "Exploring the typicity of Australian Cabernet Sauvignon wines".

3 **XIIIth International Terroir Congress**, Online platform, 17 - 18 November 2020.

Oral presentation: "Sensory characterisation and consumer perspectives of Australian Cabernet Sauvignon wine typicity".

4 **I Congresso Latino-Americano de Ciências Sensoriais e do Consumidor (SenseLatam),** Online platform, 24 - 26 November 2020.

Oral presentation: "Entendendo o comportamento do consumidor em relação à tipicidade sensorial dos vinhos Cabernet Sauvignon Australianos/ Understanding consumer behaviour towards the sensory typicity of Australian Cabernet Sauvignon wines".

5 **72nd ASEV National Conference**, Online platform, 21 – 24 June, 2021.

Oral presentation: "Sensory characterisation of the typicity in Australian Cabernet Sauvignon wines".

Co-authored conferences abstracts:

6 **XIIIth International Terroir Congress**, Online platform, 17 - 18 November 2020.

"Characterising the chemical typicity of regional Cabernet Sauvignon wines".

7 **Macrowine 2021**, Online platform, 23-30 June 2021.

"Chemical and sensory diversity of regional Cabernet Sauvignon wines".

# Panel of supervisors

Principal Supervisor

Associate Professor **David W. Jeffery**
0000-0002-7054-0374
The University of Adelaide
School of Agriculture Food and Wine

Co-Supervisor

Dr. **Dimitra L. Capone**
0000-0003-4424-0746
The University of Adelaide
School of Agriculture Food and Wine

Co-Supervisor

Associate Professor **Susan E. P. Bastian**
0000-0002-8790-2044
The University of Adelaide
School of Agriculture Food and Wine

Independent Advisor

Dr. **Paul K. Boss**
0000-0003-0356-9342
CSIRO - Agriculture and Food

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To my co-supervisors Associate Professor Susan Bastian and Dr. Dimitra Capone, my sincerest thank you. I feel very fortunate to have had such amazing women to support me during this journey. Thank you for all the care and the encouragement throughout my entire PhD. Thank you for sharing all your knowledge, expertise, and for giving me the limitless opportunities to learn with you. I will be forever indebted to you. A special thank you for Dr. Lukas Danner for the guidance, all the assistance with my beloved statistics, and great inputs during article publication.

To my parents, I can not express the full extent of my gratitude. This achievement is more yours than mine. Thank you for teaching me how to be resilient and how to dream big. Thank you for being the best role model I could ask for. Moreover, I would like to extend my immense gratitude to my husband, who embarked in this journey with me without asking for any recognition. I could not have done this without you, you are my safe harbour. Thank you for trusting me, for being there for me every night when I needed I shoulder to cry on, and for choosing me to build your life with. I also would like to thank my family in Brazil, you are my base and each one of you represent parts of who I am.

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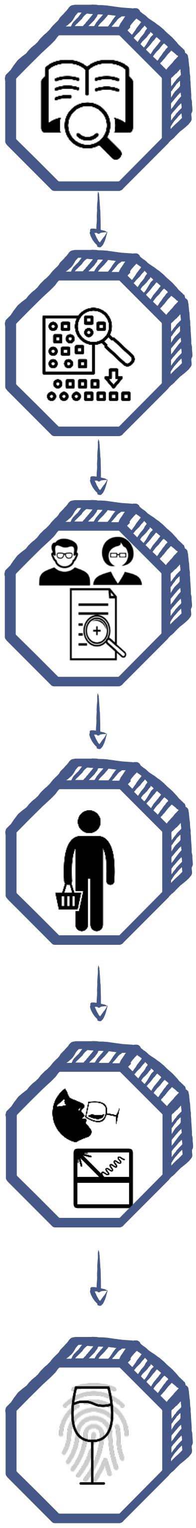
I would like to thank Dr. Paul Boss, my independent advisor for his invaluable inputs on this project. I would like to extend my appreciation to the ARC Training Centre for Innovative Wine

Production, its entire team (Professor Vladimir Jiranek, Dr. Joanna Sundstrom, Dr. Renata Ristic, Nick Van Holst), and specially the Coonawarra Vignerons. It was priceless to be part of something bigger, to have a space for collaborations, and to be able to have a strong connection with this industry that I grew to be so found of. Thank you to Wine Australia, the School of Agriculture Food and Wine at The University of Adelaide, and the Australian Research Council for giving me this opportunity and for the financial support.

# Thesis Structure

As outlined below, the thesis is structured as a compilation of manuscripts presented in chapters, beginning with a literature review that is followed by four original research chapters. The thesis culminates with conclusions and suggestions for future work.



### Chapter 1 - Review article

This paper explores the wine typicity concept, reviewing different methodologies for studying wine typicity and understanding consumer perspectives towards this concept. It considers articles from 2010 until the date of publication in late 2020. Research questions, aims, and objectives of the overall thesis are included at the end of the chapter.

### Chapter 2 - Original research article

Aiming to investigate different sensory profiles of wines according to online sources in a rapid timeframe. Content analysis was applied to more than 2,500 web-based tasting notes from renowned Australian wine writers obtained through web-scraping. The same content analysis approach was used for expert panel free hand tasting notes on 84 Cabernet Sauvignon wines from Coonawarra, Margaret River, Yarra Valley and Bordeaux.

### Chapter 3 - Original research article

The expert panel from Chapter 2 also performed a sorting task and rate-all-that-apply assessment on the 84 Cabernet Sauvignon wines. The results were compared with descriptive analysis performed by a trained panel on a subset of 52 wines from the previous sample set, to examine sensory attributes associated with each region evaluated.

### Chapter 4 - Original research article

Exploring consumer opinions about typicity, a subset of 8 wines from the previous study was chosen to be evaluated by wine consumers to assess their liking and sample characterisation through rate-all-that-apply methodology. Region of origin information was tested as a factor by segregating the panel into informed and uninformed groups. Consumers were also asked about perspectives of the typicity concept and aspects related to purchase decision.

### Chapter 5 - Original research article

The final study used unreleased Cabernet Sauvignon wines from Coonawarra to further examine regionality with less influence from winemaking processes. The relationship between sensory traits from a rate-all-that-apply tasting and fluorescence measurements was explored as a rapid methodology for investigating sensory typicity and linking sensory traits to the underlying chemical composition of the wines.

### Chapter 6 - Conclusion and Future remarks

Based on the four research studies, overall conclusions about the sensory typicity of Australian Cabernet Sauvignon wines are summarised. Research gaps and future studies have been identified to aid with further understanding the relationship between the expression of wine typicity and provenance.

# Chapter 1

## Literature Review & Research Aims

## Publication

Defining wine typicity: Sensory characterisation and consumer perspectives

**Souza Gonzaga, L.**, Capone, D. L., Bastian, S. E. P., & Jeffery, D. W. (2021), Australian Journal of Grape and Wine Research, 27, 246-256. DOI

# Statement of Authorship

| | | |
|---|---|---|
| Title of Paper | Defining wine typicity: sensory characterisation and consumer perspectives | |
| Publication Status | ☑ Published<br>☐ Submitted for Publication | ☐ Accepted for Publication<br>☐ Unpublished and Unsubmitted w ork w ritten in manuscript style |
| Publication Details | Souza Gonzaga, L., Capone, D., Bastian, S. and Jeffery, D. (2021), Defining wine typicity: sensory characterisation and consumer perspectives. Australian Journal of Grape and Wine Research. 27, 246-256. | |

## Principal Author

| | | | |
|---|---|---|---|
| Name of Principal Author (Candidate) | Lira Souza Gonzaga | | |
| Contribution to the Paper | Conceptualisation, references sourcing, writing the original draft, and implementation of correction on the revised manuscript | | |
| Overall percentage (%) | 70% | | |
| Certification: | This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper. | | |
| Signature | | Date | 10/05/2021 |

## Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

| | | | |
|---|---|---|---|
| Name of Co-Author | Dimitra L. Capone | | |
| Contribution to the Paper | Conceptualisation and critically evaluating, reviewing and editing the manuscript. Supervised the project. | | |
| Signature | | Date | 11/05/2021 |

| | | | |
|---|---|---|---|
| Name of Co-Author | Susan E. P. Bastian | | |
| Contribution to the Paper | Conceptualisation and critically evaluating, reviewing and editing the manuscript. Supervised the project. | | |
| Signature | | Date | 11/05/2021 |

| | | | |
|---|---|---|---|
| Name of Co-Author | David W. Jeffery | | |
| Contribution to the Paper | Supervised and directed the project. Conceptualisation and critically evaluating, reviewing and editing the manuscript. | | |
| Signature | | Date | 11/05/2021 |

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# Defining wine typicity: sensory characterisation and consumer perspectives

**L. SOUZA GONZAGA, D.L. CAPONE, S.E.P. BASTIAN and D.W. JEFFERY**

Australian Research Council Training Centre for Innovative Wine Production and Department of Wine Science, The University of Adelaide, Urrbrae, SA, 5064, Australia

Corresponding author: Associate Professor David W. Jeffery, email david.jeffery@adelaide.edu.au

## Abstract

Wine encapsulates the expression of multiple inputs – from the vineyard location and environment to viticultural and winemaking practices – collectively known as terroir. Each of these inputs influence a wine's chemical composition and sensory traits, which vary depending on cultivar as well as provenance. These aspects underpin the overall concept of wine typicity, an important notion that enables wine from a delimited geographical area to be differentiated and recognisable in national and international wine markets. Indeed, consumers are increasingly more aware of the significance of regionality and may use this to influence their purchasing decisions. Understanding which sensory attributes represent regional typicity and how these are best conveyed to consumers is therefore important for the prosperity and reputation of producers. As reviewed herein, the sensory typicity of wine can be identified using different types of testing methods, with the most effective being a combination of approaches, such as sorting task in combination with descriptive sensory analysis. Consumer perceptions of regionality and wine typicity are then examined to provide insight into their behaviours. This includes consideration of the importance of origin to perceptions of quality and typicity, in terms of meeting expectations and engaging consumers. Based on the literature reviewed, it is proposed that wine typicity can be defined as a juxtaposition of unique traits that define a class of wines having common aspects of terroir involving biophysical and human dimensions that make the wines recognisable, and in theory, unable to be replicated in another territory.

***Keywords:*** *expert panel, geographical indication, provenance, regionality, terroir, typicality*

## Introduction

Typicity (or typicality) is a concept that can define the amount to which a product is perceived to embody its category, considering multiple levels such as brand or provenance (Loken and Ward 1990). The notion of typicity has become increasingly important in the food trade context, considering that consumers have a higher acceptance and are disposed to spend more on food products that have a strong connection with their region of origin and are perceived to be authentic and typical (Luomala 2007, Fernández-Ferrín et al. 2019). From a research perspective, different approaches have been used to evaluate typicity for a range of foods that can be impacted by their place of origin, including cheese (Bárcenas et al. 2001, Galle et al. 2011), meat and apples (Huck-Pezzei et al. 2014), milk (Scampicchio et al. 2012), olive oil (Bajoub et al. 2014) and butter (Rossmann et al. 2000).

Based on an investigation of two decades of research outputs, a total of 185 food and beverage related publications (1990–2020, using 'typicity or typicality' as the search keyword) were recovered from the Web of Science Core Collection and visualised by a network approach. Evidently from the bibliometric map (Figure 1), typicity (typicality) is a fairly new research concept, with most of the outputs appearing from 2010 onwards. Aroma, flavour and quality terms were strongly featured, and notably, publications involving typicity were often associated with wine. Also according to Figure 1, the impact of terroir and attention on red wines has increased more recently, as has the sensory technique of descriptive analysis (DA). Hence, this review paper will focus on the definition of wine typicity, recent sensory approaches for typicity identification and characterisation and consumer perspectives of typicity.

A systematic approach was used to investigate the definition of typicity, sensory evaluation methodologies and consumer perspectives (Denyer and Tranfield 2009). In order to define wine typicity, this review exploited the ISI Web of Science database using the terms 'wine', 'typicality' and/or 'typicity' with a focus on international peer-reviewed articles written in English that also covered sensory studies. For the sensory approaches, the same database was used but the date of publication was constrained to 2013 onwards and included only articles that focused on analysing sensory typicity per se. The consumer perspectives section covers mainly natural science peer-reviewed articles that had a direct connection with wine typicity and related topics (e.g. regionality) from 2010 onwards. Overall, this review covers over 100 articles identified according to the criteria specified above.

## Defining the dimensions of wine typicity

Wine typicity enables the differentiation, identification and recognition of wines that are produced in distinctive regions (Cadot et al. 2012). As a concept, typicity can represent the individuality of a wine profile and can embody a specific class of wines (Cadot et al. 2010). For the wine sector, typicity is a term that is closely related to terroir and the associated influence this has over the properties of a wine from a delimited geographical area (Cadot et al. 2012). It expresses the impact of the terroir on the wine by bringing

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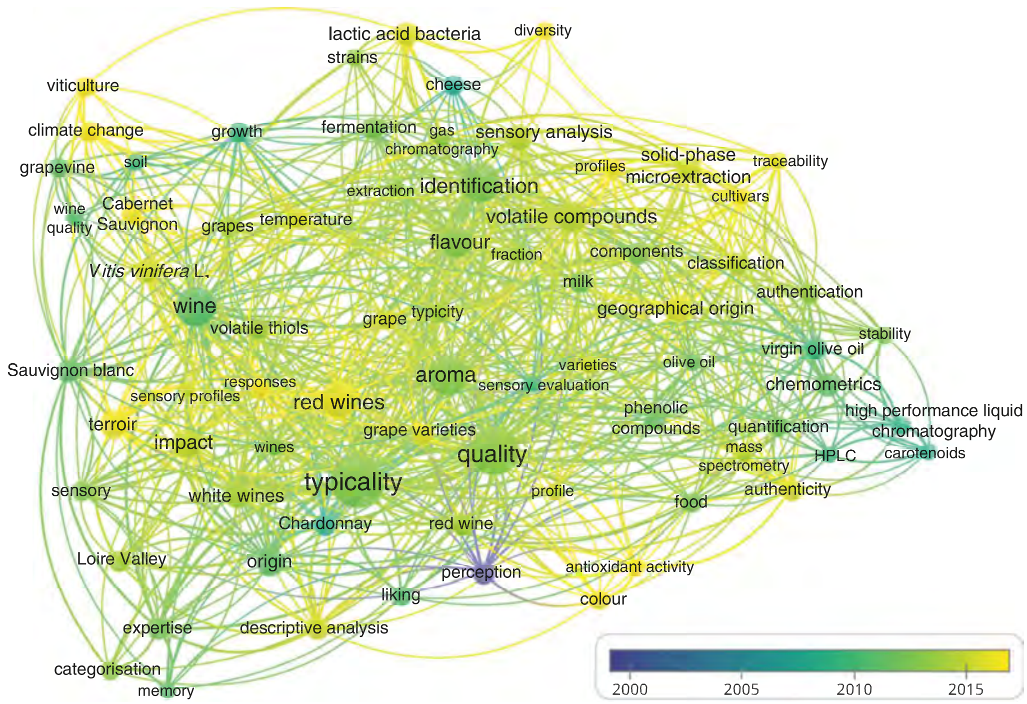


**Figure 1.** Bibliometric map of food-related research visualised from 185 publications (from 1990 to 2020) recovered from Web of Science Core Collection using 'typicity' or 'typicality' as keywords. Literature analysis and figure construction were facilitated with VOSviewer (Waltman et al. 2010).

together features that are recognisable and distinguishable (Leriche et al. 2020). Typicity is ultimately the manifestation of regional and varietal characteristics, which are themselves often interlinked as a result of the cultivation of indigenous grape cultivars or particular viticultural regions being well-suited to producing specific grape cultivars.

### *The concept of terroir and its influence on the sensory profile of wine*

**Defining terroir.** Terroir is a word of French origin that has an extensive range of definitions depending on the research angle (Gladstones 2011). The Organisation Internationale de la Vigne et du Vin (OIV) describes terroir as 'a concept which refers to an area in which collective knowledge of the interactions between the identifiable physical and biological practices develops, providing distinctive characteristics for the products originating from this area' (Organisation Internationale de la Vigne et du Vin 2010). Along the same line, professionals from two French institutes, Institut National de Recherche Agronomique (INRA)/Institut National de l'Origine et de la Qualité (formerly Institut National des Appellations D'Origine) (INAO), proposed a definition for terroir during a UNESCO gathering, considering not only the physical dimensions of a delimited geographical region but also the social interactions based on cultural and human knowledge (United Nations Educational, Scientific and Cultural Organization 2007, Unwin 2012). According to Unwin (2012), this definition covers a wide spectrum of aspects and considers factors beyond environmental impacts that some definitions are limited to. Vaudour (2002) outlined the concept of terroir in a more objective and specific meaning, and converged on it being the link between wines and the physical dimensions related to vine development in a specific area. Indeed, almost half of the members from INAO considered that terroir was predominantly related to the natural aspects of a region, such as climate, soil and sun exposure, and the other half sensed that it was a combination between the social and natural factors (Barham 2003). Ultimately, terroir can be considered as a multi-parametric construct based on three pillars: the vine itself, the environment involving the vine (i.e. climate, soil, topography), and the social influence (i.e. from viticulture and winemaking, and the human contact around the region).

**How natural and human dimensions of terroir can influence wine sensory characters.** Terroir can have distinctive impacts on a wine and will depend on a larger number of parameters that can be combined in multiple ways. Wine with high-quality parameters can be produced in diverse parts of the world, with vines enduring different types of environmental conditions, especially in relation to soil and climate. Soil is one of the important factors when considering terroir expression and regional typicity (van Leeuwen 2010). As an example for red wine production, a suitable soil has the ability to restrict vine vigour and yield through moderate water stress or limited nitrogen availability, in order to decrease the berry mass and yield, thus intensifying anthocyanin and tannin concentration (van Leeuwen 2010). Indeed, Ubalde et al. (2010) outlined that soils with higher drainage, low water-holding capacity and lower fertility resulted in a wine with red-blue hue, ripe fruit on the palate, and a complex tannin sensation for the mouthfeel, which contributed to a slightly higher overall quality rating by an experienced panel.

Climate is another environmental component that comes into play when discussing terroir. Utilising climate to maximise the terroir expression is strongly connected with differences in the phenology and ripening period of various grape cultivars (van Leeuwen 2010). Ideally grapes should present a balance between sugar and acid content as well as unique aroma and flavour traits, and desirable colour and phenolic maturity of red grapes (Waterhouse et al. 2016). As an example from a wine aroma perspective, high temperature and light exposure is negatively correlated with the concentration of methoxypyrazines in grapes (Ryona et al. 2008). These compounds, which are associated with cooler vineyard conditions or grapes that are less ripe, are responsible for the 'green' and 'vegetal' characters typical of varietal wines such as Cabernet Sauvignon and Sauvignon Blanc that might be perceived as a defect at a concentration above threshold (Ryona et al. 2008, de Orduña 2010).

Many factors that affect wine quality and the expression of terroir are determined by decisions made in the vineyard, such as the use of fertiliser, training system, yield, pruning regime, and irrigation (Robinson 2015). Some examples of viticultural practices that can have an impact on regional profiles were reported by Gutiérrez-Gamboa et al. (2017), who found that nitrogen foliar treatments decreased the amount of flavonoids in the wine. Flavonoids are known to impact wine sensory properties (i.e. bitter taste and astringent mouthfeel) and quality (Downey et al. 2006). Other work demonstrated that wines with an overall low-quality score can result from increases in the frequency and quantity of irrigation (Bravdo et al. 1985), and showed that wines made from grapes with minimal irrigation received higher scores for 'fruity' attributes and lower scores for 'vegetal' and 'bell pepper' (green capsicum) aromas (Chapman et al. 2005). Another study by Chapman et al. (2004) found that the intensity of 'vegetal' aromas decreased with increased bud number and yield, whereas the opposite occurred for 'fruity' aromas. Even cover crops have been investigated, with Xi et al. (2011) showing they have a positive impact on wine aroma, yielding a higher concentration of desirable aroma compounds and improved scores for overall quality.

In a somewhat unique twist on terroir but worthy of mention, the presence of native trees or invasive plant species in the vineyard can have a notable influence on wine composition and sensory characters. In one example, Capone et al. (2012) showed that the presence of *Eucalyptus* trees in close proximity to grapevines can have a significant impact on the concentration of 1,8-cineole, the component responsible for the 'eucalyptus/mint' flavours of various wines. Although 1,8-cineole could be a natural component of grapes (Fariña et al. 2005, Poitou et al. 2017), vine position relative to *Eucalyptus* trees (aerial transfer) and especially matter other than grapes (e.g. *Eucalyptus* or grapevine leaves that potentially result from mechanical harvesting) present in a ferment were found to contribute to the distinct presence of 1,8-cineole in grape extracts and experimental wines (Capone et al. 2012). The concentration in wine was also affected by winemaking conditions, whereby 1,8-cineole concentration increased during maceration with grape solids and remained stable after pressing (Capone et al. 2011). In the case of invasive grass, *Artemisia verlotiorum* growing in vineyards was implicated as a source of 1,8-cineole (and α-thujone) in some Bordeaux wines (Poitou et al. 2017). As with the impact of *Eucalyptus* trees, airborne transfer of 1,8-cineole was implicated, and both cases highlight the potential contribution to wine aroma and flavour of exogenous volatiles from the vineyard environment, which can ostensibly be considered as part of the terroir. Furthermore, these examples act as reminders of an important point: along with the need to control practices (or conditions) in the vineyard, appropriate harvesting and winemaking techniques need also be applied for the creation of wine of desired style and expression of terroir.

Understanding how winemaking techniques can contribute to wine characteristics is important, with respect to vineyard practices and attributes influenced by terroir, so the effects on the grapes can not only be preserved but also potentially improved. It is clear that winemaking decisions can have multiple effects on different aspects of a wine (Sacchi et al. 2005). The choice of yeast used for alcoholic fermentation is one of the most important decisions to be made during the winemaking process and can have a great impact on the aroma profile of wine (Mas et al. 2016). Winemakers must decide between guaranteeing the completion of alcoholic fermentation via inoculation of juices/musts with *Saccharomyces cerevisiae* or using indigenous yeasts (i.e. spontaneous fermentation) that can impart distinctive sensory properties. The latter case can foster recognition of the region and expression of the terroir, since microbiota diversity is known to be related to a certain territory (Bokulich et al. 2014, Jolly et al. 2014, Mas et al. 2016). As an example, 'wild' non-*Saccharomyces* yeast strains that conduct spontaneous fermentation contributed significantly to the 'fruity' aroma of Cabernet Sauvignon from a new wine producing region in China (Liu et al. 2016).

In terms of other winemaking practices, various techniques aim to improve colour or augment other wine compositional parameters that can impact on the sensory qualities of wine, and could be used as a tool to guarantee the expression of typicity over multiple vintages. One example of this is low-temperature pre-fermentative grape maceration (i.e. cold-soak), which can increase the concentration of anthocyanins in wine and improve red wine colour (Gil-Muñoz et al. 2009). Cold maceration not only improves wine colour but can also change aroma attributes, as shown by Cai et al. (2014), who found that cold maceration treatment enhanced the 'caramel' and 'floral' aromas and moderated the 'chemical aroma' of Cabernet Sauvignon wines. In another example, Pineau et al. (2011) demonstrated the importance of grape ripeness for the unique style of Marlborough Sauvignon Blanc from New Zealand, revealing that quality and terroir expression can be maintained through juice chaptalisation (i.e. adding sugar to the must or the juice during alcoholic fermentation to control the level of alcohol produced) even if the level of grape ripeness could not be achieved in the vineyard. As with other winemaking practices, chaptalisation is not a permitted technique in many countries, but the study highlights the influence that straightforward winemaking decisions can have on the expression of terroir. Overlaying a further influence, oak barrels are widely used for maturation of red wine in particular, to produce a wine with greater harmony and complexity. Winemakers aim to integrate desirable oak attributes such as 'woody', 'leather' and 'charry' with the 'varietal' and 'fruity' characteristics of wine (Crump et al. 2015). This may also be undertaken with a range of alternatives to oak barrels, such as oak staves and chips, which can be added to stainless steel tanks. Oak alternatives can yield similar sensory results and higher consumer acceptance compared to maturation in oak barrels (Crump et al. 2015). The studies above indicate how practices in the vineyard and winery can affect wine composition and consequently wine sensory proprieties. These practices, which will depend on local regulations as discussed in the Section 'Regulatory measures to protect wine typicity', can impact sensory typicity and are therefore part of the concept construction.

It is a straightforward conclusion that the combination of a unique terroir with different management techniques in the vineyard and different processes during wine production can considerably influence wine composition and the resultant sensory properties. Little is known, however, about how viticultural and oenological practices can directly affect sensory properties involved in wine typicity, leaving this as a distinct gap for future work. Instead, recent research has focused on the impacts of climate change and how these may affect wine composition and typicity, which requires viticultural and oenological practices to adapt in order to guarantee the sensory expression of the typicity (Drappier et al. 2019, Molitor and Junk 2019).

What first makes a terroir identifiable is its geographical delimitation, but then social and local characteristics and regulations of production are also important factors for the terroir construct (Deloire et al. 2008). Each wine region has its own unique conditions that tend to suit certain cultivars, which together require adaptations and certain practices to produce high-quality wine with a characteristic profile – that is how wine typicity is created. Considering the information presented above, the following can be proposed:

> Wine typicity can be defined as a juxtaposition of unique traits that define a class of wines having common aspects of terroir involving biophysical and human dimensions that make the wines recognisable, and in theory, unable to be replicated in another territory.

### *Regulatory measures to protect wine typicity*

Because of the increasing interest in wine typicity and recognition of different terroirs during the 20th century, France pioneered the adoption of a system based on food typicity, intended to legally protect the authenticity of their products through the Appellation D'Origine Contrôlée (AOC) (Ceccarelli et al. 2010). Protected Designation of Origin (PDO) or Geographical Indication (GI) systems, as they are more broadly known, protect and encourage the connection between the sense of taste and the place of origin for food products, acting as an indicator of their typicity and quality (Barham 2003, Ceccarelli et al. 2010). For instance, among French wines, almost half come from an AOC, which appears to give the wine a special and recognisable reputation (Maitre et al. 2010). Protected Designation of Origin labels as used in such a case not only certify the geographical area in which the products arose but also imply that prescribed production processes are being followed (Barham 2003), which differentiates them from GI systems where the information is focused on the geographical production location (Giovannucci et al. 2009, Lambin et al. 2014).

This French model served as a base for following European systems that aimed to protect their regional wine production (Ceccarelli et al. 2010), for example, Denominazione di Origine Controllata (DOC), and Denominazione di Origine Controllata e Garantita (DOCG) in Italy (Stasi et al. 2011), Denominación de Origen Calificada (DOCa) in Spain (Esteban Rodríguez and Climent López 2017) and Denominação de Origem Protegida (DOP) in Portugal (Santos and Ribeiro 2012). Similar systems are in place globally, including New World producing countries, such as Australia (Office of Parliamentary Counsel 2019), USA (Rose 2007), Argentina (Defrancesco et al. 2012) and Chile (Overton and Murray 2011), where regions and subregions responsible for wine production are designated, categorised, restricted and protected by GI regulations. Protected Designation of Origin and Protected GI (PGI) are regulatory systems that directly protect the provenance of a wine and may indirectly protect its typicity expression, based on the hypothesis that region of origin is a main influencer of wine sensory typicity (i.e. provenance affects berry composition, which translates into wine chemical and sensory characteristics that can be embodied in the concept of typicity). This is an area that requires further research, however, to objectively link the perceived typicity of a wine with its region of origin.

To complement the regulations, it is important to have effective implementation and control. In the case of wine production for some PDO, sensory characterisation of wine distinctiveness and quality are among the factors to be considered to 'guarantee' the product. One of the sensory methodologies used to ensure PDO accreditation was elucidated by Etaio et al. (2010), in which a panel of industry experts familiar with the region in question will follow a seven-step approach (which bears some resemblance to the DA technique elaborated in the following section):

- term generation: free description of aroma, taste, mouthfeel and appearance of the individual samples;
- selection of parameters: discussion and selection of the parameters based on the terms gathered. Parameters should reflect quality and be different among the wines;
- 'top situation' definition and quality grading of each parameter: using a 7-point scale with 7 as 'top quality' and 1 as 'null quality'. Each parameter is graded based on the typical profile of the wine from the PDO in question;
- development of references: references of each parameter are discussed and readjusted until the panel reaches a consensus, and are used to standardise the vocabulary and to train the panel;
- tasting procedure: the tasting procedure and the order of the parameters are determined by panel consensus;
- score cards: definitive score card generated; and
- contribution of each parameter to the overall sensory quality: the power of each parameter is determined and a weighting factor applied.

## Approaches to measure wine sensory typicity

Beyond guaranteeing PDO wines, understanding the typicity of wine from a sensory perspective is an important scientific undertaking. Previous work has been conducted by Maitre et al. (2010) in gathering methodologies utilised to identify wine sensory typicity. Therefore, this review will mainly outline advances that have been reported since.

### *Using an expert/professional panel for the sensory assessment of typicity*

Using the extensive knowledge of experienced industry experts/professionals is a useful tool to evaluate wine profile without the necessity of time consuming prior training (Ballester et al. 2008, Barton et al. 2020). Although it appeared that no study had validated the number of experts required for the panel, it typically comprises between 10 and 15 people. Leriche et al. (2020) demonstrated that professionals involved in a specific viticultural region are able to recognise a global conceptual typicity of their terroir using different physical dimensions, such as soil, geography and grape cultivar. In contrast, professionals from a different region can convey the typicity through the region's reputation and sensory attributes of the wines (Leriche et al. 2020). Because of these skills, various researchers have used panels comprising experts or professionals to evaluate wine typicity (Table 1).

Most of the studies in Table 1 follow the method elucidated by Ballester et al. (2005). Typicity assessment occurs by asking the panel to imagine having to explain the sensory typicity of that class of wine to someone, and then having the panel rate on a structured scale how well the sample in question represents that class. The scale is usually anchored on the left with 'very bad example' and on the right with 'very good example'. Ballester et al. (2005) used the approach to investigate typicity of Chardonnay wines from different regions of France. More recently, this methodology was used to evaluate wines from Chianti Montespertoli, a DOCG in Italy (Canuti et al. 2017), the typicity of aged bouquet of red Bordeaux wines (Picard et al. 2015), and the varietal typicity of Riesling wines from distinctive regions in Europe, Australia, New Zealand and Chile (Schüttler et al. 2015) (Table 1). This type of assessment is based in cognitive science on the prototype category theory, in which the distinction of products is achievable due to different categories (Rosch 1973). In fact, the wine typicity concept is based on a preconceived prototype that embodies past experiences from wine of that category (Casabianca et al. 2006, Maitre et al. 2010).

This approach is appropriate for arranging the set of samples into classes ranging from 'atypical' and 'very typical', but as a stand-alone method it does not elucidate the drivers for the classification. Therefore, in order to better understand the sensory profiles, typicity evaluation can be combined with descriptive sensory profiling or chemical characterisation. In their study of Chianti Montespertoli wines, Canuti et al. (2017) combined typicity assessment with a set of chemical analyses (Table 1) and were able to correlate the presence and concentration of several volatile and phenolic substances with the sensory typicity. Furthermore, they identified compounds having either a positive or a negative contribution to the typicity profile of the DOCG wines, such as hexanal and β-citronellol (positive) and free anthocyanins (negative) (Canuti et al. 2017). Similarly, Schüttler et al. (2015) used the typicity rating provided by an expert panel to correlate with wine volatile composition, and thereby indicated the volatile compound 3-sulfanylhexan-1-ol as being responsible for the varietal typicity of Riesling wines. The sensory panel also generated free descriptors for each wine, enabling the association not only of the chemical compounds but also the sensory attributes (Schüttler et al. 2015). The latter approach was also used by Picard et al. (2015), with the typicity assessment being followed by a free vocabulary generation of Bordeaux red wines that were perceived to be a good representation of typicity according to their aroma profile as a function of ageing – mainly having aroma attributes of 'undergrowth', 'truffle' and 'spicy'.

Using a sorting task to assess wine typicity with an expert/professional panel can also be a valuable approach, as elucidated by Johnson et al. (2013). In order to define the profile of Shiraz wines originating from ten Australian GIs, Johnson et al. (2013) asked panellists to group wines based on their orthonasal and retronasal attribute similarities, and to provide a short description of each group they formed. As a typicity assessment exercise, a sorting task might not be sufficient as a stand-alone method, and for that reason, the sorting task was combined with individual wine tasting notes, hedonic scores, technical quality rating and a DA task (Johnson et al. 2013), as detailed in the next section. From the sorting task data, it was shown that regionality might be the driver for segregation of some wines but not for all of them.

As a variant sorting task methodology, projective mapping is a valuable methodology to evaluate similarities/dissimilarities in wine, including assessing wine sensory typicity. Projective mapping differs from a sorting task by displaying the samples in two-dimensional space, where the closer the samples the more similar they are, and vice versa (Pagès 2005). It can be used with experts to unveil wine typicity as demonstrated by Torri et al. (2013), and also to understand consumer preference and behaviour (Vidal et al. 2016). Torri et al. (2013) used projective mapping in conjunction with quality and typicity assessment to evaluate Sangiovese wines from Tuscany compared with other monovarietal wines. The results indicated that quality and typicity are interdependent for expert panellists, and have a significant linearity (Torri et al. 2013). Additionally, quality and typicity were hypothesised to be the main drivers for the differences between the samples, demonstrating that experts usually based their judgement on the prototype theory mentioned above (Torri et al. 2013).

In another study utilising the expertise of industry professionals, Souza Gonzaga et al. (2019) used a free vocabulary description approach with the aim of elucidating the sensory typicity of Australian Cabernet Sauvignon wines. In this case, descriptions provided by the expert panel were analysed through a text mining tool so that sensory characteristics could be assessed (Souza Gonzaga et al. 2019). These results were compared with a large collection of web-based wine reviews by well-known wine writers, also analysed with the text mining methodology, thereby revealing some agreement between the two cohorts for the sensory attributes that were considered important for the evaluated GIs (Souza Gonzaga et al. 2019).

Leriche et al. (2020) have recently proposed a methodology to assess the sensory typicity of wines coming from a region controlled by PDO regulation. The proposed methodology uses a three-step evaluation process, with each step using the knowledge of the same expert panel comprising some professionals from the terroir in question and other professionals from a different terroir (Leriche et al. 2020). First, the panel participated in a focus group discussion to agree on sensory terms that characterised the wine from the specific PDO (Leriche et al. 2020). The next two steps involved each sample being rated as being between a 'bad example' and 'good example', along with a just-about-right (JAR) assessment of the attributes found to be important during the focus group exercise (Leriche et al. 2020). It was found that the samples were distinguishable based on the sensory characteristics proposed by the focus group (Leriche et al. 2020). Different outputs were also clear when comparing data of professionals from within and outside the PDO in question. Those from within the terroir were able to describe a global typicity based on the physical characteristics of the terroir (e.g. soil, climate, and grape cultivar),

**Table 1.** Details from recent studies that used an expert panel to carry out sensory evaluations to investigate wine typicity.

| Study | Main study | Wines used | Assessors | Combined analysis | Findings |
|---|---|---|---|---|---|
| Johnson et al. (2013) | Sorting task | 29 Shiraz wines from ten different Australian GIs (two or three from each region) | 22 wine professionals and researchers | Tasting notes, hedonics, technical quality rating and descriptive analysis | The expert panel was able to sort some of the wines based on the region of origin. |
| Torri et al. (2013) | Projective mapping | Six Sangiovese wines from Tuscany PDO and five monovarietal wines from different cultivars and regions | 13 Tuscany wine professionals | Quality and typicity assessment, consumer projective mapping, and descriptive analysis | A linear significant correlation was found between typicity of the Sangiovese wines and their quality scores. |
| Picard et al. (2015) | Typicity assessment | 30 commercial red wines from different Bordeaux appellations | 13 wine professionals | Free vocabulary descriptions | Three out of seven aroma attributes were identified as significant for the discrimination of wines. |
| | | Subset of the study above with five wines considered representative and five considered not representative | 11 wine professionals | Rating of the attributes found in the study above | |
| Schüttler et al. (2015) | Typicity assessment | 30 wines (23 Riesling, five Sauvignon Blanc, two Chardonnay) from six countries (Germany, France, Austria, New Zealand, Australia, Chile) | 11 wine professionals and researchers | Chemical analysis and free vocabulary descriptions | The chemical compound 3-sulfanylhexan-1-ol (passion fruit aroma) tended to contribute to Riesling wine typicity. |
| Canuti et al. (2017) | Typicity assessment | 27 wines from Chianti Montespertoli DOCG in Italy | 12 wine producers and oenologists | Chemical analysis | Eight compounds were identified as significant for the prediction of Chianti Montespertoli DOCG wine typicity, being positively or negatively related. |
| Souza Gonzaga et al. (2019) | Free vocabulary description | 84 Cabernet Sauvignon wines from three Australian GIs and Cabernet-dominant blends from Bordeaux | 11 wine professionals and researchers | Wine writers' reviews | Several sensory attributes were found to be significantly related to different regions. |
| Leriche et al. (2020) | Exemplarity rating | Ten Cuvée wines from an AOC in South France with four from outside the AOC | Six focus groups composed of wine industry professionals | Just-about-right (JAR) assessment of focus group descriptors | The wines were discriminated based on their typicity with the responsible sensory attributes being evident. |

AOC, Appellation d'Origine Controlée; DOCG, Denominazione di Origine Controllata e Garantita; GI, geographical indication.

whereas professionals from outside conveyed the sample typicity based on reputation or actual sensory attributes (Leriche et al. 2020).

### *Using a trained panel for sensory assessment of typicity*

Using experts and professionals from the wine industry is not always possible and similar outcomes are achieved by using a trained panel. Descriptive analysis is a technique described as the gold standard for wine evaluation and involves a trained panel. The panel is trained for the specific set of samples in question until agreement between panellists is reached (i.e. consensus based) and the specific vocabulary is generated: as a result, this method requires a considerably smaller number of panellists (usually between 8 and 12) and all samples are randomly tasted blind, usually in duplicate (Lawless 2013). Descriptive analysis is often used to profile wine sensory properties in detail but can also be used for characterising wine typicity (Table 2). This was demonstrated by King et al. (2014), who employed DA to characterise Malbec wines from different viticultural sites in California and Mendoza. As the first inter-country study, it demonstrated that differences in altitude can influence the sensory attributes of a wine and can be one of the factors of terroir and regional typicity, as discussed in the 'Defining terroir' section. Using the same approach, Geffroy et al. (2016) revealed the peppery typicity found in French Gamay wines from vineyards located in cool climate regions. In contrast, Kustos et al. (2020) explored the regional typicity of Australian Chardonnay and Shiraz wines and found that regional differences alone were not sufficient to describe the sensory distinction of the samples, and winemaking elements needed consideration as well.

Sensory profiles from DA studies can be correlated with chemical measurements for a more in-depth investigation, as undertaken in the abovementioned studies; e.g. 'peppery' aroma positively correlated with the compound known as rotundone (Geffroy et al. 2016) and 'cooked vegetables' aroma positively correlated with the $C_6$ compounds, hexanal and (*Z*)-3-hexen-1-ol (King et al. 2014). In the case of Kustos et al. (2020), sensory markers and chemical composition (α-terpineol, linalool, 2-phenylethyl acetate, 2-phenylethanol, 1-butanol, total anthocyanins, and 'floral' and 'olive' aromas) were responsible for the creation of models for regional typicity. Alternatively, data from DA can be combined with another type of sensory assessment, such as a sorting task with an expert panel, as demonstrated by Johnson et al. (2013). The sorting task showed how the samples were differentiated and the DA provided an explanation of the sensory attributes responsible for this differentiation ('Using an expert/professional panel for the sensory assessment of typicity' section). It was demonstrated that terroir factors like geography and size of the region impacted the sensory attributes present in the wines (Johnson et al. 2013). The results from the projective mapping by Torri et al. (2013), as discussed in the section above, were also compared with a DA study on the same set of samples. In this case, the DA results did not indicate any aroma descriptions that clearly segregated the samples according to cultivar or regionality.

## Consumer perspective of wine typicity

The sensory evaluation of wine samples can be undertaken with multiple methods and with different types of panels, as discussed already. On one hand, an expert panel will have

**Table 2.** Details of recent studies using descriptive analysis with a trained panel combined with another analysis to assess wine sensory typicity.

| Study | Wines assessed | Assessors | Combined analysis | Findings |
|---|---|---|---|---|
| Johnson et al. (2013) | 29 Shiraz wines from ten different Australian GIs (two or three from each region) | Nine panellists | Sorting task | Wine sensory characterisation can be impacted by the size and geography of the regions. |
| Torri et al. (2013) | Six Sangiovese wines from Tuscany PDO and five monovarietal wines from different cultivars and origin region | Nine panellists | Expert and consumer projective mapping | The trained panel were not able to clearly distinguish Sangiovese wines from Tuscany compared to the other samples. |
| King et al. (2014) | 41 Malbec wines from 41 viticultural sites from Mendoza, Argentina and California, USA | 15 panellists in Argentina<br>14 panellists in USA | Chemical analysis | Malbec wines were discriminated based on the altitude of their country of origin, relating to different sensory attributes. |
| Geffroy et al. (2016) | 21 Gamay wines from four French PDOs | Eight panellists | Chemical analysis and consumer study with a subset of the wines | Aroma attributes, especially peppery notes (rotundone), were responsible for discrimination between samples. |
| Kustos et al. (2020) | 32 Chardonnay wines from two different Australian GIs and 31 Shiraz from another two Australian GIs | Ten panellists for the Chardonnay and 11 panellists for the Shiraz assessment | Chemical analysis | Using geographical provenance was not sufficient to describe the sensory regional typicity of the wines and winemaking elements were discriminating parameters. |

GI, Geographical Indication: PDO, Protected Designation of Origin.

extensive knowledge about typicity concepts and sensory assessment, but there is a possibility that personal bias and preconceived notions of the wine samples will influence the evaluation (Hughson and Boakes 2001, Torri et al. 2013, Honoré-Chedozeau et al. 2020). In contrast, a trained panel requires extensive training, but can provide a more descriptive and unbiased sensory characterisation (Heymann et al. 2012). Although it is important for the industry to understand the drivers of typicity and to be able to manage those traits, understanding of consumer expectations and preferences is also important for effective targeting. Currently, consumers are educated to like wines that have already been made, rather than wine producers having an understanding of the purchasing decisions and preferences of consumers and then tailoring wine production towards those desires and needs. It is essential to keep in mind that consumers are becoming increasingly educated and more globally aware, as international markets have expanded and information has become readily available on the internet. Consumers are also more interested in what it is they consume, where it comes from and what is in the product (Angus and Westbrook 2019).

In gaining consumer perspectives of wine typicity, most of the following studies made use of a consumer survey. This approach is usually driven by the necessity to gather information on consumer opinions, attitudes and/or behaviours towards a particular question or problem (Dillman et al. 2014). For that reason, only the target population is expected to respond to the survey, usually by either choosing premeditated specific questions or using their own words in an open-ended question (Dillman et al. 2014). When the sample population is representative (e.g. when the probability percentage is maximised and the error is minimised) the results from a survey can be generalised and provide a close projection of the population distribution (Dillman et al. 2014). The studies in this review that relied on a survey to understand consumer behaviour varied between 100 and 1200 respondents, with the predominant range being 300–400 consumers. Studies tended to use the convenience sampling method, which is a non-random method where the target population is selected according to convenience in terms of availability, access and cost-effectiveness (Baxter et al. 2015).

Wine is a highly complex product that can be offered in an innumerable range of cultivars and styles and consumers are willing to search for and try wines that will satisfy their expectations (Lattey et al. 2010). According to wine professionals, regionality is mainly driven by whether a region specialises in and has a distinctive wine style, and whether it is discussed by opinion formers (Easingwood et al. 2011). For the consumer, the reputation of a region can influence their preconception of wine typicity, thereby strengthening the connection between regionality and typicity. In fact, wine consumers utilise information about a wine's origin as an indication of quality, which can ultimately impact positively on the price they are willing to pay for a bottle of wine (Schamel 2006, Hollebeek et al. 2007, D'Alessandro and Pecotich 2013, Spielmann 2015). Consumers in Old World countries use regional information to make purchase choices because they have learned to use it as an indicator of wine style, typicity and quality (Stasi et al. 2011). The same can be said, however, about consumers in the New World. For example, when it comes to important factors for consumer choice in Australia, region of origin is third, behind grape cultivar and personal recommendations, but region of origin is even more important when there is familiarity with the region (Perrouty et al. 2006, Kustos et al. 2019). Additionally, as shown by Kustos et al. (2019), consumers in Australia include regionality as one of the features for defining a fine wine.

The importance of the region will vary depending on the consumer segment, with a higher influence noted for wine consumers who are either female, have high involvement in the field, or have been involved with wine tourism (McCutcheon et al. 2009). Certification of origin (e.g. AOC) may also be an important trait for determining wine choice (Martínez-Carrasco Martínez et al. 2006), since consumers may associate PDO and PGI labels with a higher quality wine (Di Vita et al. 2019), and can even be responsible for consumers' willingness to pay twice as much when compared with a wine that has no such certification (Skuras 2002). This might indicate that a guarantee of regional typicity is valuable for the consumer; there appeared to be no indication in the literature, however, about the sensorial capacity of consumers to actually identify or distinguish wines from a protected origin. In response to this, Coste et al. (2018) demonstrated that consumers could differentiate wine from a typical warm region and a typical cool region through emotional responses, but more work is clearly required. Overall, the concept of regionality is not only an important choice driver, but it is also a concept that most consumers can understand independently of their involvement (Nallaperuma et al. 2017, Kustos et al. 2019).

Expressing the typicity of a wine is also a factor that consumers associate with a higher quality product (Boncinelli et al. 2016). It has been shown, however, that the value consumers give to typicity-related traits is not connected with the actual sensory attributes of the wine but rather the expectation around that specific class of wine (Boncinelli et al. 2016). Hence, actions that increase the link between a wine and its region of origin can increase the perceived value (Boncinelli et al. 2016). Research shows that increasing consumer awareness about a region through wine tourism can increase their wine involvement, thus positively influencing the consumer purchase decision (Famularo et al. 2010).

Having discussed consumer attitudes in relation to wine typicity, it is worth reminding the reader that this review has used certain criteria as established in the 'Introduction' section, namely, the use of Web of Science and restricting the search to scientific publications. This approach has its constraints when considered against the body of literature involving social science, marketing and business studies, but it does not invalidate the chosen perspective for considering consumer behaviour. Nonetheless, it is reasonable to acknowledge that consumers do not only base their purchase decisions on provenance or sensory cues, as this review might otherwise imply. In contrast to wine professionals, consumers may arguably be more concerned about price rather than taste, as demonstrated by Lockshin and Rhodus (1993), although when it comes to wine price range they may not be loyal to a single one (Romaniuk and Dawes 2005). It can also be considered that consumers behave differently and make decisions beyond simply being driven by brand or product, which can be better understood with segmentation of consumers based on their purchasing involvement (Lockshin et al. 1997). These brief examples draw attention to different factors that underpin consumer behaviour and ultimately highlight the need to understand the target demographic, which may be motivated by price, brand, region of origin or other cues (or combinations thereof).

## Conclusion

Typicity is a concept that has become increasingly important for food product research over the past 10 years, and this statement applies equally to the wine sector. As a term, it encapsulates how a product is distinguishable and is connected with the region of origin and associated terroir. In the case of wine production, terroir can include the environmental conditions impacting the grapevine, the viticultural management practices employed, the winemaking processes thereafter, and all the social construct involved in wine commercialisation. Those factors will shape the chemical and sensory composition of wine, creating unique and recognisable wine styles.

Because of the importance of wine typicity for wine trading and for consumer perspectives, researchers have attempted to identify and quantify sensory descriptors responsible for the uniqueness of different viticultural regions and the grape cultivars grown within. Several methods can be used, either with a panel of wine professionals and experts or a panel trained for specific sensory evaluations. All methods have their advantages but none so far are sufficient to fully characterise regional typicity, due to the complex interactions that go into producing a wine. Thus, sensory evaluation is combined with another methodology, being either chemical analysis or other modality of sensory analysis, thereby giving a more comprehensive understanding of the important sensory attributes and ultimately their origin within the grape and wine production phases. With this knowledge, industry practitioners move closer to developing tools to harness the expression of typicity of their regions.

The study of typicity is even more important in light of the increasing interest of the consumer. Several studies have shown that consumers view the region of origin as an indication of high quality wine and as something that will influence how much they are willing to pay for a bottle of wine. As for the concept of typicity, the consumer will connect the expression of typicity with their own expectation of that category. These results highlight the need for viticultural regions and wine brands to create a strong connection between their product and the place of origin for the consumer, which can be accomplished through marketing, wine tourism and increasing the engagement of consumers with the industry. There is still a gap, however, in determining if consumers can use sensory traits to identify and differentiate wines from a protected region, as well as to recognise the expression of typicity based on intrinsic cues.

Expressing wine typicity while maintaining quality and at the same time attending to consumer expectations and demands in an ever changing globalised world can be a challenging task. There will always be opportunities for studies that connect different aspects of the physical and human dimensions of a terroir with the sensory and chemical profiling of regional wines. Climate change, for example, is a reality for all food production sectors across the globe, and the wine sector is not immune from this challenge. Ongoing research is therefore necessary to understand how the industry can adapt to new environmental conditions while guaranteeing the production of regional wines that are a true reflection of typicity. In addition, more research should be conducted to directly connect practices in the vineyard and winery with the final typicity expression of a wine sensory profile.

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# Research Questions

There is a current industry drive to better understand the influences on style and quality of unique Australian terroirs as outlined in the Wine Australia Strategic Plan 2015-2020. This is coupled with the need to determine how regional influences can be enhanced or preserved, and utilised to improve Australia's international reputation as a fine wine producing nation. Therefore, the following research questions arise:

### Question 1: What are the sensory traits that characterise the regional profiles of Australian Cabernet Sauvignon wines?

Previous work on a small number of Cabernet Sauvignon wines from different Australian Geographical Indications (GIs) has been undertaken. That work assessed two to three wines from each region and made inferences about the sensory characteristics that may or may not be specifically attributable to the region. However, it remained to be determined whether there are sensory attributes that can characterise the regional style of Australian Cabernet Sauvignon wines.

### Question 2: What are the unique sensory descriptors that represents the typicity of Australian Cabernet Sauvignon wine?

The distinction between regions in Australia based on sensory profiles is proven to be possible but the specific attributes that drive the distinctiveness of regional Cabernet Sauvignon wines still remained unclear. In other words, traits that represent typicity for Cabernet Sauvignon wines from different Australian GIs neede to be determined.

### Question 3: What are consumer perspectives and expectations around wine typicity and its connection with the region of origin?

According with the literature cited, origin is one of the components that forms the consumer purchase choice. Nonetheless there was still a gap regarding the link between consumer preference and sensory drivers of typicity and how provenance information can modify their purchase behaviour.

### Question 4: How can the sensory traits connected with wine typicity be further verified and interpreted from the chemical composition of the wine and its connection with the terroir?

It is clear in the literature that terroir, including viticultural and winemaking techniques, can have a significant impact on wine sensory attributes and chemical composition. However, to explore whether sensory typicity can be verified for a specific Australian GI (Coonawarra) and whether the connection with the chemical composition existed based on spectrofluorometric analysis and chemometric modelling.

# Summary of research aims

This project aims to understand the representation of typicity for Australian Cabernet Sauvignon wines at a sensory level and use it to understand influences of terroir so the industry can have an improved their knowledge around their unique regional style, and offer consumers a consistently high quality wine that attends to their desires and expectations of that region. This aim will be met through the following objectives:

1. Identify the sensory attributes that characterise the regional style for Australian Cabernet Sauvignon wines by undertaking content analysis of wine writers' reviews available on-line and compare the outcomes with an extensive sensory tasting with industry experts on a sample set of wines.
2. Verify the sensory attributes that represent the typicity of Australian Cabernet Sauvignon wine through a sorting task with industry experts linking those results with a comprehensive sensory assessment with a trained panel (descriptive analysis) and a specific attributes list.
3. Explore consumer knowledge of wine typicity and purchase behaviour through a survey, and identify regional sensory traits correlated with consumer preference through a consumer liking task in conjunction with rate-all-that apply (RATA) exercise.
4. Examine the correlation between sensory and chemical composition of regional Cabernet Sauvignon wines from Coonawarra through RATA assessment and spectrofluorometric analysis. Additionally, attempt to verify sensory traits found to be related with typicity found by previous study and explore their influence on terroir by assessing unreleased Cabernet Sauvignon wine.

# Chapter 2

## Publication

### Using content analysis to characterise the sensory typicity and quality judgements of Australian Cabernet Sauvignon wines

**Souza Gonzaga, L.**, Capone, D. L., Bastian, S. E. P., Danner, L., & Jeffery, D. W. (2019), Foods, 8(12), 691. DOI

# Statement of Authorship

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## Principal Author

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|---|---|
| Name of Principal Author (Candidate) | Lira Souza Gonzaga |
| Contribution to the Paper | Extracted the data related to the online wine reviews. Sourced all the wine samples. Designed, prepared and conducted the sensory evaluation. Transcribed and carried out statistical analysis of the data collected during sensory evaluation and from the online reviews. Prepared the complete first draft of the manuscript and incorporated revisions. |
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| Signature | Date 03/11/2020 |

## Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution

| | |
|---|---|
| Name of Co-Author | Dimitra L. Capone |
| Contribution to the Paper | Assisted with sample sourcing and preparation. Assisted with the study design and supervised the project. Discussed the results and provided critical feedback. Critically evaluated and revised the manuscript. |
| Signature | Date 03/11/2020 |

| | |
|---|---|
| Name of Co-Author | Susan E. P. Bastian |
| Contribution to the Paper | Assisted with the study design and supervised the project. Discussed the results and provided critical feedback. Critically evaluated and revised the manuscript. |
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| | |
|---|---|
| Name of Co-Author | Lukas Danner |
| Contribution to the Paper | Assisted with the study design and data extraction. Discussed the results and provided critical feedback. Critically evaluated and revised the manuscript. |
| Signature | Date 3/11/2020 |

| | |
|---|---|
| Name of Co-Author | David W. Jeffery |
| Contribution to the Paper | Supervised and directed the project. Discussed the study design and results, and provided critical feedback. Critically evaluated and revised the manuscript. Acted as corresponding author. |
| Signature | Date 3/11/2020 |

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# Using Content Analysis to Characterise the Sensory Typicity and Quality Judgements of Australian Cabernet Sauvignon Wines

**Lira Souza Gonzaga [1,2], Dimitra L. Capone [1,2], Susan E.P. Bastian [1,2], Lukas Danner [1] and David W. Jeffery [1,2,*]**

1 Department of Wine and Food Science, The University of Adelaide (UA), PMB 1, Glen Osmond, South Australia 5064, Australia; lira.souzagonzaga@adelaide.edu.au (L.S.G.); dimitra.capone@adelaide.edu.au (D.L.C.); sue.bastian@adelaide.edu.au (S.E.P.B.); lukas.danner@adelaide.edu.au (L.D.)

2 Australian Research Council Training Centre for Innovative Wine Production, UA, PMB 1, Glen Osmond, SA 5064, Australia

* Correspondence: david.jeffery@adelaide.edu.au; Tel.: +61-8-8313-6649

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**Abstract:** Understanding the sensory attributes that explain the typicity of Australian Cabernet Sauvignon wines is essential for increasing value and growth of Australia's reputation as a fine wine producer. Content analysis of 2598 web-based wine reviews from well-known wine writers, including tasting notes and scores, was used to gather information about the regional profiles of Australian Cabernet Sauvignon wines and to create selection criteria for further wine studies. In addition, a wine expert panel evaluated 84 commercial Cabernet Sauvignon wines from Coonawarra, Margaret River, Yarra Valley and Bordeaux, using freely chosen descriptions and overall quality scores. Using content analysis software, a sensory lexicon of descriptor categories was built and frequencies of each category for each region were computed. Distinction between the sensory profiles of the regions was achieved by correspondence analysis (CA) using online review and expert panellist data. Wine quality scores obtained from reviews and experts were converted into Australian wine show medal categories. CA of assigned medal and descriptor frequencies revealed the sensory attributes that appeared to drive medal-winning wines. Multiple factor analysis of frequencies from the reviews and expert panellists indicated agreement about descriptors that were associated with wines of low and high quality, with greater alignment at the lower end of the wine quality assessment scale.

**Keywords:** sensory assessment; web scraping; wine expert; wine review; wine score; text mining

## 1. Introduction

Typicity is a term that indicates the degree to which the characteristics of a wine reflect its delimited geographical area, and is influenced by terroir, grape variety, and viticultural and winemaking techniques [1]. It can be used to define a specific class of wine and embody the individuality of a wine profile [2], enabling wines from distinctive regions to be differentiated, identified and recognised [1]. Trading wine on the basis of typicity has become important for "Old-World" European wine producing countries such as France, where provenance and wine regional typicity are valuable tools used to recognise high quality wines [3]. Wine regions in Europe are also synonymous with certain grape varietals, but it is "New-World" producers that have tended to use varietals as a means of differentiating their wines [4]. This has been the case in Australia, a successful New-World country that occupied fifth place for global production (accounting for 5%) in 2016 [5]. However, that is not to say that provenance is an unrecognised concept in places like Australia, where wine producing regions and their wines are protected and represented by their geographical indication (GI) as defined by the Wine Australia Act 2013 [6].

Notably, wines possess a high level of aroma and flavour complexity due to the large compositional influences of grape origin, in combination with climate, differences among cultivars and cultural practices. Due to its complexity, wine is available in a wide array of styles and prices from numerous brands, which also attests to the willingness of consumers to look for and pay for products that are tailored to suit their expectations [7]. As alluded to for Old-World wines, consumers use place of origin information as a cue for quality, and it also influences their willingness to pay [8,9]. However, the indication of place of origin is no less important for New-World wine consumers [10] independent of their involvement with wine [11]. These findings are also tied in with the approach increasingly emphasised by the Australian wine industry and supported by the Wine Australia strategic plan for 2015–2020, which is to promote regional branding and delimitation of regions so each local style and variety can be easily recognisable and distinguished [12].

In order to meet consumers' wine flavour preferences, a better understanding of wine regionality and typicity from a sensory perspective is important. Wine professionals are often used for such studies but the pool of wines is generally small (i.e., up to two dozen wines but typically about half that number) and the criteria used to define the regions chosen for comparison is often not specified [3]. Although unexplored, it appeared that content analysis of wine writers' descriptions could serve as a useful, rapid and cost-effective methodology to help screen and select representative regional wines for sensory assessment and determine regions to be benchmarked. Content analysis has been studied for decades and has proven useful in multiple fields, including political science [13], linguistics [14], health care [15,16], and consumer research [17]. Content analysis can be used in conjunction with text mining, a methodology that enables the extraction of information that has a context meaning from data that are textual and unstructured, and has been used to analyse social media content [18], consumers' opinions on controversial topics [19], and smartphone applications [20]. Even though it is still not widely used in the wine and food science field, this methodology has been applied to understand consumer responses to mouthfeel attributes of wine [21], indicating that it could be useful more broadly for evaluating wine sensory characteristics.

This research aimed to demonstrate how content analysis can be used as a tool to investigate regionally distinctive wine sensory profiles and to select regional wines for future studies, using the abundant tasting data that is available in online wine reviews. It also aimed to relate that data with the content analysis of freely written descriptors obtained from 11 wine professionals, who evaluated the sensory attributes of a set of 84 Cabernet Sauvignon wines from different regions of Australia and from Bordeaux. Overall quality judgements of the assessed wines were also used in the comparison.

## 2. Materials and Methods

The regions were selected based on the relevance of the Cabernet Sauvignon variety for that GI, regional climate similarities (for the Australian regions), and benchmark indications provided by industry stakeholders. Consequently, the regions selected for this study were Coonawarra, Margaret River, and Yarra Valley, along with Bordeaux in the case of the expert assessment aspect of the study.

### *2.1. Wine Reviews*

#### 2.1.1. Sample Selection

The selection of wine review sources was based on their relevance to the Australian wine market context, their online availability, and the existence of reviews of Cabernet Sauvignon wines from the Margaret River, Coonawarra, and Yarra Valley GIs of Australia across multiple vintages. Ultimately, the sources included Huon Hooke [22], Wine Spectator [23], Wine Enthusiast Magazine [24], Jeremy Oliver [25], James Halliday [26], and The Wine Front [27]. Bordeaux wines were included in the next phase of this study, but were not included in the first analysis due to the lack of chosen online sources that consistently reviewed wines from that region.

#### 2.1.2. Sample Extraction

A total of 8454 reviews were extracted using Octoparse web scraping software (version 7.1.2, Octopus Data Inc., Walnut, CA, USA). For each source of reviews, a unique workflow chart was created in the software to extract the required information. The data gathered by the software were downloaded into Microsoft Excel 2016 and input into Wordstat (version 8, Provalis Research, Montreal, QC, Canada). The software was programmed to extract the tasting notes and overall quality scores on a 100-point scale. To cope with the different numbers of reviews per region for each writer, a subset of reviews was randomly selected based on the lowest number of reviews per region for a writer, yielding 2598 reviews in total. For example, if a writer had written 460 reviews for Yarra Valley and more for each of the other regions, then 460 reviews for each of those other regions were randomly selected from the respective pool to derive the set of reviews for that writer. The chosen reviews were also restricted to vintages from 2001 through to 2016.

### *2.2. Expert Panel*

#### 2.2.1. Sample Selection

A total of 84 commercially-available Cabernet Sauvignon wines were selected from the chosen regions based on the following criteria: vintage 2015; maximum retail price of AU$150; Cabernet Sauvignon in the blend, with a minimum of 60% for the Bordeaux and 85% for the Australian wines, respectively. Ultimately, the sample set consisted of 34 wines from Coonawarra, 20 from Margaret River, 20 from Yarra Valley, and 10 from Bordeaux. Within these criteria, the analysis of the online wine reviews served as a guide to identify samples that had a positive review, in order to avoid faulty wines, and that matched with the regionality profile found in the first part of the study.

#### 2.2.2. Sensory Analysis

An 11-member panel was composed of senior winemakers and/or experienced wine show judges and educators from Australia who were highly familiar with Cabernet Sauvignon wines and accustomed to tasting large sets of samples in one sitting. Sensory evaluation was conducted during a single day in an open plan focus group room designed for sensory analysis. Each wine sample (20 mL) was served in a clear XL5 wine tasting glass (Bormioli Luigi Glassmaker, Parma, Italy) randomly coded with a three-digit number and covered by a petri dish. The samples were randomised without considering region and divided into two flights, with 40 wines in the first and 44 wines in the second, and presented in a random order for each panellist. The first flight of wines was tasted between 9 am and 10:30 am. A 20 min break with light refreshments was provided before tasting the second flight from 10:50 am to 12:10 pm. The panellists were not aware of the regions nor sample selection criteria, but received instructions about the number of samples and the two tasks they were going to perform. For the first task, sheets with the random wine codes and spaces to hand-write descriptions were provided. The panellists were instructed to taste the wine and write down tasting notes using their own words for each sample. The second task involved scoring each sample out of 20 points based on the overall perceived quality. All the data were collected on paper and transcribed to produce an electronic version.

### *2.3. Data Preparation*

The electronic version of the tasting notes and the online reviews were loaded into the content analysis software program. The program ran an automatic code on each raw dataset to exclude words that are usually not relevant for an analysis, such as prepositions, verbs, adverbs, etc. Prior to building a sensory lexicon, words that were not applicable to the analysis as a sensory attribute and that were not automatically excluded by the program (e.g., "Cabernet", "Vintage" and "Wine") were manually added to the exclusion list and were not considered for the analysis.

A sensory lexicon was then created to agglomerate similar terms used by the wine writers and expert panellists into the same sensory category (Table 1) encompassing plurals and derivative words of the same attribute (e.g., blueberry and blueberries; dust and dusty) and keeping together words that represented the same category for the wine tasting context. Considering the expert panel data, only words used with a frequency of higher than five were considered in the categorisation. In the same way for the reviews, only words with a frequency higher than 50 were studied. All descriptors in the same category were analysed together, and each category was analysed based on its frequency within the region, to generate percentages. The data were exported to MS Excel for subsequent analysis with XLSTAT (Addinsoft, Paris, France, version 2019.1.1).

**Table 1.** Categories and respective descriptors created in Wordstat to analyse content from wine reviews and expert sensory panellists (plurals and derivative words are not listed in this table but were considered in the analysis).

| | Category | Descriptors | Category | Descriptors |
|---|---|---|---|---|
| Aroma/Flavour | Dark Fruits | Dark fruit, blackcurrant, blueberry, blue fruits, black cherry, black fruit, blackberry, cassis, juniper, mulberry, and plum. | Red Fruits | Red fruit, red cherry, red berry, red currant, boysenberry, cranberry, raspberry, and strawberry. |
| | Chemical | Band-Aid, boot polish, medicinal, metallic, ozone, plastic, petroleum, pungent, and soapy. | Herbal | Herbal, bay leaf, herbaceous, rosemary, tea, thyme, and sage. |
| | Ripe Fruits | Ripe berry, apricot, fruit cake, fig, jam, overripe, porty, prune, raisin, shrivelled, and ripe fruit. | Green | Green, dill, grass, capsicum, sappy, shaded, stalky, vegetal, and weedy. |
| | Savoury | Savoury, sea salt, barbeque sauce, beef stock, gamey, iodine, meat, oyster, pancetta, salty, salami, sea spray, seaweed, soy sauce, steak, and vegemite. | Oaky | Oaky, cigar box, coffee beans, burnt, butterscotch, caramel, cedar, chocolate, cocoa, coconut, mocha, tarry, vanilla, and woody. |
| | Nutty | Nuts, almond, chestnut, and nutty. | Peppery | Pepper, peppercorn, and white pepper. |
| | Smoky | Smoky, ashtray, charcoal, roasted and tobacco, guaiacol. | Confectionery | Confectionery, jelly, lolly, marshmallow, and juicy fruit. |
| | Floral | Floral, rose water, geranium, lavender, rose, Turkish delight, and perfumed. | Cooked Vegetables | Cooked vegetable, canned green bean, sulphide, vegetable, and eggplant. |
| | Minty | Minty and spearmint. | Sweetness | Sweet. |
| | Eucalyptus | Eucalyptus, gum leaf, camphor, and pine. | Leafy | Leafy, foliage, stem. |
| | Spicy | Spicy, clove, curry, cardamom, and ginger. | Citric | Jaffa, orange, chinotto, rhubarb, and zesty. |
| | Leather | Leather, barnyard, horse, and hay. | Violets | Violet and blue flower. |
| | Brett | Brett-related characters associated with *Brettanomyces* spp. activity. | Olives | Olive, tapenade. |
| | Earthy | Earthy, forest floor, dirt, dust, fungal, mossy, muddy, mushroom, musk. | Yeasty | Yeasty, barley, arrowroot, and toast. |
| | Mineral | Mineral, graphite, stone. | Apples | Apple and apple skin. |
| | Liquorice | Liquorice and anise. | Varietal | Varietal, typical, and Cabernet characters. |
| | Oxidative | Oxidised and aldehyde. | | |
| Mouthfeel, Taste, Body | Soft | Soft, plush, silky, smooth, suede, and talc. | Firm | Firm and robust. |
| | High Acidity | High acidity, acidic, crisp, sour, and tart. | Grainy | Grainy, crunchy, powdery, and sandy. |
| | Fine | Fine tannins | Astringency | Astringent, drying, and puckering. |
| | Hotness | Hot and warming. | Balanced | Polished and rounded. |
| | Short | Short and fading. | Grippy | Grippy. |
| | Long | Lingering and persistent. | Chewy | Chewy. |
| | Complexity | Complex, layered, and structured. | Bitterness | Bitter, pips, and quinine. |
| | Medium Body | Medium body. | Full body | Full body, mouth filling. |

Overall quality scores were also prepared for analysis by aligning them with the Australian wine show judging criteria for awarding medals (Table 2) [28].

**Table 2.** Scoring system used in online reviews and by expert panellists and their equivalence to wine medals based on the Australian wine show judging system [28].

| 100 Point Scale Used in Reviews | 20 Point Scale Used by Expert Panellists | Medal Equivalent |
|---|---|---|
| 95–100 | 18.5–20 | Gold |
| <95–90 | <18.5–17 | Silver |
| <90–85 | <17–15.5 | Bronze |
| <85 | <15.5 | No medal |

*2.4. Statistical Analysis*

The same statistical analysis and lexicon categories were used to investigate tasting notes against regions and tasting notes against medals for the expert panel as well as for the wine reviews. Chi-square testing was performed with the word counts using Wordstat to determine categories that were significantly different between the regions as well as between medals. Before further evaluation, categories that had a count of < 5 for any region or assigned medal were disregarded. Assessing the relationship between the regions or medals and the descriptors, categories with $p$-values $\leq 0.1$ were analysed through correspondence analysis (CA). A significance level of $\alpha = 0.1$ was considered appropriate for the discrimination of categories due to the sensory nature of this study and the large set of samples evaluated by a small panel (in the case of the expert panel assessments) [29]. Multiple factor analysis (MFA) was conducted to compare the medal profiles using the significantly different categories ($\alpha = 0.1$) that were common between the online reviews and expert panellists. MFA was performed in the same way with regional profiles to obtain regression vector (RV) coefficients and test how well the online review and expert panel datasets correlated. Chi-square tests were performed to examine the relationship between regions and medals along with Fisher's exact test, considering $\alpha = 0.05$. Apart from the chi-square tests performed with Wordstat, all statistical analyses were performed in XLSTAT.

## 3. Results

The use of the web scraping software was essential in extracting a large number of online reviews in an adequate timeframe. A sensory lexicon was built in Wordstat by agglomerating words with the same meaning (in terms of a wine tasting lexicon) within the same category, yielding 47 categories (Table 1). With the categories assembled, Wordstat provided the percentages and chi-square results for each category (Tables S1 and S2 of the Supplementary Materials).

*3.1. Regional Profiles of Cabernet Sauvignon Wines*

Only online reviews for Australian wines underwent CA (Figure 1), which incorporated 17 significantly different categories ($\alpha = 0.1$ and count $\geq 5$; Table S1 of the Supplementary Materials). Axis F1 explained 70.97% of the data variance, and was mainly influenced by "Minty", "Sweetness", "Earthy", "Full Body" and "Astringency" descriptors to the right and by "Floral", "Soft", "Red Fruits", "Green", "Herbal", and "Medium Body" descriptors to the left. Axis F2 contributed 29.03% to the explained variance, mainly due to "Green", "Medium Body", "Herbal", "Minty", and "Astringency" in the top half of the biplot, in contrast to "Full Body", "Olives", "Firm", "Complexity", and "Leafy" in the bottom half. Some descriptors, such as "Dark Fruits" and "Oaky", were not major drivers of the variance for these wines, as they were found close to the origin of the plot. With regard to the regions, Figure 1 shows Coonawarra loaded on the right side of the F1 axis, with Yarra Valley and Margaret River appearing opposite along F1. Axis F2 separated Margaret River in the bottom half of the plot from Yarra Valley in the top half (Figure 1).

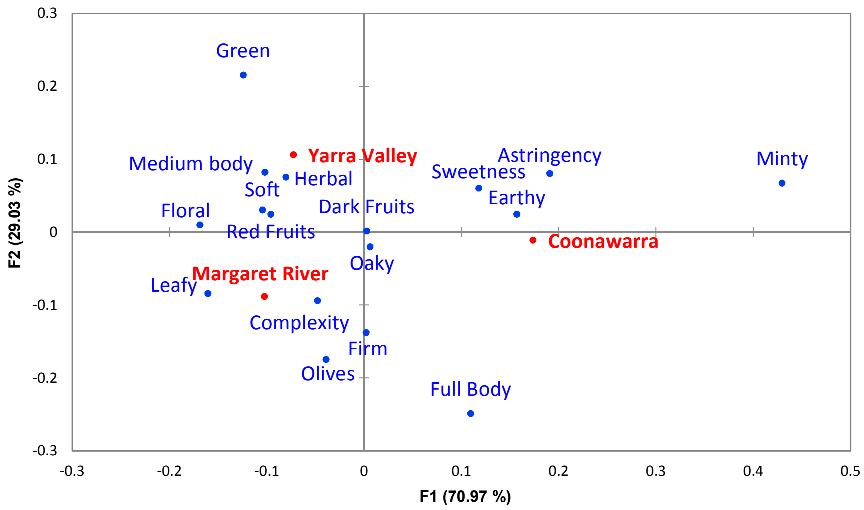


**Figure 1.** Correspondence analysis biplot for the online reviews of Cabernet Sauvignon wines based on significantly different descriptor categories (α = 0.1, chi-square test) for the three Australian regions.

CA was also performed using the frequency of 12 significantly different descriptor categories (α = 0.1 and count ≥ 5) from the expert panel tasting notes (Table S2 of the Supplementary Materials), using four wine regions that produce Cabernet Sauvignon (Figure 2). Axis F1 explained 71.37% of the variance found in the categories describing the wines, and was related to the descriptors "Brett", "Mineral", "Leather", "Astringency", "Savoury" and "Complexity" on the right along axis F1, as opposed to "Minty", "Floral", "Medium Body", "Soft" and "Ripe Fruits" to the left. Axis F2 explained 23.47% of the variance found for the wines, and primarily related to "Floral", "Soft", "Mineral", "Brett", "Minty", "Medium Body" and "Savoury" on the top of the plot. The lower part of axis F2 revealed the importance of "Ripe Fruits", "High Acidity", "Leather", and "Astringency". In terms of the regions, Bordeaux was on the right side of the plot along axis F1 whereas the three Australians regions appeared on the left. Furthermore, F2 shows separation of Margaret River along the top of the axis in comparison to Yarra Valley and Coonawarra, which can be found in the bottom half of the plot (Figure 2).

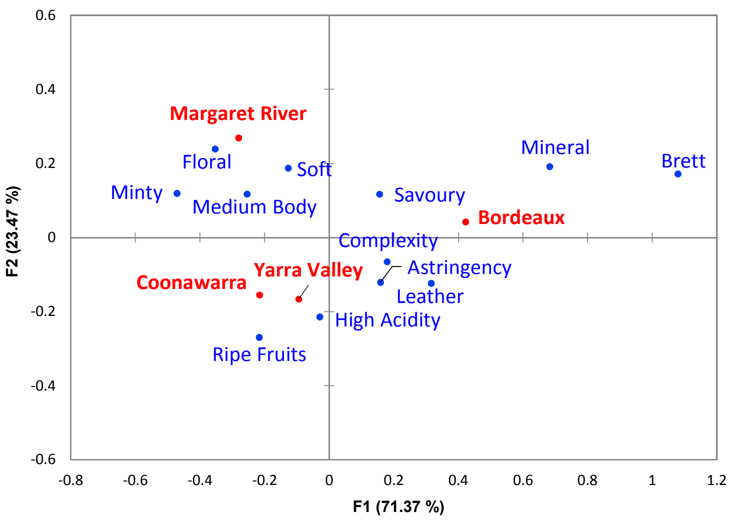


**Figure 2.** Correspondence analysis biplot for the expert panel assessment of Cabernet Sauvignon wines based on significantly different descriptor categories (α = 0.1, chi-square test) showing all four regions in this study.

MFA was conducted with the significant descriptor categories ($\alpha = 0.1$ and count $\geq 5$) for the three Australian regions, using eight categories that were common between the two datasets (Figure S1 of the Supplementary Materials). This analysis yielded a moderate RV coefficient of 0.440, with F1 explaining 64.02% of the variation in the data and F2 contributing 35.98%. The projected mid-points for the regions (Figure S1a) showed that Coonawarra (having the best agreement between expert panel and online reviews) and Yarra Valley were separated from Margaret River along axis F1, whereas F2 separated Yarra Valley from the other two regions. Based on proximity of the descriptors, agreement was mostly evident for "Astringency" in the top right quadrant and "Medium Body" in the bottom left quadrant (Figure S1b), with other categories being located further apart but within the same half of the plot (along F1 or F2).

### 3.2. Medal Profiles

A chi-square significance test was performed on the wine reviews for assigned medals (based on a 100-point scale) against region in order to explore the relationship between quality (using medal as a proxy) and wine origin. With a $p$-value < 0.0001, the interaction between the regions and the frequencies of medals awarded was highly significant. Evaluating this further, Fisher's exact test was performed on the data, based on observed frequencies, and theoretical frequencies for which no effect between medals and regions existed (Table 3). Results for Coonawarra were not significant, irrespective of the medal being considered. In comparison, Margaret River had a higher frequency of Gold medal wines and lower frequency of Bronze/No Medal wines, whereas Yarra Valley had a lower frequency of Gold medal wines and higher frequency of wines with no medals.

**Table 3.** Significance according to Fisher's exact test from an assessment of assigned medal (derived from a score out of 100) in relation to region for the online wine reviews. Values in bold are significantly different from the theoretical frequency at the level $\alpha = 0.05$. NS, not signifcant.

| | | Coonawarra | | Margaret River | | Yarra Valley | |
|---|---|---|---|---|---|---|---|
| **Medal** | **Theoretical Frequency** | **Observed Frequency** | **Result** | **Observed Frequency** | **Result** | **Observed Frequency** | **Result** |
| Gold | 285 | 284 | NS | **326** | **Higher** | **246** | **Lower** |
| Silver | 409 | 404 | NS | 413 | NS | 410 | NS |
| Bronze | 131 | 143 | NS | **103** | **Lower** | 147 | NS |
| No Medal | 41 | 35 | NS | **24** | **Lower** | **63** | **Higher** |

A chi-square test of significance was also performed on data from the expert panellists to assess the relationship between regions (including Bordeaux) and the frequencies of assigned medals based on a 20-point scale. In contrast to the online reviews, no significant difference was found in this case ($p$-value = 0.489).

CA was performed according to assigned medal using the significantly different ($\alpha = 0.1$ and count $\geq 5$) descriptor categories, which totalled 26 attributes for the online reviews (Figure 3a) and 27 for the expert panel (Figure 3b). Considering the online reviews, F1 explained 89.04% of the variance of the data (Figure 3a), and was mainly related with "Chemical", "Short", "Green", "High Acidity", "Astringency", "Savoury", "Herbal", "Sweetness, and "Earthy" attributes on the right side of the F1 axis, as opposed to "Complexity", "Full Body", "Olives", "Fine", "Grainy", "Floral", and "Long" on the left. This separated Silver and Gold medal wines to the left from Bronze and No Medal wines to the right. Axis F2 explained a further 10.26% of the sample variance (Figure 3a), mostly with respect to "Chemical", "Violets", "Short", "Complexity", "Floral", and Long" attributes in the top half of the plot and "Minty", "Medium Body", "Firm", "Balanced", and "Red Fruits" below. Axis F2 distinguished Bronze from No Medal wines and Silver from Gold medal wines.

For the expert panel assessment, axis F1 explained 60.00% of the variance between the wines (Figure 3b) and was mostly defined by higher frequencies for "Brett", "Nutty", "Short", "High Acidity", "Astringency", "Green". "Yeasty", "Red Fruits", "Full Body", and "Fine" on the right side. The opposite direction along F1 was mostly related to "Long", "Bitterness", "Mineral", "Liquorice", "Leather", "Earthy", and "Green" descriptors. Axis F1 was mainly able to differentiate Gold medals on the left, from Bronze and No Medal wines on the right. Axis F2 explained 33.44% of the variance between the wines (Figure 3b) and mainly related in the top half to higher frequencies for "Brett", "Short", "Chewy", "Astringency", "Long", "Leather", "Earthy", and "Green" descriptors. On the opposite side along F2 were descriptors involving "Olives", "Violets", "Full Body", "Fine", and "Yeasty". Attributes that were not cited were mostly close to the origin and did not have a large contribution to explaining the variance between samples. Axis F2 was mainly able to separate Bronze and Silver medal wines on the bottom half from No Medal wines on the top half of the plot.

As with the regions, MFA was performed based on assigned medals and significantly different categories ($\alpha = 0.1$) that were common to the expert assessments and the online reviews, to assess the agreement between the data from both cohorts (Figure 4). The projected points of the medals (Figure 4a) positioned Gold and Silver medals in the right quadrants of axis F1 (which explained 80.61% of the data variance) and Bronze and No Medal wines to the left. Axis F2 (17.06% explained) separated Gold and No Medal wines above the origin and Bronze and Silver medal wines below. Figure 4a also showed a good level of agreement between the wine reviews and the expert panel when assigning the medals (RV coefficient of 0.826), with the best agreement for Silver medals and the worst with Gold. Descriptors that were loaded on the MFA plot in close proximity and thus in agreement between the expert panel and the wine reviews were "Oaky", "Mineral", "Complexity", "Floral", "Dark Fruits", "Green", and "Short" (Figure 4b).

## 4. Discussion

This study sought to evaluate whether content analysis based on wine sensory attributes could differentiate wines from different regions and generate a guide for sample selection of regional wines for this and future studies. This was undertaken for Cabernet Sauvignon wines from selected Australian regions by assessing descriptors from online wine reviews in comparison to those arising from sensory assessment of wines by an expert panel. The approach was also utilised to examine sensory descriptors based on assigned medal (derived from 20- and 100-point scoring scales) for deeper insights into how overall Cabernet Sauvignon wine quality was perceived. Bordeaux red wines were included in the expert panel assessment for comparison and benchmarking with the Australian wines because Bordeaux is a renowned Old-World wine region with a strong appellation system and substantial production of Cabernet Sauvignon wines of quality. Bordeaux red wines are blends of red grape varietals, so for practical reasons, a minimum of 60% Cabernet Sauvignon was set as a selection criterion.

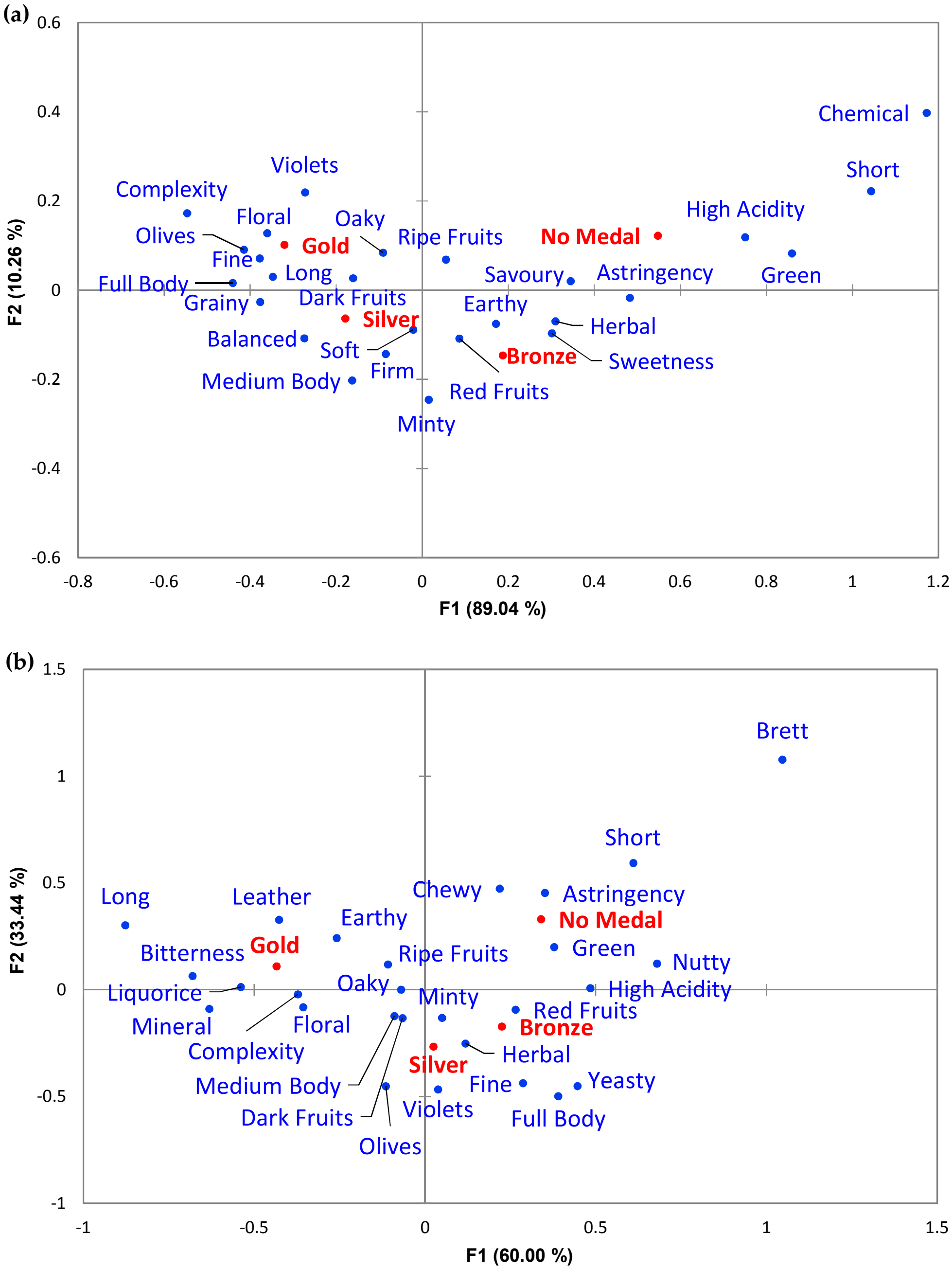


**Figure 3.** Correspondence analysis biplots of Cabernet Sauvignon wines from three Australian regions with significantly different descriptor categories based on the medals assigned ($\alpha = 0.1$, chi-square test) for (**a**) the online reviews, and (**b**) the expert panel.

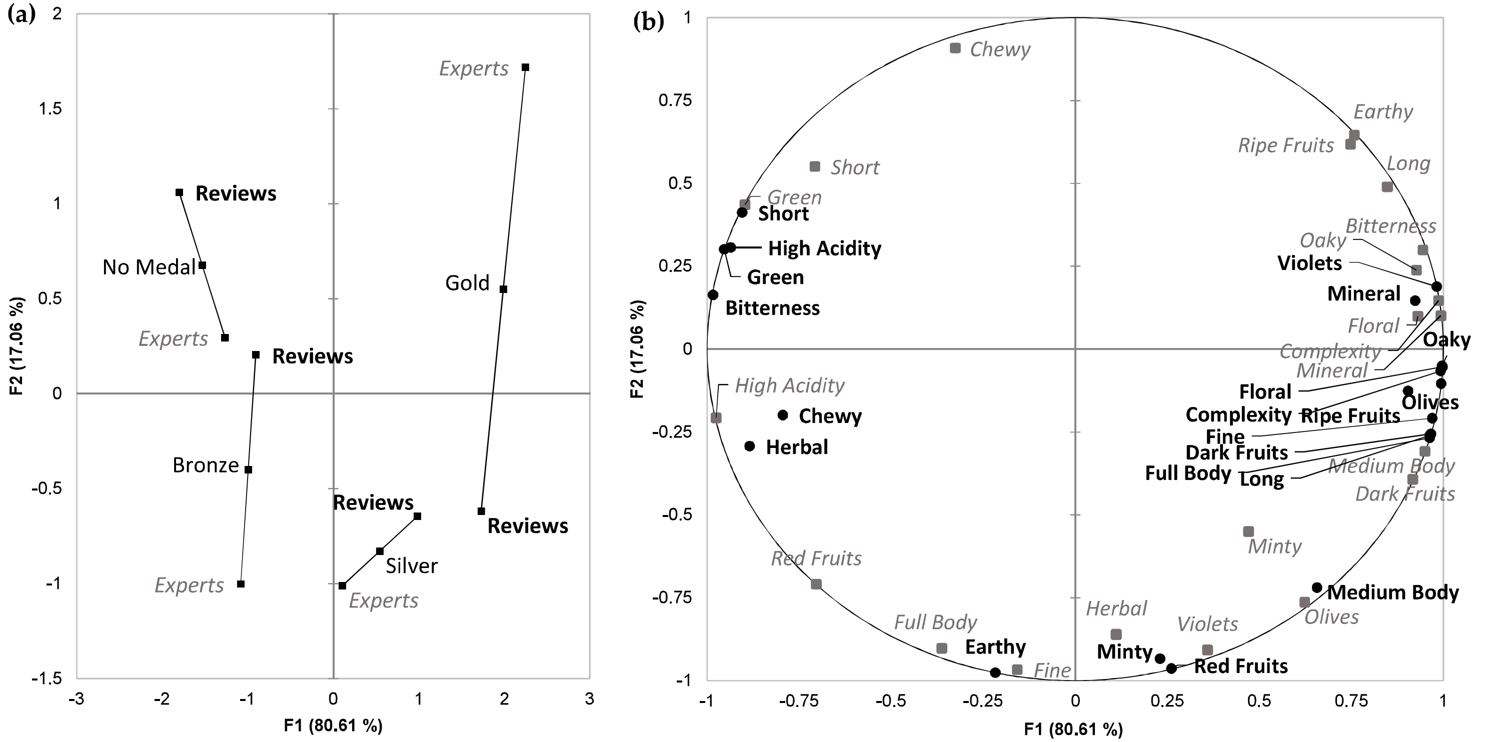


**Figure 4.** Multiple factor analysis plots of Cabernet Sauvignon wines with significantly different ($\alpha = 0.1$, chi-square test) descriptor categories that were common between online reviews and expert panel showing (**a**) projected points of the assigned medals positioned about the mid-point in relation to the two descriptor datasets, where the length of the line is inversely related to the strength of the agreement, and (**b**) descriptors arising from the online reviews (●) and the expert panel assessments (■).

### 4.1. Regional Sensory Profiles for the Online Reviews and the Expert Panel

CA of the significant descriptors obtained from online reviews (Figure 1) revealed a distinction between the three Australian regions analysed in this study. Margaret River was characterised by "Leafy", "Complexity" and "Floral" descriptors and less frequently described with "Minty" and "Astringency". Coonawarra was described more frequently with the terms "Minty", "Astringency", "Sweetness", and "Earthy" and less described with "Soft", "Red Fruits", and "Floral". Yarra Valley was related to "Herbal", "Green", and "Medium Body" and less frequently described as "Full body" and "Firm". CA (Figure 1) showed that the descriptors "Oaky" and "Dark Fruits" were plotted in close proximity to the origin of the plot and at a similar distance between the samples, showing that comparable frequencies were found between the regions. This is understandable, especially when dealing with commercial wines, because winemakers tend to aim for the presence of "Dark Fruits" attributes that can be considered as a marker of quality, as noted by Hopfer and Heymann [30] and borne out with an assessment based on medals (see Section 4.2). "Oaky" descriptors are associated with a winemaker's decision regarding oak contact (e.g., barrel maturation or use of chips or staves), generating notes of "Vanilla", "Buttery", and "Caramel" depending on the raw material origin and prior treatment of the wood (e.g., heating, toasting, seasoning) [31,32]. Oak treatment is commonly used to increase mouthfeel and aroma complexity, and help stabilise colour [33], with a desirable influence as indicated by Hopfer and Heymann [30], Crump, et al. [34] and reinforced in the present study (see Section 4.2). Mouthfeel attributes like "Astringency" and "Soft" noted above are usually associated with the presence and structure of phenolic compounds, especially tannins that are present in grape skins and seeds [35]. The "Green" and "Herbal" descriptors characterising the Yarra Valley region were deemed to be related to 3-isobutyl-2-methoxypyrazine (IBMP), a compound commonly found in Cabernet Sauvignon wines and noted for its low odour detection threshold [36]. IBMP in wine originates directly from the grapes, and its concentration is influenced largely by viticultural practices and environmental conditions [37–39]. The influence of climate can be inferred by considering that the Yarra Valley is characterised by a cooler mean temperature and lower heat summation compared to the other two Australian regions [40].

Conducting CA in the same way on the expert panel assessment, which included wines from Bordeaux (Figure 2), showed clear separation along F1 of the Australian regions from Bordeaux, which appeared on the opposite side of the plot. This suggested that the descriptors used by the experts for the Australian wines were more similar than those attributed to wines from Bordeaux. A possible explanation relates to the divergence of Old-World countries compared to New World countries with respect to winemaking practices (e.g., fermentation processes, maturation techniques, and blending likely being the most important of all due to Bordeaux wines being composed of red blends), environmental conditions (e.g., soil, climate, and topography), and viticulture practices (e.g., pruning regime, irrigation, and training system) [41]. From Figure 2 it is possible to imply that Bordeaux wines were more frequently related to characters such as "Brett", "Mineral", and "Savoury", whereas Coonawarra and Yarra Valley were related to "Ripe Fruits" and "High Acidity" descriptors. Coonawarra was less often described with the characters found in the Bordeaux wines in comparison to Yarra Valley, which was the closest region to Bordeaux in the plot and shared some attributes like "Leather", "Astringency", and "Complexity". On the other hand, Margaret River was frequently associated with "Floral", "Minty", "Medium Body", and "Soft", but less so with "Astringency", "Complexity", and "Leather". "Brett" and "Leather" (or less-frequently cited "Barnyard", data not shown) terms used for the Bordeaux wines are often associated together [42] and originate from bioconversion of hydroxycinnamic acids present in the grapes [43], generating volatile phenols including 4-ethylphenol, 4-ethylguaiacol, and 4-ethylcathecol [44]. The compound 4-ethylcathecol has also been described as presenting a "Savoury" aroma [45]. The distinction of Australian GIs based on sensory attributes has been revealed before by Robinson, et al. [46], with regionality deemed in that work to have similarly influenced the sensorial properties of Cabernet Sauvignon wines. Although not apparent from the expert panel data of the present study, the work of Robinson, et al. [46] accords well with the "Minty" description cited in the wine reviews for Coonawarra Cabernet Sauvignon wines. Wine reviews and the expert panellists were aligned in their description of Margaret River wines as "Floral", which is not clearly related to a single chemical compound in Cabernet Sauvignon wines, but could be influenced by monoterpenoids, $C_{13}$-norisoprenoids, and sesquiterpenoids [47].

Evidently, the methods used to build the wine profiles were not identical and they were different sets of wine samples, making a direct comparison difficult. The expert panellists experienced a controlled environment where they evaluated the same bottle under the same blind conditions. With the wine reviews, descriptors were collated with no information on the conditions in which the wines were tasted, and the information was diffused through public media, which could have influenced the vocabulary and the descriptors used. The wine reviews would also portray vintage-to-vintage variation that influenced the overall profile of the regions, as opposed to the expert panel assessment that evaluated a snapshot from vintage 2015. Vintage variation of Cabernet Sauvignon wine sensory profiles has been demonstrated by Forde, et al. [48]. Considering the difference between both methods, it may be expected that not much concordance exists among the frequency of terms used, as was evident from the MFA results (Figure S1 of the Supplementary Materials) with only eight attributes in common for both datasets and a moderate RV coefficient of 0.440. Nonetheless, it was possible to see that both approaches could distinguish among the wine regions using the descriptors as drivers.

### 4.2. *Quality Judgements for the Online Reviews and the Expert Panel*

Chi-square testing of the results from wine reviews showed that there was a significant interaction between the number of wines that were assigned a certain medal and the region of origin (Table 3). That interaction was evident for Margaret River and Yarra Valley wines, but not those from Coonawarra. A higher proportion of Margaret River wines were deemed to be Gold medal standard, which was contrasted by a lower proportion of wines that were assigned Bronze or No Medal. A somewhat opposite trend was revealed for Yarra Valley, whereby there was a lower proportion of wines assigned Gold medal and a higher proportion of wines with No Medal. This makes sense when considering the descriptors from the wine reviews associated with each region (i.e., Margaret River wines associated with positive traits like "Floral" and "Soft" terms in contrast to Yarra Valley wines being associated with "Herbal" and "Green" descriptors). It is not possible to ascribe this result to a true reflection of the quality expressed by the regions because it is unknown how the wines were evaluated, when reviews were written and how the wines were chosen to be evaluated by the reviewers. It could be possible that the reviews reflected some pre-conceived notion of the potential scores (and hence assigned medals) that each region should receive, if the evaluations were not conducted blind. The outcome from the online reviews contrasts with the results from the expert panel assessment, where the chi-square analysis showed no interaction between the medal counts and the regions. This implied that the overall quality scores from the expert panel were not strongly impacted by the regions where the wines arose. Even though the quality judgement presented in this study differs in methodology when compared to wine shows, it could be considered in line with the work of Allen and Germov [49], who demonstrated that judging of wine quality at Australian capital city wine shows appeared to be based on either national or international standards and not regional specifications.

CA of the assigned medals and the sensory descriptors from the wine reviews (Figure 3a and Table S1 of the Supplementary Materials) showed that Gold medal wines were associated with "Fine", "Floral", "Complexity", "Long", "Olives", "Full Body", "Violets" and "Oaky" descriptors, whereas Silver medal wines were more frequently associated with "Grainy" and "Balanced" and less so with "Green", "Short", and "Chemical". The "Dark Fruits" descriptor was plotted between Silver and Gold medals wines, which might indicate that this descriptor is more associated with higher wine quality. On the opposite side of Figure 3a, Bronze medal wines were associated with "Earthy" "Red Fruits", "Herbal", and "Sweetness" descriptors and a lack of "Oaky" and "Complexity", whereas wines that received No medal were associated with "Green", "Short" "High Acidity", and "Chemical", but generally lacking in fruit characters. It is noteworthy to observe that many descriptors were plotted between Silver and Bronze wines, such as "Medium Body", "Minty", "Red Fruits", "Earthy", and "Herbal", which may indicate that these descriptors could have a positive or negative impact on the quality perception of the wine, depending on the balance of these and other sensory attributes.

Analysing the expert panel assessment in the same way (Figure 3b and Table S2 of the Supplementary Materials), Gold medal wines stood out more prominently from the rest, with terms including "Complexity", "Bitterness", "Earthy", "Long", and "Leather". Silver medal wines were linked to "Herbal", "Violets", "Minty", "Full Body", and "Olives". Some descriptors such as "Dark Fruits", "Medium Body", "Oaky" and "Floral" were plotted between Silver and Gold medal wines, which might demonstrate their influence on the sensory profiles of wines that express higher quality. Bronze medal wines were more frequently associated with "Red Fruits" and "Yeasty" descriptors and less with "Earthy", "Leather", and "Long", and wines that were assigned as No medal were more correlated with "Green", "Astringency", "Short", and "Brett" and less with "Dark Fruits" and "Medium Body". Terms such as "High Acidity" and "Nutty" were associated with both Bronze and No medal wines, implying that those attributes were not perceived by the expert panellists as quality characteristics for these wines. Some of the present findings accorded with those of Lattey, Bramley and Francis [7], in which wines with higher quality ratings were associated with "Minty", "Spicy", "Woody" (e.g., "Oaky"), "Complexity" and "Persistence" (e.g., "Long"), and lower quality wines were associated with *Brett*-related flavours of "Barnyard", "Band-Aid" (e.g., "Chemical") and "Leather". These sorts of traits are associated with *Brettanomyces* spp., indigenous yeast species that can be present during wine fermentation or ageing and produce aroma compounds that impact on the finished wine [50]. The effect can be perceived as negative when in higher quantities or positive when contributing to the developed characters of the wine, which might explain the term "Leather" being frequently described by the expert panel [50,51]. It is also noteworthy to recall that wines tasted by the expert panel were 2015 commercial wines, so developed characters such as "Leather" (a tertiary character that does not necessarily have to arise from *Brettanomyces*) were to be expected. In relation to "Green" being correlated with No medal wines, Hopfer, et al. [52] showed that "Fresh Green" (and "Soy Sauce") aromas had a negative impact on the quality ratings of wines. Furthermore, the attributes related to low quality ratings were also in alignment with the consumer preferences investigated by Ristic, et al. [53], whereby savoury-like flavours (e.g., "Gamey/ Meaty", "Soy Sauce", "Salami", and "Barnyard") and green-like flavours (e.g., "Capsicum", "Green Beans", "Green Peas", "Green Tea", and "Green Grass") were the least favourite. Finally, Niimi, et al. [54] explained that higher perceived quality was linked to more complex, wines where sensory characteristics such as "Dark Fruit", "Colour", "Body" and "Astringency" were more intense. It was also implied by Niimi, et al. [54] that the balance of "Green" flavour drives quality ratings in Cabernet Sauvignon wines, where too much or too little can be perceived as negative. Overall, those observations align well with the present results.

### *4.3. Quality Judgment Correlation Between the Wine Reviews and Expert Panel*

MFA was conducted to investigate the online review and expert panel descriptor datasets with respect to assigned medal (as a proxy for quality). It is interesting to note in Figure 4b that the expert panel and the wine reviewers agreed with their use of "Dark Fruits", "Complexity", "Oaky", "Mineral" and "Floral" descriptors based on their close proximity, to the right along axis F1. As observed in Figure 4a, those attributes appeared to be important for wines that were perceived as higher in quality (i.e., assigned Gold or Silver medals). On the other hand, both sources of data agreed that "Green" and "Short" were attributes associated with wine perceived to be at the lower end of quality, and not receiving a medal. From Figure 4a it is clear that the expert panel could better differentiate the four medal classes, with each appearing in a distinct quadrant; this did not happen with the wine reviews. Nonetheless, strong agreement between both data sources was evident, with MFA producing an RV coefficient of 0.826. Agreement between the expert assessment and the online reviews was better when evaluating lower quality wines, with a particular contrast between wines assigned as No medal versus Gold medal (Figure 4a). This might imply that it is easier to judge (or agree upon) factors that have a negative impact on wine quality as opposed to traits that are indicators of higher quality wine. This assertion is supported by the work of Hodgson [55] and Allen and Germov [49], who evaluated wine competitions in Australia and USA, respectively. They concluded that wine judges had more concordance between wines that should receive a medal or not, as opposed to assigning Gold, Silver or Bronze medals to the wine. Overall, the results from MFA pointed to the potential validity of using content analysis as a new methodology to explore wine characterisation and wine typicity in an efficient and low-cost way, with a view to selecting wines for further study.

### *4.4. Concepts of Typicity in Relation to Quality*

Quality is a multifaceted concept that involves a complex link between intrinsic (appearance, gustatory, origin, variety, typicity and potential) and extrinsic (grapes, production, marketing) characterisation [56]. This is corroborated by Verdú Jover, et al. [57], suggesting that red wine quality should be evaluated using a two-dimensional scale: one for extrinsic attributes (involving origin, image and presentation) and one for intrinsic attributes (involving age, harvest, sensitivity and acuteness). Typicity of a region could be a term that is connected directly with wine quality, although the scores were assigned and the respective tasting notes were obtained from the expert panel without any knowledge about the regions being evaluated. Even with the online reviews, it might be anticipated that there was limited prior knowledge of the wine being tasted. The present study therefore dealt only with some aspects of intrinsic characterisation, but still revealed attributes that might be able to profile sensory typicity, which features in one of the dimensions of quality. It was possible to connect some terms that were important both for assigned medals (proxy for quality) and for certain regions. For example, "Floral" that was a term highly cited for Gold medal wines and for Margaret River wines. However, further research is necessary to better understand the relationship between wine quality and typicity in a sensory manner.

## 5. Conclusions

The use of web scraping and content analysis software has been proposed as a valuable approach for investigating different sensory profiles of wines according to online sources in a rapid timeframe. The methodology can also serve as a selection guide of regional wines that can undergo more in-depth sensory work, such as by expert panellists. This aspect was demonstrated with commercial Cabernet Sauvignon wines from Margaret River, Coonawarra, Yarra Valley, and Bordeaux, which could be distinguished by different sensory profiles, indicating that terroir, viticulture and winemaking practices can have an impact on the final characteristics of the wine in a region-specific manner.

Results from the medal assignments based on quality score showed that assessments by those with high involvement in the industry (i.e., wine reviewers or winemaker as in this study) can lead to a distinction between wines considered to be at the higher and the lower end of wine quality. Furthermore, based on the frequencies of the descriptors used, certain sensory characteristics appeared to be more important when judging the overall quality of the wine as "Complexity" and "Dark Fruits" for high quality and "Green" for lower quality.

MFA of frequencies obtained from the reviews and expert panellists revealed the extent of agreement between common descriptors from both data sources that were associated with the different regions and with wines of different ascribed quality. Based on RV coefficients, there was very good agreement for wines based on quality, with greater alignment at the lower end of the wine quality assessment scale, and moderate agreement based on region. The use of MFA helped to highlight the potential of using content analysis according to the proposed methodology to efficiently explore wine characterisation and typicity while minimising the costs of such an undertaking of the scale presented in this work.

Overall, this study has presented a strategy to select wines that will undergo further analysis, using sensory methods in this case, but the concept could be extended to exploring the chemical profiles of wines. Indeed, the approach will be exploited in upcoming trials to characterise the typicity of the

Australian Cabernet Sauvignon wines from different origins. The present work lays the foundation that will become important to the wine industry when aiming to understand regionality and the associated unique attributes, which can serve as a tool to promote regional wines and attend to consumer demands for uniqueness. It also provides understanding of the existence of regional profiles and how these may relate to quality scores.

**Supplementary Materials:** The following are available online at http://www.mdpi.com/2304-8158/8/12/691/s1, Table S1: Frequencies of each categories for regions and medals based on the wine writers' reviews along with the chi-square results and *p*-values; Table S2: Frequencies of each categories for regions and medals based on the expert panel assessment along with the chi-square results and *p*-values; Figure S1: Multiple factor analysis plot of Cabernet Sauvignon wines with common significantly different descriptor categories (α = 0.1, chi-square test) based on the regional profile.

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# SUPPLEMENTARY MATERIALS FOR

## Using Content Analysis to Characterise the Sensory Typicity and Quality Judgements of Australian Cabernet Sauvignon Wines

Lira Souza Gonzaga [1,2], Dimitra L. Capone [1,2], Susan E. P. Bastian [1,2], Lukas Danner [1], David W. Jeffery [1,2,*]

[1] Department of Wine and Food Science, The University of Adelaide, PMB 1, Glen Osmond, South Australia 5064, Australia

[2] Australian Research Council Training Centre for Innovative Wine Production, The University of Adelaide, PMB 1, Glen Osmond, South Australia 5064, Australia

* Correspondence: david.jeffery@adelaide.edu.au

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**Table S1.** Frequencies of each category for regions and medals based on the online wine writers' reviews along with the chi-square results and *p*-values (significantly different categories with α = 0.1 with a count of 5 or more are shown in bold). Observed values that are higher than the theoretical value are shown in red and those that are lower are shown in blue.

| Wine Reviews | Region | | | | | Medals | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Categories | Coonawarra | Margaret River | Yarra Valley | Chi-square | *p*-value | Gold | Silver | Bronze | No Medal | Chi-square | *p*-value |
| Dark Fruits | 72.40% | 73.21% | 68.48% | **5.436** | **0.066** | 82.71% | 74.57% | 48.35% | 33.61% | **247.096** | **<0.001** |
| Chemical | 1.50% | 1.27% | 1.04% | 0.737 | 0.692 | 0.47% | 0.73% | 2.80% | 7.38% | **50.823** | **<0.001** |
| Ripe Fruits | 23.67% | 21.71% | 20.79% | 2.190 | 0.335 | 23.36% | 23.15% | 17.05% | 18.03% | **8.582** | **0.035** |
| Savoury | 16.05% | 18.01% | 16.74% | 1.220 | 0.543 | 14.14% | 17.52% | 19.59% | 22.13% | **9.385** | **0.025** |
| Nutty | 0.35% | 0.58% | 0.92% | 2.390 | 0.303 | 0.47% | 0.98% | 0.00% | 0.00% | 6.129 | 0.105 |
| Smoky | 9.24% | 9.01% | 9.58% | 0.174 | 0.917 | 9.46% | 9.62% | 6.87% | 12.30% | 4.229 | 0.238 |
| Floral | 8.43% | 12.70% | 11.66% | **8.832** | **0.012** | 14.84% | 10.84% | 5.09% | 3.28% | **34.533** | **<0.001** |
| Minty | 24.02% | 8.78% | 12.01% | **87.937** | **<0.001** | 11.80% | 17.36% | 16.54% | 7.38% | **18.585** | **<0.001** |
| Eucalyptus | 2.54% | 3.12% | 1.50% | 4.990 | 0.082 | 1.75% | 3.10% | 1.78% | 1.64% | 5.047 | 0.168 |
| Spicy | 8.66% | 8.31% | 7.62% | 0.644 | 0.725 | 8.76% | 8.31% | 7.63% | 4.92% | 2.293 | 0.514 |
| Leather | 1.96% | 1.27% | 0.58% | 6.630 | 0.036 | 0.82% | 1.63% | 1.02% | 1.64% | 2.996 | 0.392 |
| Brett | 0.12% | 0.23% | 0.00% | 2.002 | 0.367 | 0.12% | 0.16% | 0.00% | 0.00% | 0.836 | 0.841 |
| Earthy | 25.17% | 17.78% | 18.48% | **17.718** | **<0.001** | 17.17% | 22.66% | 21.63% | 18.03% | **10.087** | **0.018** |
| Mineral | 3.58% | 2.08% | 2.19% | 4.742 | 0.093 | 3.39% | 2.69% | 1.02% | 1.64% | 6.421 | 0.093 |
| Liquorice | 2.66% | 1.50% | 1.04% | 7.056 | 0.029 | 1.75% | 1.87% | 1.02% | 2.46% | 1.705 | 0.636 |
| Oxidative | 0.00% | 0.00% | 0.46% | 8.012 | 0.018 | 0.00% | 0.08% | 0.51% | 0.82% | 8.477 | 0.037 |
| Red Fruits | 21.02% | 26.10% | 25.17% | **6.937** | **0.031** | 20.68% | 27.14% | 24.17% | 17.21% | **14.844** | **0.002** |
| Herbal | 17.21% | 19.63% | 21.36% | **4.830** | **0.089** | 16.00% | 19.56% | 25.45% | 22.13% | **16.099** | **0.001** |
| Green | 6.70% | 7.39% | 10.85% | **11.270** | **0.004** | 3.74% | 6.85% | 17.56% | 25.41% | **117.804** | **<0.001** |
| Oaky | 66.28% | 67.90% | 60.28% | **12.248** | **0.002** | 77.80% | 64.79% | 44.53% | 39.34% | **168.956** | **<0.001** |
| Peppery | 3.00% | 1.85% | 1.15% | 7.692 | 0.021 | 1.52% | 2.12% | 2.54% | 2.46% | 1.825 | 0.610 |
| Confectionery | 0.23% | 0.58% | 0.69% | 2.010 | 0.366 | 0.12% | 0.65% | 0.51% | 1.64% | 6.275 | 0.099 |
| Cooked Vegetables | 0.23% | 0.81% | 1.39% | 7.201 | 0.027 | 0.58% | 0.65% | 1.53% | 1.64% | 4.491 | 0.213 |
| Sweetness | 12.24% | 9.01% | 10.16% | **4.961** | **0.084** | 7.59% | 11.57% | 12.98% | 11.48% | **11.916** | **0.008** |
| Leafy | 10.05% | 15.94% | 11.89% | **14.243** | **0.001** | 12.27% | 13.37% | 12.21% | 9.02% | 2.211 | 0.530 |
| Citric | 0.46% | 0.12% | 0.46% | 2.007 | 0.367 | 0.23% | 0.33% | 0.51% | 0.82% | 1.422 | 0.700 |
| Violets | 7.74% | 9.82% | 9.24% | 2.452 | 0.294 | 13.20% | 7.91% | 4.33% | 4.10% | **34.53** | **<0.001** |

**Table S1. contd.**

| Wine Reviews | Region | | | | | Medals | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Categories | Coonawarra | Margaret River | Yarra Valley | Chi-square | *p*-value | Gold | Silver | Bronze | No Medal | Chi-square | *p*-value |
| Olives | 7.62% | 9.82% | 5.89% | **9.351** | **0.009** | 10.63% | 7.66% | 3.82% | 1.64% | **24.75** | **<0.001** |
| Yeasty | 3.93% | 4.16% | 4.16% | 0.079 | 0.961 | 5.37% | 3.50% | 3.31% | 3.28% | 5.499 | 0.139 |
| Apples | 0.35% | 0.00% | 0.00% | 6.007 | 0.05 | 0.23% | 0.08% | 0.00% | 0.00% | 1.755 | 0.625 |
| Varietal | 8.78% | 9.58% | 10.16% | 0.975 | 0.614 | 9.11% | 10.02% | 10.18% | 4.92% | 3.729 | 0.292 |
| Soft | 18.59% | 23.44% | 22.86% | **7.170** | **0.028** | 21.14% | 23.47% | 19.85% | 12.30% | **9.582** | **0.022** |
| High Acidity | 2.54% | 2.31% | 3.70% | 3.450 | 0.178 | 1.52% | 2.77% | 4.58% | 7.38% | **18.797** | **<0.001** |
| Fine | 20.90% | 21.71% | 24.36% | 3.281 | 0.194 | 27.69% | 24.21% | 9.92% | 5.74% | **70.905** | **<0.001** |
| Hotness | 1.85% | 0.46% | 1.27% | 7.117 | 0.028 | 0.93% | 1.55% | 0.76% | 0.82% | 2.56 | 0.465 |
| Short | 1.27% | 0.92% | 1.73% | 2.205 | 0.332 | 0.47% | 0.90% | 3.05% | 5.74% | **34.098** | **<0.001** |
| Long | 5.77% | 7.39% | 5.89% | 2.369 | 0.306 | 7.71% | 6.85% | 3.31% | 1.64% | **13.837** | **0.003** |
| Complexity | 10.97% | 13.51% | 9.93% | **5.784** | **0.055** | 16.24% | 11.74% | 3.31% | 1.64% | **56.645** | **<0.001** |
| Medium Body | 18.94% | 22.63% | 24.83% | **8.903** | **0.012** | 21.14% | 24.94% | 20.36% | 6.56% | **23.984** | **<0.001** |
| Firm | 13.28% | 15.24% | 10.05% | **10.644** | **0.005** | 11.80% | 14.83% | 11.20% | 5.74% | **11.618** | **0.009** |
| Grainy | 12.47% | 13.16% | 12.01% | 0.533 | 0.766 | 14.37% | 14.18% | 6.62% | 2.46% | **29.488** | **<0.001** |
| Astringency | 9.82% | 6.00% | 7.39% | **9.027** | **0.011** | 5.49% | 7.74% | 11.20% | 12.30% | **16.189** | **0.001** |
| Balanced | 7.04% | 7.27% | 5.20% | 3.696 | 0.158 | 6.66% | 7.58% | 4.33% | 1.64% | **10.18** | **0.017** |
| Grippy | 3.58% | 2.66% | 2.42% | 2.307 | 0.316 | 0.93% | 3.59% | 4.33% | 4.92% | 18.474 | <0.001 |
| Chewy | 2.66% | 0.92% | 0.81% | 12.872 | 0.002 | 0.47% | 2.04% | 1.53% | 2.46% | 9.549 | 0.023 |
| Bitterness | 2.08% | 1.50% | 1.96% | 0.891 | 0.640 | 0.58% | 1.87% | 3.56% | 4.92% | 20.255 | <0.001 |
| Full Body | 13.16% | 13.39% | 6.35% | **28.400** | **<0.001** | 13.67% | 11.82% | 5.34% | 1.64% | **30.897** | **<0.001** |

**Table S2.** Frequencies of each category for regions and medals based on the expert panel assessment along with the chi-square results and *p*-values (significantly different categories with α = 0.1 with a count of 5 or more are shown in bold). Observed values that are higher than the theoretical value are shown in red and those that are lower are shown in blue.

| *Expert Panel* | Regions | | | | | | Medals | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Categories | Bordeaux | Coonawarra | Margaret River | Yarra Valley | Chi-square | *p*-value | Gold | Silver | Bronze | No Medal | Chi-square | *p*-value |
| Dark Fruits | 37.27% | 39.49% | 30.45% | 36.82% | 5.034 | 0.169 | **49.06%** | **49.10%** | **34.87%** | **26.59%** | **36.745** | **<0.001** |
| Chemical | 4.55% | 6.58% | 5.91% | 8.64% | 2.375 | 0.498 | 5.66% | 7.53% | 7.66% | 5.74% | 1.231 | 0.746 |
| Ripe Fruits | **18.18%** | **30.13%** | **15.91%** | **27.27%** | **18.657** | **<0.001** | **41.51%** | **21.86%** | **23.37%** | **25.08%** | **9.557** | **0.023** |
| Savoury | **46.36%** | **18.73%** | **27.73%** | **25.00%** | **35.323** | **<0.001** | 32.08% | 28.67% | 26.44% | 21.45% | 5.631 | 0.131 |
| Nutty | 5.45% | 4.05% | 5.00% | 4.55% | 0.537 | 0.911 | **0.00%** | **5.02%** | **2.68%** | **6.65%** | **7.920** | **0.048** |
| Smoky | 0.91% | 1.01% | 0.91% | 1.36% | 0.274 | 0.965 | 3.77% | 0.36% | 0.38% | 1.81% | 7.793 | 0.050 |
| Floral | **5.45%** | **7.59%** | **11.82%** | **5.91%** | **6.765** | **0.080** | **18.87%** | **9.68%** | **9.20%** | **3.93%** | **17.52** | **0.001** |
| Minty | **6.36%** | **17.22%** | **19.09%** | **10.00%** | **15.340** | **0.002** | **16.98%** | **16.13%** | **18.39%** | **11.18%** | **6.571** | **0.087** |
| Eucalyptus | 0.91% | 1.52% | 2.27% | 1.82% | 0.943 | 0.815 | 1.89% | 1.08% | 3.45% | 0.91% | 6.559 | 0.087 |
| Spicy | 11.82% | 13.92% | 10.00% | 14.09% | 2.415 | 0.491 | 9.43% | 14.34% | 12.26% | 12.69% | 1.189 | 0.756 |
| Leather | **17.27%** | **6.58%** | **4.55%** | **10.45%** | **18.675** | **<0.001** | **24.53%** | **7.17%** | **4.21%** | **10.27%** | **25.799** | **<0.001** |
| Brett | **14.55%** | **0.76%** | **0.91%** | **1.36%** | **72.707** | **<0.001** | **0.00%** | **0.00%** | **1.15%** | **5.74%** | **25.871** | **<0.001** |
| Earthy | 20.00% | 19.24% | 12.73% | 20.00% | 5.452 | 0.142 | **39.62%** | **17.56%** | **10.73%** | **21.45%** | **28.436** | **<0.001** |
| Mineral | **8.18%** | **1.27%** | **1.82%** | **1.36%** | **20.555** | **<0.001** | **7.55%** | **3.94%** | **1.53%** | **0.60%** | **14.934** | **0.002** |
| Liquorice | 0.91% | 1.77% | 0.91% | 3.64% | 5.319 | 0.150 | **5.66%** | **3.23%** | **0.77%** | **1.21%** | **9.065** | **0.028** |
| Oxidative | 2.73% | 2.53% | 3.64% | 1.82% | 1.446 | 0.695 | 1.89% | 2.15% | 2.30% | 3.32% | 1.107 | 0.775 |
| Red Fruits | 47.27% | 47.59% | 46.36% | 44.09% | 0.731 | 0.866 | **30.19%** | **48.03%** | **49.43%** | **43.20%** | **8.041** | **0.045** |
| Herbal | 9.09% | 12.91% | 14.09% | 12.73% | 1.692 | 0.639 | **11.32%** | **14.70%** | **16.48%** | **7.85%** | **11.552** | **0.009** |
| Green | 17.27% | 18.23% | 19.55% | 15.00% | 1.706 | 0.636 | **11.32%** | **10.75%** | **18.39%** | **23.26%** | **18.015** | **<0.001** |
| Oaky | 40.00% | 39.24% | 32.27% | 43.64% | 6.216 | 0.102 | **58.49%** | **41.22%** | **39.85%** | **34.44%** | **11.908** | **0.008** |
| Peppery | 2.73% | 3.54% | 2.27% | 4.55% | 1.914 | 0.591 | 0.00% | 1.79% | 4.60% | 4.53% | 6.367 | 0.095 |
| Confectionery | 5.45% | 3.54% | 5.45% | 5.45% | 1.890 | 0.596 | 0.00% | 5.38% | 3.83% | 5.74% | 4.079 | 0.253 |
| Cooked Vegetables | 4.55% | 7.85% | 6.82% | 10.45% | 4.056 | 0.255 | 1.89% | 7.89% | 7.66% | 8.76% | 3.015 | 0.389 |
| Sweetness | 9.09% | 16.20% | 12.27% | 14.55% | 4.369 | 0.224 | 15.09% | 12.90% | 14.18% | 14.80% | 0.510 | 0.917 |
| Leafy | 10.91% | 12.41% | 12.73% | 10.91% | 0.544 | 0.909 | 20.75% | 11.11% | 14.18% | 10.27% | 6.017 | 0.111 |
| Citric | 0.00% | 2.78% | 3.64% | 2.27% | 4.095 | 0.251 | 1.89% | 3.94% | 3.83% | 0.60% | 8.870 | 0.031 |
| Violets | 0.91% | 5.57% | 5.00% | 4.09% | 4.512 | 0.211 | **3.77%** | **8.24%** | **4.60%** | **1.81%** | **14.219** | **0.003** |

**Table S2. contd.**

| *Expert Panel* | Regions | | | | | | Medals | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Categories | Bordeaux | Coonawarra | Margaret River | Yarra Valley | Chi-square | *p*-value | Gold | Silver | Bronze | No Medal | Chi-square | *p*-value |
| Olives | 0.00% | 3.80% | 2.73% | 4.09% | 4.849 | 0.183 | **3.77%** | **6.09%** | **3.07%** | **0.91%** | **13.042** | **0.005** |
| Yeasty | 6.36% | 2.53% | 3.18% | 3.64% | 3.933 | 0.269 | **0.00%** | **6.45%** | **1.92%** | **2.72%** | **11.772** | **0.008** |
| Apples | 3.64% | 2.53% | 2.73% | 3.64% | 0.819 | 0.845 | 0.00% | 2.51% | 4.60% | 2.72% | 4.206 | 0.240 |
| Varietal | 0.00% | 3.80% | 1.82% | 2.27% | 5.917 | 0.116 | 5.66% | 2.51% | 2.68% | 2.11% | 2.286 | 0.515 |
| Soft | **24.55%** | **19.75%** | **28.18%** | **16.36%** | **10.589** | **0.014** | 26.42% | 20.79% | 20.69% | 21.75% | 0.956 | 0.812 |
| High Acidity | **19.09%** | **17.97%** | **10.45%** | **19.55%** | **8.354** | **0.039** | **5.66%** | **13.98%** | **18.01%** | **19.03%** | **7.797** | **0.050** |
| Fine | 12.73% | 9.87% | 10.91% | 6.36% | 4.350 | 0.226 | **3.77%** | **15.05%** | **10.73%** | **5.74%** | **17.237** | **0.001** |
| Hotness | 5.45% | 6.33% | 5.91% | 6.82% | 0.288 | 0.962 | 9.43% | 5.38% | 7.28% | 5.74% | 1.891 | 0.595 |
| Short | 7.27% | 5.06% | 4.55% | 4.09% | 1.685 | 0.640 | **1.89%** | **2.51%** | **2.68%** | **9.67%** | **22.478** | **<0.001** |
| Long | 0.91% | 1.77% | 0.91% | 0.91% | 1.366 | 0.714 | **7.55%** | **1.08%** | **0.77%** | **0.91%** | **17.227** | **0.001** |
| Complexity | **36.36%** | **22.03%** | **14.55%** | **18.18%** | **22.431** | **<0.001** | **49.06%** | **31.18%** | **14.18%** | **14.50%** | **57.381** | **<0.001** |
| Medium Body | **10.91%** | **10.63%** | **17.73%** | **15.00%** | **7.257** | **0.064** | **18.87%** | **17.92%** | **12.64%** | **9.67%** | **10.286** | **0.016** |
| Firm | 9.09% | 6.58% | 4.09% | 8.18% | 4.201 | 0.241 | 5.66% | 9.68% | 5.75% | 5.14% | 5.715 | 0.126 |
| Grainy | 13.64% | 12.66% | 16.82% | 12.27% | 2.557 | 0.465 | 13.21% | 14.34% | 17.62% | 10.57% | 6.166 | 0.104 |
| Astringency | **19.09%** | **12.15%** | **7.27%** | **11.36%** | **10.134** | **0.017** | **9.43%** | **6.09%** | **8.43%** | **19.94%** | **32.675** | **<0.001** |
| Balanced | 1.82% | 3.54% | 3.64% | 2.27% | 1.586 | 0.663 | 1.89% | 3.58% | 3.45% | 2.72% | 0.729 | 0.866 |
| Grippy | 2.73% | 3.04% | 1.82% | 4.09% | 2.005 | 0.571 | 0.00% | 1.79% | 3.45% | 3.93% | 4.285 | 0.232 |
| Chewy | 9.09% | 7.09% | 7.73% | 4.55% | 2.985 | 0.394 | **7.55%** | **3.58%** | **4.60%** | **11.78%** | **18.880** | **<0.001** |
| Bitterness | 2.73% | 3.54% | 5.45% | 3.18% | 2.289 | 0.515 | **15.09%** | **5.38%** | **2.68%** | **1.81%** | **24.248** | **<0.001** |
| Full Body | 4.55% | 7.34% | 6.82% | 8.18% | 1.542 | 0.673 | **1.89%** | **9.32%** | **10.73%** | **3.63%** | **15.203** | **0.002** |

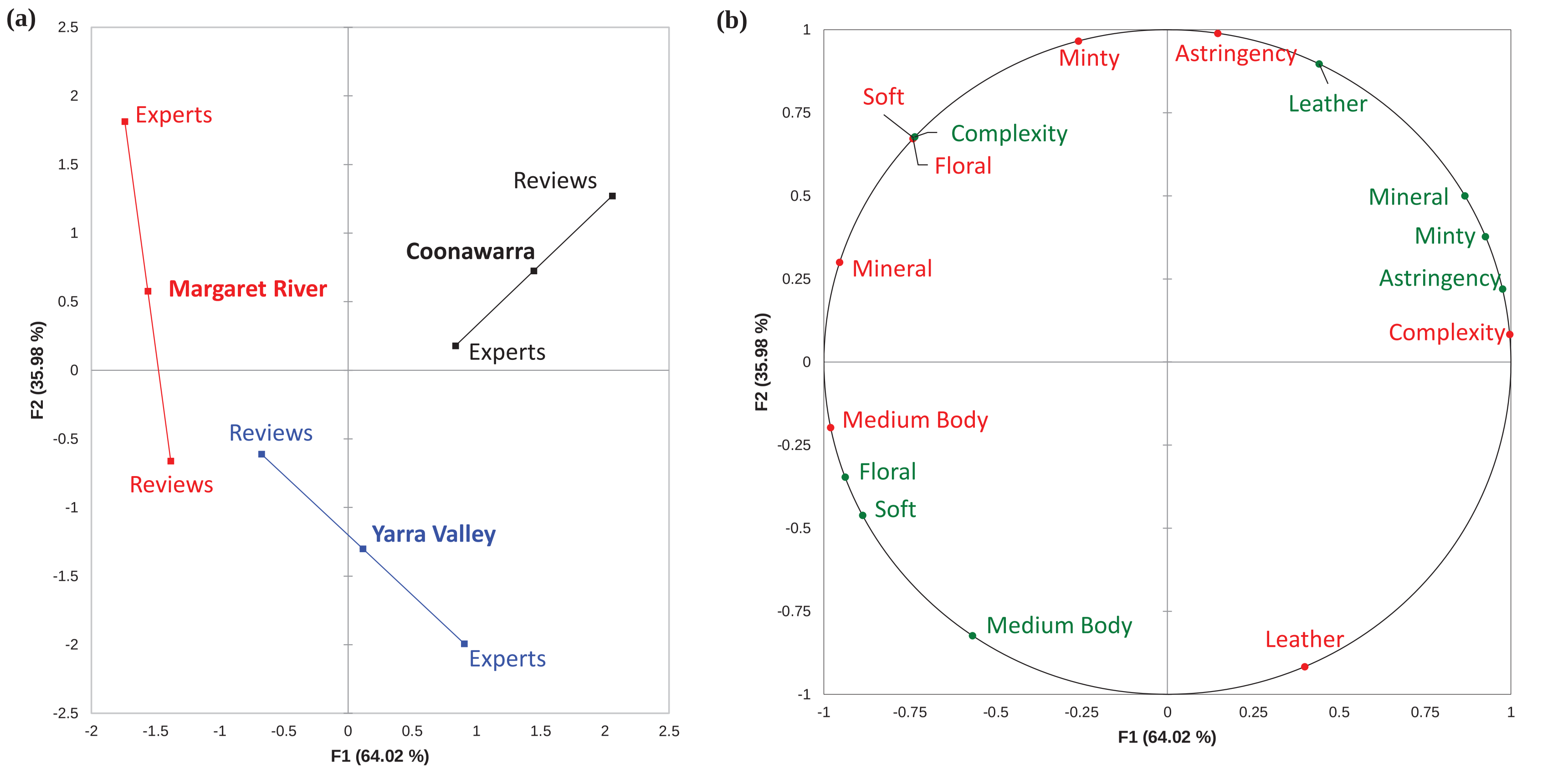


**Figure S1.** Multiple factor analysis plot of Cabernet Sauvignon wines with common significantly different descriptor categories (α = 0.1, chi-square test) based on the regional profiles showing (**a**) projected points of the regions according to online reviews and expert panel, where the length of the line is inversely related to the strength of the agreement, and (**b**) descriptors arising from the online reviews (green) and the expert panel assessments (red).

# Chapter 3

## Publication

Sensory typicity of regional Australian Cabernet Sauvignon wines according to expert evaluations and descriptive analysis

**Souza Gonzaga, L.**, Capone, D. L., Bastian, S. E. P., Danner, L., & Jeffery, D. W. (2020) Food Research International, 138, Part A, 109760. DOI

# Statement of Authorship

| | |
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## Principal Author

| | | | |
|---|---|---|---|
| Name of Principal Author (Candidate) | Lira Souza Gonzaga | | |
| Contribution to the Paper | Sourced all the wine samples. Designed, prepared and conducted both sensory evaluations. Transcribed and carried out statistical analysis of the data collected during the two sensory studies. Prepared the complete first draft of the manuscript and incorporated revisions. | | |
| Overall percentage (%) | 70% | | |
| Certification: | This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper. | | |
| Signature | | Date | 03/11/2020 |

## Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);
ii. permission is granted for the candidate in include the publication in the thesis; and
iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

| | | | |
|---|---|---|---|
| Name of Co-Author | Dimitra L. Capone | | |
| Contribution to the Paper | Assisted with sample sourcing and preparation. Assisted with the study design and supervised the project. Discussed the results and provided critical feedback. Critically evaluated and revised the manuscript. | | |
| Signature | | Date | 03/11/2020 |

| | | | |
|---|---|---|---|
| Name of Co-Author | Susan E. P. Bastian | | |
| Contribution to the Paper | Assisted with the study design and supervised the project. Discussed the results and provided critical feedback. Critically evaluated and revised the manuscript. | | |
| Signature | | Date | 3.NOV.2020 |

| | |
|---|---|
| Name of Co-Author | Lukas Danner |
| Contribution to the Paper | Assisted with the study design and data extraction. Discussed the results and provided critical feedback. Critically evaluated and revised the manuscript. |
| Signature | Date: 3/11/2020 |

| | |
|---|---|
| Name of Co-Author | David W. Jeffery |
| Contribution to the Paper | Supervised and directed the project. Discussed the study design and results, and provided critical feedback. Critically evaluated and revised the manuscript. Acted as corresponding author. |
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Please cut and paste additional co-author panels here as required.

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# Sensory typicity of regional Australian Cabernet Sauvignon wines according to expert evaluations and descriptive analysis

Lira Souza Gonzaga [a,b], Dimitra L. Capone [a,b], Susan E.P. Bastian [a,b], Lukas Danner [a], David W. Jeffery [a,b,*]

[a] Department of Wine Science, Waite Research Institute, The University of Adelaide, PMB 1, Glen Osmond, South Australia 5064, Australia
[b] Australian Research Council Training Centre for Innovative Wine Production, The University of Adelaide, PMB 1, Glen Osmond, South Australia 5064, Australia

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ABSTRACT

The concept of wine typicity has been an important tool for the international wine trade, and especially for Old World wine producing countries, where provenance criteria are regulated and act as a quality indicator. Provenance in Australia is governed by Geographical Indications, for which typicity should also be evident in terms of regional sensory profiles of wine from a given grape cultivar. Two approaches were used to identify sensory drivers for regional typicity of commercial Cabernet Sauvignon wines from three Australian regions, namely Coonawarra, Margaret River, and Yarra Valley. Cabernet Sauvignon-dominant wines from Bordeaux were also assessed for benchmarking purposes. A set of 84 wines underwent a sorting task and rate-all-that-apply (RATA) analysis of the sorted groups with an expert panel. Agglomerative hierarchical clustering of the sorting task data did not show a clear regional driver upon separating the samples into four main clusters, although certain sensory traits could be associated with the different clusters. On the other hand, canonical variate analysis (CVA) of the group-RATA results indicated several sensory drivers for the separation between the regions, such as 'mint' and 'dark fruits' being important for Coonawarra wine profiles, 'floral' and 'green pepper' for Margaret River, 'stemmy' for Yarra Valley, and 'barnyard' and 'savoury' differentiating Bordeaux wines from the other regions.

A subset (n = 52) of wines was selected for further evaluation by descriptive analysis with a trained panel. Statistical evaluation with CVA revealed similar results to the expert evaluation, with Bordeaux wines showing more dissimilarity when compared to Australian regions, and having 'savoury' and 'earthy' as significant characters. The results also demonstrated that 'mint' and 'Mallee leaf' were relevant characters for Coonawarra regional sensory profile, 'violets' and 'red fruits' for Margaret River, and 'cooked vegetables' for Yarra Valley. Analysing both data sets (expert RATA and DA) revealed some agreement between the sets of results for attributes such as 'mint', 'cooked vegetables', 'floral', green-related characters, and oak characters like 'vanilla' and 'chocolate'. Overall, experts and trained panellists were able to distinguish regions based on a few characteristic sensory traits.

## 1. Introduction

Wine is a product shaped by extensive compositional influences ranging from raw material origins, environmental conditions, and cultivars, to viticultural and winemaking practices. Together, these influences are responsible for the high level of aroma and flavour complexity of wines, and ultimately, their typicity. The concept of typicity relates to how much a wine expresses sensory characteristics that are representative of its delimited geographical area of origin. In other words, it is driven by compositional characteristics of a wine that are influenced by grape variety and terroir (i.e., aspects including grape environment, viticulture, and winemaking practices) (Cadot et al., 2012; Drappier, Thibon, Rabot, & Geny-Denis, 2019). The typicity concept represents a class of wine that expresses its regional individuality, making it identifiable, recognisable, and differentiated (Cadot et al., 2012; Cadot, Caillé, Samson, Barbeau, & Cheynier, 2010).

For "Old World" wine producing countries of Europe, provenance and typicity are used as valuable tools to make high quality and

* Corresponding author at: Department of Wine Science, Waite Research Institute, The University of Adelaide, PMB 1, Glen Osmond, South Australia 5064, Australia.
*E-mail address:* david.jeffery@adelaide.edu.au (D.W. Jeffery).

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recognisable wines in the global market (Maitre, Symoneaux, Jourjon, & Mehinagic, 2010). They are also important for consumers that use place of origin to construct a quality expectation and make a purchase decision (Boncinelli, Casini, Contini, Gerini, & Scozzafava, 2016; Schamel, 2006). This is not only true for "Old World" wine consumers though; "New World" wine consumers also rely on place of origin indicators on wine labels (McCutcheon, Bruwer, & Li, 2009), independently of their formal involvement with wine (Johnson & Bastian, 2007). In fact, the capability of a wine to express its regionality is part of the consumer's definition of a "New World" fine wine (Kustos, Goodman, Jeffery, & Bastian, 2019). Addressing consumer expectations, the Australian wine industry, with the strategic support of Wine Australia, has been increasingly emphasising the importance of promoting regional branding, so that local styles can be easily distinguished and recognised (Wine Australia, 2015). Similarly, to other countries, viticultural regions and subregions in Australia are classified and delimited by Geographical Indications (GIs) and are protected by the Wine Australia Act 2013 (Office of Parliamentary Counsel, 2019).

The next step in increasing Australia's reputation as a fine wine producer is understanding the characteristics that typify a region and how they can be translated to the consumer (Kustos et al., 2019). Sensory characterisation of wine typicity has been undertaken in a range of studies using different types of sensory panels and methodologies. Notably, the extensive knowledge of experienced industry professionals (experts) can be used as a valuable tool to evaluate sensory profiles of wines without the necessity of time consuming training prior to evaluation (Ballester, Patris, Symoneaux, & Valentin, 2008). Indeed, researchers have been using the methodology elucidated by Ballester, Dacremont, Le Fur, and Etiévant (2005), in which an expert panel performs a typicity assessment, characterising the samples on a scale between "very bad example" and "very good example" (Canuti, Picchi, Zanoni, Fia, & Bertuccioli, 2017; Picard, Tempere, de Revel, & Marchand, 2015; Schüttler, Friedel, Jung, Rauhut, & Darriet, 2015).

On the other hand, Johnson, Hasted, Ristic, and Bastian (2013) demonstrated that a sorting task can also be used to characterise wine typicity profiles using an expert panel. However, possible downsides to using experts include accommodating their availability and the difficulty in replacing panellists if necessary. There is also the more tedious but information-rich process of undertaking descriptive analysis (DA) as described by Lawless and Heymann (2010), in which a sensory panel of 8–12 participants is trained to specifically describe the samples in question with the definition of precise descriptors. In contrast, a noteworthy rapid sensory assessment method is known as rate-all-that-apply (RATA), in which around 50 untrained panellists rate attributes found in the samples from a set list of descriptors (Danner et al., 2018; Meyners, Jaeger, & Ares, 2016). According to Danner et al. (2018), RATA methodology can generate comparable information to DA with a trained panel. Whichever sensory methodology is used, sensory characters can potentially be correlated with the presence of single or multiple compounds, as reported by Botha (2010), Robinson et al. (2011), and Kustos et al. (2020), for example.

With the aim of defining unique regional sensory traits of Cabernet Sauvignon wines from different Australian GIs, a combination of sensory approaches was used with experts and a trained panel. Commercially available wines from Coonawarra, Yarra Valley, and Margaret River were assessed alongside a selection of wines from Bordeaux, France for benchmarking. In total, 84 wines were evaluated by experts using a sorting task and a variant of RATA was performed on the sorted groups. A subset of wines (n = 52) was then profiled using DA, to further assess whether certain sensory attributes could be assigned to a regional Cabernet Sauvignon wine sensory signature for the different Australian GIs. Sensory profiles arising from experts and the trained panel were examined together to identify and verify the common drivers of regional typicity.

## 2. Material and methods

### 2.1. Expert panel sorting task with modified RATA characterisation of wine groups (group-RATA)

#### 2.1.1. Sample selection

Commercially available Cabernet Sauvignon wines were selected from Coonawarra (n = 34; **a1**-**a36**), Margaret River (n = 20; **b1**-**b20**), Yarra Valley (n = 20; **c1**-**c21**), and Bordeaux (n = 10; **d1**-**d10**) based on the criteria detailed previously (Souza Gonzaga, Capone, Bastian, Danner, & Jeffery, 2019). The Bordeaux wines were from the left bank and included the appellations St-Jullien, Pauillac, Margaux, St-Estephe, and Haut-Medóc (Appendix A, Table S1). These wines were selected based on wine writer reviews, being from a single vintage (2015), with a retail price ranging from AU$20 to AU$150, and consisting of a minimum of 60% Cabernet Sauvignon for the Bordeaux wines (Appendix A, Table S1) or a minimum of 85% for the Australian wines. Due to the large sample size it was not possible to assess each of the wines more than once, except for the duplicate samples of two wines that were selected for assessment from separate bottles (a12 and a31; c14 and c21). Sample a2 was excluded prior to sensory assessment because it had not arrived in time. Basic chemical measurements (Appendix A, Table S2) including pH, titratable acidity (TA), alcohol content, total phenolics, and total anthocyanins, were undertaken previously (Ranaweera, Gilmore, Capone, Bastian, & Jeffery, 2021).

#### 2.1.2. Sensory analysis

The sensory analysis was performed by a panel of 11 (4 females, 7 males) senior winemakers and/or experienced wine show judges from Australia who met the definition of an expert according to Parr, White, and Heatherbell (2004). More specifically, they had tertiary qualifications in winemaking, were constantly involved with wine production and tasting, and were researchers in wine science or senior professionals of the wine industry.

The panel was well acquainted with tasting Cabernet Sauvignon wines and had experience in being able to evaluate dozens of wines in one sitting by virtue of their profession. Other details of the sensory procedure were reported previously (Souza Gonzaga et al., 2019). Briefly, clear IXL5 wine glasses randomly coded with a three-digit number were used to serve 20 mL of each sample, with the 84 wines randomised into two sets; one set contained 40 wines and the other had 44 wines. Samples within each set were randomly presented to each panellist and 90 min per set was allocated, with a 20-min break and light refreshments provided between each set. This was a blind tasting, but prior to beginning, panellists were informed of the number of samples and received instructions about the sensory tasks to be performed. However, they were not informed about the wine selection criteria and regions chosen for the evaluation.

First the panel was asked to taste the wine and write down tasting notes using their own words for each sample, as reported previously (Souza Gonzaga et al., 2019), to support their first assignment. This involved a sorting task, in which the panel was instructed to sort the samples based on their sensory similarities into as many groups as they found necessary. After a lunch break, the second assignment used a variant of the RATA methodology (Danner et al., 2018), conducted on a sorted group as a whole, rather than on individual wines within the group. RATA with experts has been applied previously with a similar number of panellists (Franco-Luesma et al., 2016; Sáenz-Navajas, Ferrero-del-Teso, Jeffery, Ferreira, & Fernández-Zurbano, 2020). RATA was performed over 90 min after all samples had been tasted and sorted into their respective groups. Panellists received a list of 34 attributes (25 aroma/flavour, 3 taste, and 6 mouthfeel descriptors) common to red wine and adapted from in-house experience, and were instructed to rate (5-point scale) only the attributes that applied for each of the groups they had formed from the 84 wines (Appendix A, Table S3). The data from the experts were collected on paper and transcribed into an electronic version.

### 2.2. Descriptive analysis (DA)

#### 2.2.1. Sample selection

From among the sample set outlined in Section 2.1.1, a subset of 52 wines was selected to undergo further sensory evaluations as detailed in Table 1.

#### 2.2.2. Sensory analysis

The sensory evaluation was performed by 10 panellists (ranging from 25 to 65 years of age, 3 males and 7 females) that were recruited on the basis of their availability and their red wine consumption behaviour. The panel assessed the 52 wines after a consensus training method (Lawless & Heymann, 2010). Prior to formal sample evaluation, the panel went through 9 × 2 h training sessions, 3 times a week. This involved basic taste detection and scaling, and detection and intensity rating of aroma/flavour attributes in the wine samples. Practice evaluation sessions were conducted in sensory booths under the same conditions used during the formal sample evaluation. Data were evaluated after each practice session in order to determine when formal sample evaluation should commence. The panel settled on using 20 aromas, 22 flavours, and 3 mouthfeel attributes (Appendix A, Table S4), with the addition of 'Overall aroma', 'Overall flavour', 'Overall fruity aroma', 'Overall fruity flavour' attributes.

During formal sample evaluations, each sample was presented in duplicate throughout 9 sessions of 2 h, with 12 samples being presented in each session (with the exception of the last session that was composed of eight wines). Breaks of 60 s were enforced after each sample, and a 10 min break was enforced after six samples. Black stemmed ISO wine glasses were randomly coded with a four-digit number and used to serve 20 mL of each sample, covered by a petri dish. Samples were randomly presented to each panellist in individual tasting booths at 22–23 °C, and rated on a 100-point line scale with the anchor points 'low' and 'high' located at 10 and 90% from the left hand end of the scale, respectively. Aroma reference standards were provided for each formal sample evaluation session in covered black glasses and panellists were required to reacquaint themselves with the standards. Distilled water, crackers and plain lactose-free yoghurt were provided as palate cleansers. All sensory data were collected using Red Jade software (2016, Redwood City, USA). Informed consent was obtained from panellists and this study was approved by the Human Research Ethics Committee of the University of Adelaide (approval number: H-2019-031).

### 2.3. Statistical analysis

The sorting task data had to be prepared before statistical analysis. The groups formed by each panellist were transformed into a similarity matrix where the number inside the matrix represented how many times an individual sample in the column was grouped together with an individual sample in the row. The raw RATA data was based on the groups formed by each panellist, but for analysis purposes the results were assigned to each wine sample within a group. Prior to statistical analysis, 4 of the 34 original attributes were excluded from further analysis because they were absent in more than 60% of the cases.

The sorting task similarity matrix was firstly analysed with multidimensional scaling (MDS) using an absolute model and Kruskal's stress value, and then by agglomerative hierarchical clustering (AHC) with automatic truncation using unweighted pair-group average (UPGMA) or Ward clustering methods. Two-way analysis of variance (ANOVA) with panellists as random factor and samples as fixed factor was performed with the raw RATA data so that significantly different attributes could be identified. For the rest of the analyses, only the mean values of the attributes that had a p-value $\leq 0.1$ (according to the ANOVA results) were used. Using a significance level of $\alpha = 0.1$ was deemed suitable for the distinction of the attributes due to the large group of samples that were assessed by a small number of panellists, and due to the sensory nature of this study (Bower, 1995). With the clusters established by AHC in combination with the results from RATA of the groups, a covariance principal component analysis (PCA) was performed to reveal the sensory drivers for the clustering found by AHC. Lastly, canonical variate analysis (CVA) (i.e., discriminant analysis function in XLSTAT) was performed with the RATA results of the samples within the groups in order to test for any sensory pattern within the regions. During DA training sessions, the panel performance was evaluated using PanelCheck (Nofima Mat and DTU – Informatics and Mathematica Modelling, Norway, version 1.4.2). A mixed model two-way ANOVA with panellists as random effects and samples as fixed effect was performed with the DA data and attributes that had a p-value $\leq 0.1$ were considered for further analysis. CVA was performed with the significantly different attributes ($\alpha = 0.1$) so that the discrimination between regional profile could be evaluated and compared with the expert panel data results. All statistical analyses were performed with XLSTAT (Addinsoft, New York, USA, version 2019.4.1).

**Table 1**
Subset of 52 wines that underwent assessment by descriptive analysis.

| Wine region | Wine codes |
|---|---|
| Coonawarra | a3, a5-a14, a16-a18, a20-a29, a35, a36 |
| Margaret River | b1-b5, b8, b12, b13, b15, b19 |
| Yarra Valley | c1, c4, c6, c7, c10, c11, c13-c19, |
| Bordeaux | d1, d7, d8, d9, d10 |

## 3. Results and discussion

### 3.1. Wine clustering of the expert sorting task

MDS and AHC were selected as appropriate methods to analyse the type of data acquired through the approach used in section 2.1 because they are qualitative statistical modelling methods that can measure the proximity of the points to obtain the similarities of the wine samples (Lawless, Sheng, & Knoops, 1995). These methods also give insights into the clusters and/or categories based on the product differences (Lawless et al., 1995). UPGMA and Ward were chosen as the clustering methods for AHC, with cophenetic correlation coefficients used to gauge how well the dendrograms represented the input data (Hale & Dougherty, 1988).

The similarity matrix from the expert sorting task of 84 wines (and duplicates for two wines) underwent MDS to visualise the similarities among regional wines, but the data (not shown) had a poor goodness of fit, with Kruskal's stress values of 0.383 and 0.270 for the first and second dimensions of the model, respectively (Kruskal, 1964). The model only started having a fair fit with the ninth dimension (Kruskal's stress no. = 0.095), meaning that this was not the best approach to analyse the separation between the samples (data not shown). This result could be a consequence of the large number of samples and small number of panellists who could create as many groups as they liked, resulting in a limited number of matches. However, Johnson et al. (2013) were able to achieve better results using the same MDS approach and a similar number of panellists and samples in a study of commercial Australian Shiraz wines, and the same applied for studies by Ballester et al. (2005), Ballester et al. (2008), and Parr, Green, White, and Sherlock (2007). Listening to the post evaluation discussion, it was likely that the commercial wines in the present study had sensory profiles that were not so distinct from one other, potentially making it harder to classify them into discrete groups. In addition, the criteria used by the panel members to create groups had great differences between them.

As an alternative to MDS, AHC was undertaken with the same similarity matrix using UPGMA in preference to Ward's method (cophenetic correlation coefficients of 0.551 and 0.354, respectively), generating a dendrogram and grouping the samples into four main clusters using automatic truncation that considers the most homogenous groups (Fig. 1). Cluster 1 (in blue) consisted of 6 samples from Bordeaux and 2 from Yarra Valley. Cluster 2 (in red) had 1 sample from Bordeaux, 12 from Yarra Valley, 21 plus 1 replicate (a12 and a31) from Coonawarra, and 9 from Margaret River. Cluster 3 (in green) was composed of 1 sample from Bordeaux, 5 plus 1 replicate (c14 and c21) from Yarra Valley, 7 from Coonawarra, and 5 from Margaret River. Cluster 4 (in purple) encompassed 2 samples from Bordeaux, 1 from Yarra Valley, 6 from Coonawarra, and 6 from Margaret River. The duplicates included in the evaluation were both paired together in their respective cluster, which implied that the panel grouped them relatively consistently, even if they were not the most similar within a cluster in terms of proximity. In line with the MDS results, regions were not clearly separated from each other by AHC, and apart from cluster 1, which was mainly composed of Bordeaux wines, there did not appear to be a clear regionality dominance within the clusters. However, calculation of relative percentages (data not shown) revealed that cluster 4 had a dominance of Margaret River wines, cluster 2 had similar relative amounts of wines from Yarra Valley and Coonawarra, and cluster 3 of Yarra Valley and Margaret River wines.

Similar results were found for Australian Shiraz wines assessed with a sorting task, in which a definitive regional profile was not evident for all regions under consideration (Johnson et al., 2013). The same can be said of the results from Kustos et al. (2020), in which a different methodology was used to evaluate the regionality of Australian Chardonnay and Shiraz wines. It was proposed that different winemaking processes likely had a greater impact than the regionality of the wine, and that geographical origin was not sufficient to characterise their regional typicity (Kustos et al., 2020). The segregation of most of the samples coming from Bordeaux in cluster 1 in the present study could be a consequence of assessing Old World wines with New World wines (Remaud & Couderc, 2006), and a certain distinctiveness of Bordeaux wines, taking into account differences in climate between the Australian regions and Bordeaux (Baciocco, Davis, & Jones, 2014). In addition, the Bordeaux samples were composed of red blends with a smaller proportion of Cabernet Sauvignon compared to the Australian counterparts.

### 3.2. *Sensory characterisation of the wine clustering using RATA data*

Clustering results from AHC underwent PCA with the outcomes from RATA conducted by each expert on their groups. From the 30 RATA attributes, 21 were found to be significantly discriminating (two-way ANOVA, $\alpha = 0.1$) and were included in the analysis (Fig. 2).

A total of almost 85% of the variance was explained with the first two principal components, with F1 representing 47.56% and F2 accounting for 37.32%. Cluster 1 was characterised by the higher ratings for developed characters like 'dried fruits', 'woody', 'barnyard', 'leather', and 'savoury', and by the lack of green characters like 'herbaceous', 'mint' and 'green pepper'. Cluster 2 was composed of wines with aroma and flavour attributes of 'dark fruits', with the presence of 'floral' traits (especially of 'blue flowers') and 'mint', along with 'fine tannin' and 'full body' mouthfeel. The group of wines in cluster 3 were characterised with lower ratings for the fruit and floral descriptors found in cluster 2, and having some presence of vegetative attributes like 'stemmy' and 'cooked vegetables'. Cluster 4 was related to green characters including 'green pepper' and 'herbaceous', and like cluster 2, had some presence of 'mint' aroma/flavour attribute. The results for cluster 1 agreed with a previous study by Souza Gonzaga et al. (2019), which also reported that 'savoury' and 'leather' were important attributes for Bordeaux wines, and with Picard et al. (2015) who demonstrated 'truffle', 'toasted', and 'spicy' as being important for the ageing development of Bordeaux wine aroma profile. Overall, the allocation of the attributes showed similar conclusions to Heymann and Noble (1987), as discussed in more detail in Section 3.5. This result could indicate that although the wines in a given cluster might not share characteristics associated with terroir of the regions, they do display some intrinsic traits that might arise from common factors (e.g., varietal traits, winemaking and viticultural practices), as noted by Kustos et al. (2020) in a study involving the geographical origin of Australian Chardonnay and Shiraz wines. It could also indicate the existence of a common sensory style that wineries tend to aim for, although further research under controlled winemaking conditions would be necessary to confirm these hypotheses.

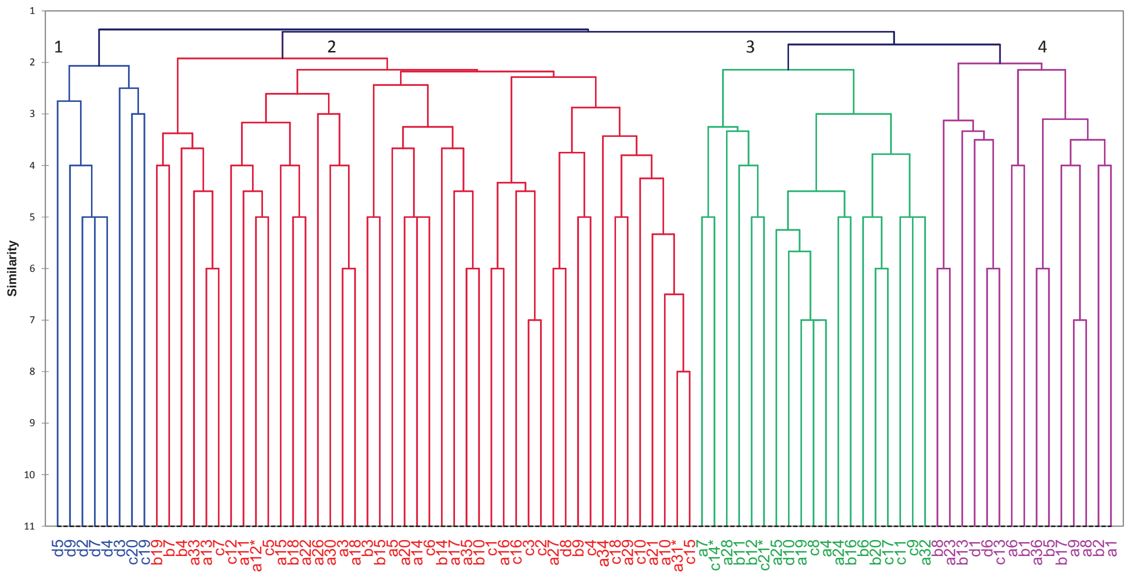


**Fig. 1.** Agglomerative hierarchical clustering (using UPGMA as the agglomeration method) dendrogram of 84 Cabernet Sauvignon wines (and two replicates) grouped by similarity according to the expert sorting task. Cluster 1 is shown in blue, cluster 2 in red, cluster 3 in green, and cluster 4 in purple, with replicates indicated by an asterisk. See Section 2.1.1 for sample codes. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

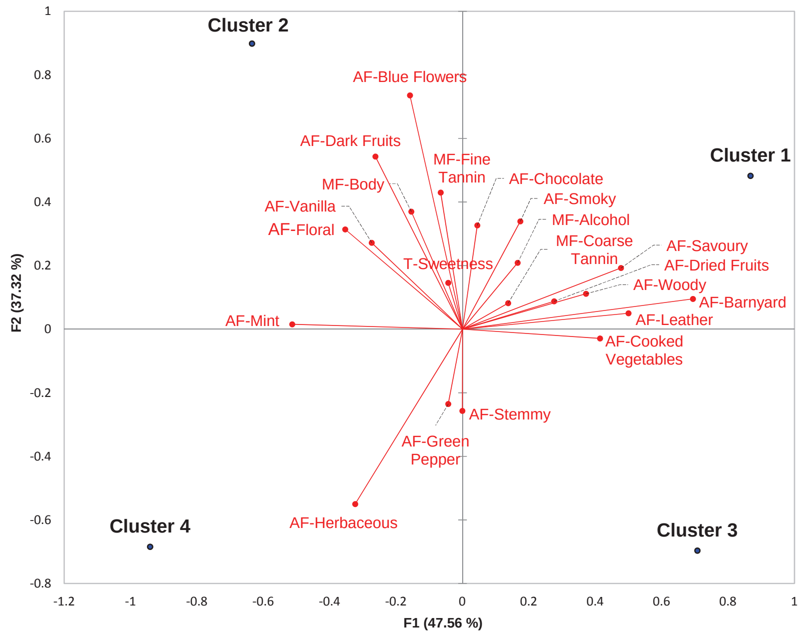


**Fig. 2.** Principal component analysis biplot of significant RATA attributes (in red) in combination with the agglomerative hierarchical clustering results. AF, aroma/flavour; T, taste; MF, mouthfeel. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

### *3.3. Regional characteristics based on RATA sensory profiles*

Using the same 21 significantly different attributes ($\alpha = 0.1$) mentioned in Section 3.2, CVA was performed to explore whether a regional profile might be present according to the RATA data from the experts. The CVA results in Fig. 3 reveal that a total of 87.5% of the variance within the sensory data space was explained by F1 (72.35%) and F2 (15.15%). Fig. 3a illustrates how the regions of the 84 wines can be graphically represented, showing that Bordeaux wines were the most distinctive when compared to the Australian regions, resolving along F1. Within the Australian regions, Yarra Valley and Margaret River wines had a degree of overlap and were more similar than Coonawarra wines, which separated along F2. The replicated samples were relatively distant from each other, which might indicate that the panel had difficulties in replicating their profiling assessment with such a large set of wines. Considering the region centroids in Fig. 3a, Bordeaux wines were characterised by more developed and oak-related characters such as ‘barnyard’, ‘woody’, ‘smoky’, ‘fine tannin’, ‘savoury’, and ‘leather’

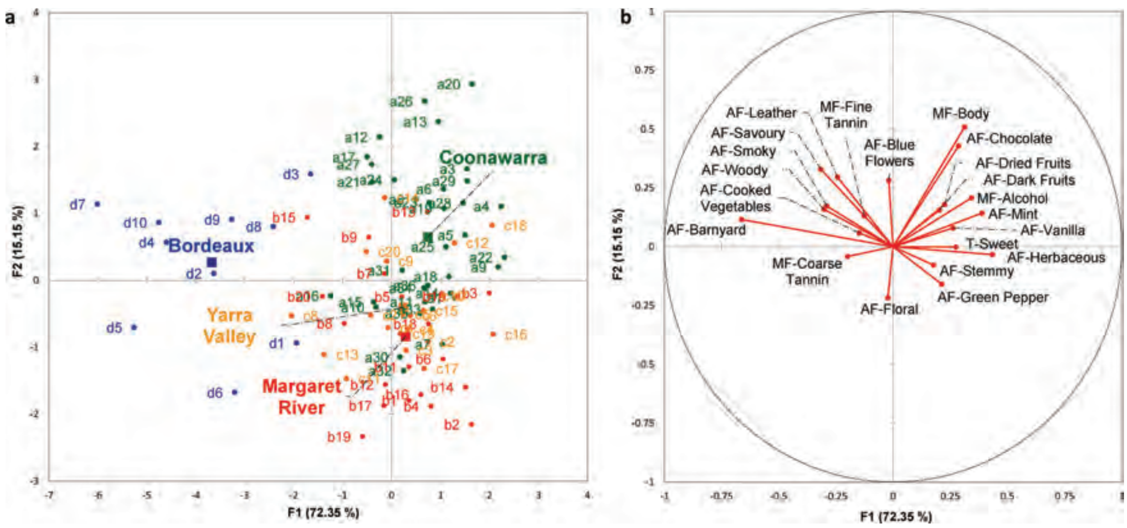


**Fig. 3.** Canonical variate analysis plots of the RATA results from experts using the wine regions as variables showing (a) region centroids with square markers, Coonawarra samples in green, Margaret River samples in red, and Yarra Valley samples in orange, and Bordeaux samples in blue, and (b) significantly different sensory attributes ($\alpha = 0.1$); AF, aroma/flavour; T, taste; MF, mouthfeel. See Section 2.1.1 for sample codes. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(Fig. 3b). The oak-related characters were deemed related to the maturation regime that the wines underwent, as discussed in more detail in Section 3.4. The same applied for the developed characteristics in terms of maturation technique. Bordeaux samples d1 and d8 that grouped separately from cluster 1 (mainly composed of Bordeaux wines, Fig. 1) were from the appellations of St-Julien and Margaux and among the few Bordeaux wines that were plotted closer to the Australian samples (Fig. 3a), indicating they had a sensory profile that was more similar to the Australian wines. Coonawarra wines were generally related to fruity and sweet characters like 'chocolate', 'dried fruits, 'dark fruits', and 'mint', along with a higher perception of 'body'. Yarra Valley and Margaret River wines were broadly characterised by green characters such as 'green pepper', 'stemmy', and 'herbaceous', but also to an extent by sweet taste, 'vanilla', 'mint', and some fruity traits, especially for Yarra Valley. Green-related characters in Cabernet Sauvignon can typically be associated with the presence of 3-isobutyl-2-methoxypyrazine (IBMP), a character impact odorant with a very low odour detection threshold (Noble, Elliott-Fisk, & Allen, 1995). Concentrations of IBMP in grape and wine are largely influenced by viticultural practices and vineyard environmental conditions (Sala, Busto, Guasch, & Zamora, 2004, 2005). This may explain the presence of green characters in wines from Yarra Valley GI as it is characterised by a lower heat summation and cooler mean January temperature than the other Australian regions in this study (Wine Australia, 2019).

### 3.4. Regional characteristics based on DA results

From the attribute list generated during the DA panel training (Appendix A, Table S4), 10 aroma and 9 flavour attributes differed significantly (two-way ANOVA, α = 0.1) among the wines (Appendix A, Table S5). These significant attributes were used for CVA with regions as variables in order to identify any regional profile from the DA data. The plots shown in Fig. 4 explained a total of 88.16% of the variance along F1 (59.97%) and F2 (28.19%), with Fig. 4a demonstrating how the samples and regions can be graphically explained and Fig. 4b showing the sensory attributes. Considering the region centroids in Fig. 4a, the same trend was evident as described in Section 3.3, namely that Bordeaux wines were more distinguishable than the Australian wines along F1, although there was less overlap between the Australian regions with DA compared to the expert RATA. This time, Coonawarra wines clearly differed from Yarra Valley wines, and Margaret River wines were located between both regions along F2, having some characteristics that were similar to wines from Coonawarra and Yarra Valley.

Bordeaux wines were characterised by more developed and complex aromas such as 'tobacco', 'savoury', 'earthy', and 'yeasty', along with 'chocolate/vanilla' aroma, and 'savoury' and 'yeasty' flavours (Fig. 4b). Bordeaux wines were also generally perceived to be lower in 'floral' and fruity flavour attributes. Together these observations accorded with a study by Botha (2010) that suggested the presence of 'savoury' attributes could suppress the perception of fruity ones. Coonawarra wines were described as having a 'mint' aroma and 'green', 'chocolate/vanilla', and 'Mallee leaf' flavours, and were rated relatively low in 'cooked vegetables' aroma and flavour. 'Mallee leaf' or 'eucalyptus' character in wines is commonly associated with the presence of 1,8-cineole, a volatile compound that is often correlated with *Eucalyptus* trees adjacent to vineyards (Capone, Jeffery, & Sefton, 2012). The proximity of vineyards close to these species of trees is a common scenario for many Australian vineyards but also found in other places such as California and South Africa. Exploring the consumer rejection threshold of 1,8-cineole in red wine, Saliba, Bullock, and Hardie (2009) found that only at relatively high levels (i.e., around 25 times above threshold) is it considered a negative attribute; at moderate intensities it should not be considered a fault, and might even be preferred by some consumers in comparison to wines without any 'eucalyptus' character. Indeed, some consumer clusters appeared to prefer the 'eucalyptus' attributes at an elevated concentration (Osidacz et al., 2010).

Margaret River wines displayed various fruity aromas along with 'violets' and 'floral' aroma attributes and were less associated with oak-derived or developed characters like 'chocolate/vanilla' and 'tobacco' compared to Coonawarra and Bordeaux wines. The same applies to Yarra Valley wines in terms of the influence of oak and developed aromas/flavours. This result could imply that the Margaret River and Yarra Valley wines generally had a different oak regime compared to Bordeaux or Coonawarra wines. Attributes such as 'chocolate/vanilla' and 'tobacco' are important characteristics for winemakers to consider when deciding on an oak regime, as well as the origin of the raw material

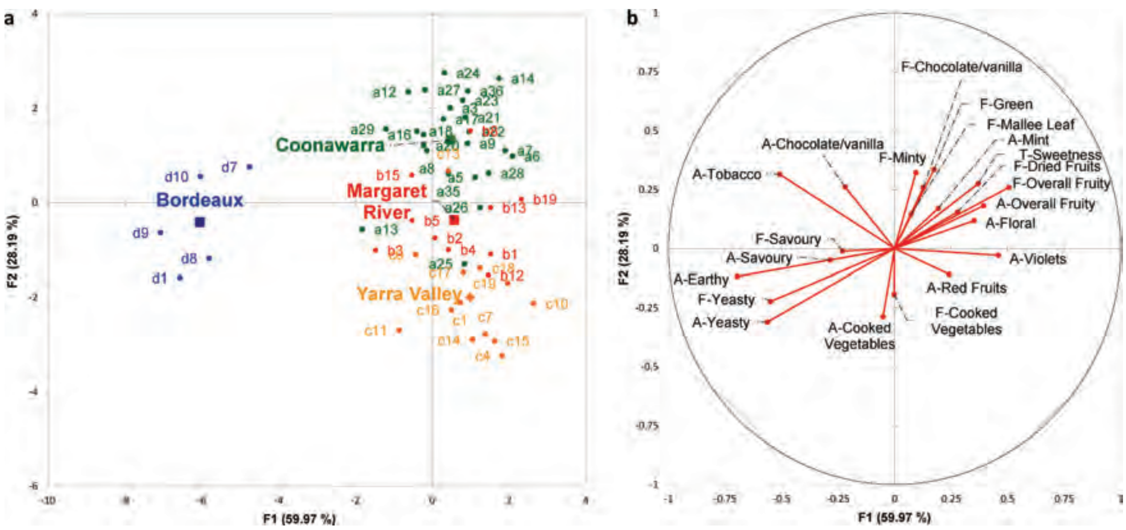


**Fig. 4.** Canonical variate analysis plots for the DA results of 52 Cabernet Sauvignon wines using the regions as variables showing (a) region centroids with square markers, Coonawarra samples in green, Margaret River samples in red, and Yarra Valley samples in orange, and Bordeaux samples in blue, and (b) significantly different sensory attributes (α = 0.1). A, Aroma; F, Flavour; T, taste. See Section 2.2.1 for sample codes. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and its prior treatment (Crump, Johnson, Wilkinson, & Bastian, 2015; Francis, Sefton, & Williams, 1992). Additionally, for Yarra Valley wines, attributes like 'cooked vegetables' aroma/flavour and 'red fruits' aroma were rated relatively higher, with the latter potentially being indicative of earlier harvest wines (Bindon et al., 2014), or in case of the 'cooked vegetables', the presence of dimethyl sulfide (DMS) (Segurel, Razungles, Riou, Salles, & Baumes, 2004).

### 3.5. Attributes in agreement between the expert RATA and descriptive analysis panel data

Comparing Fig. 3 and Fig. 4 it is possible to assess the extent of agreement between the experts and trained panel. Due to differences in terms of the data collection, sensory procedures, and panel composition, it could be expected that some differences in the assignment of attributes would be found, but both panels concurred when evaluating attributes such as, 'mint', 'cooked vegetables', 'floral', other green-related characters such as 'green pepper' and 'herbaceous', and oak-associated characters like 'vanilla' and 'chocolate'. In terms of the regions, it was evident that both sensory approaches agreed that 'savoury' and 'cooked vegetables' appeared commonly to describe wines from Bordeaux and Yarra Valley, whereas 'mint' was important for Coonawarra wines, and 'floral' for Margaret River wines.

With a desire to understand the notion of sensory attributes driving regional differences, Heymann and Noble (1987) applied sensory assessment to evaluate California Cabernet Sauvignon wines from different regions. Their results showed similarities with the present study, with fruity traits being contrasted by 'green' attributes, and oak-related characters being opposed to the 'eucalyptus' attribute (Heymann & Noble, 1987). From an Australian perspective, Robinson et al. (2012) investigated regional Cabernet Sauvignon wines, which revealed sensory properties having a similar impact in terms of regionality as identified in the current work. It was also evident from Robinson et al. (2012) and Souza Gonzaga et al. (2019) that a 'mint' attribute may be important for Coonawarra wines, although the chemical compound that correlates with this sensory character still requires elucidation.

Robinson et al. (2011) found that 'mint' and 'eucalyptus' aromas were correlated with the presence of eucalyptol (i.e., 1,8-cineole) and hydroxycitronellol, but the two sensory attributes could not be distinguished by the panel. The same could be seen in the present study, in which 'Mallee leaf' and 'mint' appear in close proximity (Fig. 4), indicating that expert and DA panels evaluated those attributes in the same manner. In another study, Picard et al. (2015) found nuances of mint aroma associated with the aroma of aged red blends from Bordeaux, with further investigation associating this trait with the volatile compound piperitone (Picard, Lytra, et al., 2016). Picard, Tempere, de Revel, and Marchand (2016) further showed that the levels of piperitone were connected with the proportion of Cabernet Sauvignon in the blend and were related to geographical origin within the Bordeaux region. Given that 'mint' seems to be an important regional character for some Cabernet Sauvignon wines, further research is necessary to understand chemical drivers of this attribute in Australian red wines, along with its origin and consumer preferences.

The expert and trained DA panels (Fig. 3 and Fig. 4) seemed to evaluate Margaret River wines similarly and agreed that 'floral' was an important trait for the sensory profile of those wines. As a broader term, 'floral' cannot usually be associated with a single chemical compound, and Robinson et al. (2011) found the trait to be related to the presence of sesquiterpenoids, $C_{13}$-norisoprenoids, and monoterpenoids. Further chemical investigation of Cabernet Sauvignon wines would be required to confirm the drivers for the 'floral' trait. The 'savoury' attribute was also found to be in agreement between the two panels (Fig. 3 and Fig. 4), and was meaningful for Yarra Valley and Bordeaux wines. Although not necessarily the sole driver, a 'savoury' character could be associated with *Brettanomyces* presence during winemaking and a result of the production of the volatile phenol 4-ethyphenol (Botha, 2010).

## 4. Conclusion

The expert sorting task designed for this study did not lead to a clear regional driver that explained the differences between samples from different GIs using either MDS or AHC. This outcome could have been impacted by the disparity between the number of samples and number of panellists and differences between the criteria each panellist used to form their groups. It could be valuable in future investigations to undertake a comparative study using the current approach and one where the groups have been pre-defined according to region. Nonetheless, from RATA conducted on the groups determined by the experts, the general sensory profile used to separate the samples became evident using PCA to evaluate the data. Thus, four main groups of sensory attributes arose: developed and non-fruit like characters (including 'dried fruits', 'savoury' and 'smoky'), fruity and floral characters, fresh green-related characters (containing 'green pepper' and 'herbaceous'), and vegetative characters (profiles between 'cooked vegetables' and 'stemmy') with a lack of fruity and floral characters.

Through CVA based on the regions, both the trained DA panel and expert sorting task methods showed a clear separation between the Bordeaux samples and the Australian counterparts. Among the three Australian regions, the sensory profile of the wines from Margaret River were deemed to be closer to the profile found for the Yarra Valley wines. Evaluating the agreement between the expert RATA and DA results demonstrated that although there was a level of disagreement, some attributes were commonly evaluated by the two sensory cohorts despite the differences in methodology. In general for Coonawarra, 'minty' arose as an important characteristic, whereas 'floral' was seemingly representative of Margaret River wines, and 'savoury/cooked vegetables' appeared to typify wines from Bordeaux and Yarra Valley. Together, the results implied that certain sensory attributes could be good indications of the sensory typicity of the regions in question.

Undertaking sensory evaluation with different methodologies can be an important tool when dealing with a complex sample matrix like wine and with a multifaceted concept like typicity. Exploring wine expert knowledge with a sorting task and using a trained panel to perform DA of a subset of the same wines has shown some variability amongst the results, but also indicated some sensory tendencies of each of the evaluated regions. As a limitation, little was known about the oenological processes associated with the wines, so further research is required to control the winemaking and viticultural practices to advance the understanding of the importance of the sensory drivers of Australian Cabernet Sauvignon wine typicity.

Overall, this multicomponent sensory study helped verify the outcomes presented previously (Souza Gonzaga et al., 2019) and also offered an understanding for the Australian industry about how typicity may be represented in the sensory space for Cabernet Sauvignon wines from different regions. This knowledge can serve as a tool for the Australian wine industry to be able to promote regional style and harness the unique identities of the regions to accommodate consumer needs and expectations. With that in mind, there is still an opportunity for studies that explore consumer knowledge with regard to regional typicity and preferences for wines whose sensory profiles may be representative of the region.

## Credit authorship contribution statement

**Lira Souza Gonzaga:** Conceptualisation, Data curation, Formal analysis, Investigation, Methodology, Visualisation, Writing - original draft, Writing - review & editing. **Dimitra L. Capone:** Conceptualisation, Methodology, Supervision, Writing - review & editing. **Susan E.P. Bastian:** Conceptualisation, Funding acquisition, Methodology, Resources, Supervision, Writing - review & editing. **Lukas Danner:** Methodology, Supervision, Writing - review & editing. **David W. Jeffery:** Conceptualisation, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing - review & editing.

**Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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**Appendix A. Supplementary material**

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodres.2020.109760.

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# SUPPLEMENTARY INFORMATION FOR

## Sensory typicity of regional Australian Cabernet Sauvignon wines according to expert evaluations and descriptive analysis

Lira Souza Gonzaga[a,b], Dimitra L. Capone[a,b], Susan E. P. Bastian[a,b], Lukas Danner[a], David W. Jeffery[a,b]*

[a] Department of Wine Science, and Waite Research Institute, The University of Adelaide, PMB 1, Glen Osmond, South Australia 5064, Australia

[b] Australian Research Council Training Centre for Innovative Wine Production, The University of Adelaide, PMB 1, Glen Osmond, South Australia 5064, Australia

* Corresponding author.

*Email address*: david.jeffery@adelaide.edu.au (D.W. Jeffery)

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**Table S1.** Sample code, appellation and composition of the blend for Bordeaux wines used for the sorting task.

| Sample code | Appellation | Blend |
|---|---|---|
| d1 | St-Julien | 75% Cabernet Sauvignon, 17% Merlot, 8% Cabernet Franc |
| d2 | Cantenac-Margaux | 65% Cabernet Sauvignon, 35% Merlot |
| d3 | Pauillac | 72% Cabernet Sauvignon, 28% Merlot |
| d4 | St-Julien | 60% Cabernet Sauvignon, 30% Merlot, 4% Cabernet Franc, 6% Petit Verdot |
| d5 | St-Estephe | 60% Cabernet Sauvignon, 30% Merlot, 6% Cabernet Franc, 4% Petit Verdot |
| d6 | St-Julien | 66% Cabernet Sauvignon, 27% Merlot, 7% Petit Verdot |
| d7 | St-Julien | 60% Cabernet Sauvignon, 30% Merlot, 4% Cabernet Franc, 6% Petit Verdot |
| d8 | Margaux | 70% Cabernet Sauvignon, 25% Merlot, 5% Petit Verdot |
| d9 | Pauillac | 72% Cabernet Sauvignon, 28% Merlot |
| d10 | Haut-Medoc | 60% Cabernet Sauvignon, 30% Merlot, 10% Petit Verdot |

**Table S2.** Basic chemical measures of the 86 samples evaluated by the expert panel and results of one-way ANOVA based on the regions.

| Samples | pH[1] | TA[1] | Alcohol (% v/v)[2] | Total phenolics (au)[3] | | Total anthocyanins (mg $L^{-1}$)[3] | | Hue[3] | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Mean | SD | Mean | SD | Mean | SD |
| a1 | 3.61 | 5.9 | 13.8 | 63 | 2 | 124 | 11 | 0.94 | 0.00 |
| a3 | 3.58 | 5.9 | 14.2 | 70 | 3 | 139 | 9 | 0.83 | 0.00 |
| a4 | 3.54 | 6.5 | 14.3 | 72 | 2 | 82 | 3 | 0.91 | 0.01 |
| a5 | 3.60 | 6.2 | 14.6 | 76 | 2 | 160 | 6 | 0.80 | 0.00 |
| a6 | 3.56 | 6.7 | 15.9 | 46 | 1 | 80 | 8 | 0.86 | 0.00 |
| a7 | 3.52 | 5.9 | 13.7 | 63 | 3 | 130 | 11 | 0.89 | 0.00 |
| a8 | 3.55 | 6.5 | 13.5 | 67 | 3 | 88 | 20 | 0.89 | 0.00 |
| a9 | 3.60 | 5.8 | 13.6 | 64 | 1 | 100 | 3 | 1.00 | 0.00 |
| a10 | 3.57 | 5.8 | 13.8 | 62 | 2 | 135 | 11 | 0.79 | 0.00 |
| a11 | 3.60 | 6.1 | 14.7 | 79 | 2 | 145 | 15 | 0.83 | 0.00 |
| a12 | 3.59 | 5.5 | 14.4 | 74 | 3 | 132 | 8 | 0.80 | 0.00 |
| a13 | 3.54 | 6.0 | 14.0 | 73 | 3 | 148 | 13 | 0.86 | 0.01 |
| a14 | 3.67 | 5.7 | 14.5 | 64 | 2 | 144 | 14 | 0.84 | 0.00 |
| a15 | 3.57 | 5.8 | 13.7 | 65 | 3 | 138 | 10 | 0.89 | 0.00 |
| a16 | 3.49 | 5.7 | 13.6 | 63 | 2 | 110 | 3 | 0.87 | 0.00 |
| a17 | 3.64 | 5.9 | 13.9 | 65 | 3 | 158 | 20 | 0.85 | 0.00 |
| a18 | 3.47 | 7.3 | 13.5 | 80 | 3 | 94 | 6 | 0.89 | 0.00 |
| a19 | 3.65 | 5.8 | 14.2 | 73 | 4 | 93 | 9 | 0.94 | 0.00 |
| a20 | 3.54 | 6.2 | 13.5 | 74 | 2 | 149 | 16 | 0.83 | 0.00 |
| a21 | 3.63 | 5.4 | 13.7 | 77 | 3 | 117 | 5 | 0.88 | 0.01 |
| a22 | 3.62 | 5.8 | 13.4 | 69 | 2 | 120 | 5 | 0.89 | 0.00 |
| a23 | 3.34 | 7.7 | 14.4 | 63 | 2 | 94 | 5 | 0.91 | 0.00 |
| a24 | 3.51 | 6.7 | 14.1 | 80 | 3 | 125 | 3 | 0.88 | 0.00 |
| a25 | 3.60 | 5.5 | 14.0 | 67 | 2 | 145 | 9 | 0.92 | 0.00 |
| a26 | 3.53 | 5.8 | 13.9 | 70 | 1 | 125 | 6 | 0.81 | 0.00 |
| a27 | 3.60 | 6.0 | 13.9 | 71 | 3 | 202 | 15 | 0.83 | 0.00 |
| a28 | 3.54 | 6.1 | 13.6 | 74 | 2 | 91 | 6 | 0.88 | 0.00 |
| a29 | 3.54 | 6.1 | 14.5 | 62 | 3 | 113 | 12 | 0.88 | 0.00 |
| a30 | 3.40 | 6.8 | 14.2 | 69 | 1 | 99 | 6 | 0.88 | 0.00 |
| a31 | 3.61 | 5.6 | 14.5 | 74 | 2 | 142 | 7 | 0.80 | 0.00 |
| a32 | 3.57 | 6.2 | 14.6 | 73 | 3 | 92 | 10 | 0.92 | 0.00 |
| a33 | 3.67 | 6.0 | 13.9 | 64 | 3 | 156 | 10 | 0.90 | 0.00 |
| a34 | 3.44 | 6.3 | 14.0 | 69 | 2 | 79 | 7 | 0.81 | 0.00 |

**Table S2. contd.**

| Samples | pH[1] | TA[1] | Alcohol (% v/v)[2] | Total phenolics (au)[3] | | Total anthocyanins (mg L$^{-1}$)[3] | | Hue[3] | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Mean | SD | Mean | SD | Mean | SD |
| a35 | 3.55 | 6.1 | 14.0 | 71 | 2 | 139 | 24 | 0.78 | 0.00 |
| a36 | 3.66 | 5.9 | 14.9 | 72 | 9 | 213 | 45 | 0.87 | 0.00 |
| b1 | 3.62 | 6.1 | 14.4 | 48 | 1 | 83 | 10 | 0.90 | 0.01 |
| b2 | 3.82 | 5.1 | 13.8 | 62 | 1 | 141 | 7 | 0.89 | 0.01 |
| b3 | 3.70 | 5.1 | 13.2 | 53 | 1 | 107 | 8 | 0.89 | 0.00 |
| b4 | 3.76 | 5.4 | 13.5 | 60 | 3 | 148 | 23 | 0.93 | 0.00 |
| b5 | 3.62 | 5.6 | 14.3 | 56 | 3 | 94 | 14 | 0.89 | 0.00 |
| b6 | 3.68 | 5.6 | 14.2 | 56 | 2 | 171 | 12 | 0.87 | 0.00 |
| b7 | 3.66 | 6.2 | 14.7 | 48 | 1 | 103 | 9 | 0.88 | 0.00 |
| b8 | 3.65 | 5.1 | 14.2 | 46 | 1 | 41 | 14 | 0.86 | 0.00 |
| b9 | 3.77 | 4.9 | 14.4 | 70 | 2 | 165 | 9 | 0.86 | 0.00 |
| b10 | 3.54 | 5.3 | 13.9 | 51 | 1 | 184 | 10 | 0.78 | 0.00 |
| b11 | 3.60 | 5.7 | 13.4 | 68 | 3 | 144 | 13 | 0.90 | 0.00 |
| b12 | 3.66 | 5.2 | 13.8 | 61 | 3 | 199 | 18 | 0.87 | 0.00 |
| b13 | 3.57 | 5.9 | 13.7 | 58 | 2 | 167 | 13 | 0.83 | 0.01 |
| b14 | 3.56 | 5.8 | 14.0 | 56 | 2 | 166 | 9 | 0.81 | 0.00 |
| b15 | 3.76 | 5.6 | 14.3 | 64 | 1 | 128 | 4 | 0.87 | 0.00 |
| b16 | 3.73 | 5.1 | 13.7 | 42 | 1 | 78 | 9 | 0.96 | 0.00 |
| b17 | 3.61 | 5.5 | 13.6 | 45 | 1 | 81 | 14 | 0.88 | 0.00 |
| b18 | 3.45 | 6.0 | 14.1 | 57 | 2 | 122 | 10 | 0.86 | 0.00 |
| b19 | 3.53 | 5.5 | 14.3 | 51 | 2 | 146 | 12 | 0.79 | 0.00 |
| b20 | 3.56 | 5.5 | 15.1 | 56 | 1 | 75 | 18 | 0.84 | 0.00 |
| c1 | 3.52 | 6.3 | 14.0 | 79 | 4 | 56 | 15 | 0.96 | 0.00 |
| c2 | 3.66 | 5.5 | 14.5 | 70 | 1 | 124 | 21 | 0.85 | 0.01 |
| c3 | 3.51 | 6.1 | 13.6 | 73 | 3 | 92 | 5 | 0.87 | 0.00 |
| c4 | 3.49 | 5.6 | 14.0 | 62 | 5 | 138 | 26 | 0.79 | 0.00 |
| c5 | 3.68 | 5.9 | 13.9 | 60 | 1 | 131 | 19 | 0.92 | 0.00 |
| c6 | 3.61 | 5.4 | 14.2 | 61 | 1 | 72 | 9 | 0.75 | 0.00 |
| c7 | 3.61 | 5.9 | 14.0 | 72 | 2 | 130 | 6 | 0.88 | 0.00 |
| c8 | 3.83 | 5.2 | 13.7 | 64 | 1 | 180 | 9 | 0.95 | 0.00 |
| c9 | 3.65 | 6.2 | 15.3 | 65 | 1 | 41 | 4 | 0.97 | 0.00 |
| c10 | 3.47 | 5.9 | 14.6 | 67 | 2 | 111 | 5 | 0.82 | 0.00 |
| c11 | 3.46 | 5.9 | 14.8 | 63 | 1 | 63 | 9 | 0.88 | 0.00 |
| c12 | 3.64 | 5.2 | 13.4 | 61 | 1 | 142 | 4 | 0.85 | 0.00 |
| c13 | 3.48 | 5.8 | 14.0 | 70 | 3 | 159 | 29 | 0.87 | 0.00 |
| c14 | 3.61 | 5.7 | 13.4 | 57 | 2 | 141 | 11 | 0.88 | 0.00 |
| c15 | 3.56 | 6.4 | 14.6 | 82 | 2 | 166 | 17 | 0.83 | 0.00 |
| c16 | 3.62 | 5.5 | 14.0 | 73 | 1 | 127 | 10 | 0.83 | 0.00 |
| c17 | 3.49 | 5.6 | 14.8 | 61 | 1 | 174 | 6 | 0.82 | 0.00 |
| c18 | 3.57 | 5.8 | 13.7 | 61 | 1 | 100 | 9 | 0.91 | 0.00 |
| c19 | 3.64 | 5.9 | 13.9 | 66 | 1 | 86 | 2 | 0.95 | 0.00 |
| c20 | 3.74 | 5.5 | 13.6 | 62 | 2 | 182 | 12 | 0.86 | 0.00 |
| c21 | 3.64 | 5.4 | 14.0 | 64 | 2 | 176 | 11 | 0.85 | 0.00 |
| d1 | 3.60 | 5.6 | 13.3 | 55 | 1 | 139 | 2 | 0.87 | 0.00 |
| d2 | 3.90 | 4.5 | 14.4 | 53 | 1 | 139 | 9 | 0.87 | 0.01 |
| d3 | 3.72 | 4.9 | 14.0 | 64 | 2 | 191 | 9 | 0.85 | 0.00 |
| d4 | 3.68 | 5.2 | 13.4 | 60 | 1 | 158 | 5 | 0.87 | 0.01 |
| d5 | 3.71 | 5.1 | 13.4 | 64 | 1 | 177 | 8 | 0.83 | 0.01 |

**Table S2. contd.**

| Samples | pH[1] | TA[1] | Alcohol (% v/v)[2] | Total phenolics (au)[3] | | Total anthocyanins (mg L$^{-1}$)[3] | | Hue[3] | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Mean | SD | Mean | SD | Mean | SD |
| d6 | 3.58 | 5.6 | 14.4 | 67 | 3 | 181 | 13 | 0.79 | 0.00 |
| d7 | 3.77 | 5.1 | 13.6 | 62 | 3 | 177 | 56 | 0.82 | 0.00 |
| d8 | 3.81 | 4.6 | 14.6 | 72 | 3 | 194 | 17 | 0.83 | 0.00 |
| d9 | 3.78 | 4.8 | 14.0 | 54 | 2 | 154 | 13 | 0.93 | 0.01 |
| d10 | 3.80 | 4.8 | 13.9 | 68 | 2 | 130 | 13 | 0.89 | 0.00 |
| Pr > F | **< 0.0001** | **< 0.0001** | 0.19 | **< 0.0001** | | **0.007** | | 0.83 | |

[1]Obtained with a Mettler Toledo T50 autotitrator
[2]Obtained with an Anton Paar Alcolyser
[3]Obtained by modified Somers assay performed with a SpectraMax M2 microplate reader in triplicate

**Table S3.** Tasting sheet used for RATA evaluation of the groups sorted by each expert panellist from 84 Cabernet Sauvignon wines.

| Rate only those attributes that appear in each group (Please Circle all that apply) | | | | | | |
|---|---|---|---|---|---|---|
| **Group Number:** | | **Judge Name:** | | | | |
| **Aroma/Flavour** | | | | | | |
| 1 | Dark fruit (e.g., blackberry, blackcurrant, plum, dark cherry...) | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 2 | Red fruit (e.g., raspberry, strawberry, red cherry, red currant...) | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 3 | Dried fruit (e.g., prune, raisins, fig and dried apricot) | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 4 | Fresh Jam | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 5 | Confectionery/Lolly/Musk/Bubblegum | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 6 | Floral/Perfume | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 7 | Blue Flowers/Violets | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 8 | Mint | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 9 | Eucalypt | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 10 | Green pepper/Capsicum/Green bean | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 11 | Herbaceous/Leafy/Herbal | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 12 | Stemmy/Stalky/Tomato leaf | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 13 | Cooked vegetables (cabbage and beans)/Reductive/Sulfide | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 14 | Pepper (black or white) | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 15 | Spice (anise, clove, cinnamon, liquorice, nutmeg) Nutty | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 16 | Savoury/Meaty/Gamey/Salami/Olive | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 17 | Forest floor/Mushrooms | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 18 | Barnyard/Horsey/Roasted vegetables | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 19 | Earthy/Dusty | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 20 | Leather | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 21 | Chocolate | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 22 | Toasty/Smoky/Charry/Burnt | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 23 | Vanilla/Coconut/Sweet oak | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 24 | Woody (cedar, pencil shavings) | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 25 | Aged Character (cigar box, tobacco) | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| **Taste** | | | | | | |
| 26 | Bitter | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 27 | Sweet | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 28 | Sour | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| **Mouth Feel** | | | | | | |
| 29 | Body | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 30 | Alcohol/Heat | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 31 | Astringency | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 32 | Puckering/Grippy | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 33 | Fine sandy suede like tannin | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |
| 34 | Coarse grainy tannin | **Low** | **Low-Med** | **Med** | **Med-High** | **High** |

**Table S4.** Aroma and flavour attributes list with reference standard recipes used for descriptive analysis of 52 Cabernet Sauvignon wines.

| Aroma/Flavour | Definition (reference standard in 30ml of base wine; source, country of origin) |
|---|---|
| **Dark Fruits** | Blueberry, blackberry, plum, blackcurrant, prunes (1/4 fresh black plum, 1 frozen blueberry (Coles, Product of Chile) and 1 frozen blackberry (Coles, Product of Chile)) |
| **Red Fruits** | Strawberry, redcurrant, confectionery, red lolly (1/4 frozen strawberry (Coles, Product of Australia), 1/4 Ripe Raspberry lolly (Allen's, Australia), 1 frozen raspberry (Coles, Product of Chile)) |
| **Jammy** | Matured fruits, cooked fruits (1 tsp of wild blueberry spread (St Dalfour, France)) |
| **Dried Fruits** | Raisins, sultanas (3 raisins, 2 tsp of prune juice (Sunraysia, Product of Chile)) |
| **Cooked Vegetables** | Cooked beans, pickles (2 tsp of canned green beans water (Coles, Product of France)) |
| **Yeasty** | Bread, toast (5 × 5 cm of fresh sourdough bread) |
| **Oaky** | Woody (1 pinch of heavy toasted oak chips) |
| **Tobacco** | Smoky (1 tsp of loose tobacco (Murray's, Australia)) |
| **Pepper** | Ground black and white pepper (1 pinch of white pepper powder, 1 pinch of grounded black pepper) |
| **Spices** | Sweet spices, cinnamon (1 pinch of Allspices (Woolworths Select, Australia), 1 pinch of cinnamon powder (MasterFoods, Australia)) |
| **Liquorice** | Anise (1/2 star anise (Hoyt's, Australia)) |
| **Savoury** | Olives, soy sauce, meaty, balsamic (1 tsp soy sauce (Fountain, Australia), 1 whole black olive (Coles, Australia)) |
| **Green** | Fresh green, capsicum (2 × 2 cm of fresh green capsicum) |
| **Grassy** | Stalky, fresh herbs, fresh leaf (5 × 5 cm fresh cut grass) |
| **Earthy** | Mushroom, musty, truffle, tree moss, cardboard (1 slice of fresh mushroom, 1 pinch of potting soil) |
| **Mallee leaf** | Eucalyptus (1 drop of eucalyptus soluble solution (Eureka, Australia)) |
| **Minty** | Minty (1/2 Minties candy, (Allen's, Australia)) |
| **Violets** | Blue flowers (1 drop of violet aroma standard (Le Nez du Vin, France)) |
| **Floral** | Roses, dried roses (2 drops of rosewater flavour (Queen, Australia)) |
| **Chocolate/vanilla** | Sweet, chocolate, vanilla (5 × 5 cm 85% dark chocolate (Lindt, France), 1 tsp imitation vanilla essence (Queen, Australia)) |
| **Astringency** | Drying, roughing and puckering sensation (low = 0.5 g/L grape seed extract, high = 1.5 g/L grape seed extract (Tarac Technologies, Australia) + 0.5g/L tartaric acid) |
| **Acidity** | Tart and sour taste (low = 0.5 g/L tartaric acid, high 1.5 g/L tartaric acid (Merc, Australia)) |
| **Sweetness** | Sweet taste (low = 10 g/L sucrose, high 25 g/L sucrose (Woolworths, Australia)) |
| **Alcohol** | Warmth or burning sensation (addition of 10% of 96% ethanol (Tarac Technologies, Australia)) |
| **Body** | Weight of the wine when swirled in the mouth (low = 0.1 g/L xanthan gum, high = 0.5 g/L xanthan gum (The Melbourne Food Ingredient Depot, Australia)) |

**Table S5.** Mean values of each attribute along with least significant difference (LSD) and p-value (significantly different categories with $\alpha = 0.1$ are shown in bold) for the 52 Cabernet Sauvignon wines that underwent descriptive analysis.

| | Samples | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Attributes | d1 | d10 | d7 | d8 | d9 | a12 | a13 | a14 | a16 | a17 | a18 | a20 | a21 | a22 | a23 | a24 | a25 | a26 |
| A-Overall Aroma | 46.4 | 46.3 | 45.0 | 47.5 | 49.4 | 46.6 | 48.3 | 49.0 | 43.2 | 43.5 | 47.2 | 43.9 | 47.5 | 46.0 | 48.9 | 48.8 | 47.8 | 48.4 |
| **A-Overall Fruity Aroma** | 24.9 | 28.7 | 22.4 | 24.9 | 25.7 | 31.1 | 28.2 | 35.6 | 23.6 | 27.7 | 26.3 | 31.5 | 30.7 | 26.8 | 26.8 | 32.5 | 22.5 | 30.5 |
| A-Dark Fruits | 24.6 | 27.3 | 20.9 | 19.9 | 22.4 | 27.5 | 24.4 | 31.7 | 22.8 | 22.9 | 23.2 | 30.1 | 30.3 | 23.9 | 25.9 | 30.2 | 21.5 | 27.2 |
| **A-Red Fruits** | 19.2 | 16.5 | 12.5 | 16.7 | 16.6 | 18.6 | 19.9 | 22.7 | 13.4 | 14.5 | 16.1 | 17.1 | 16.7 | 17.2 | 15.0 | 19.7 | 14.1 | 16.0 |
| A-Jammy | 15.5 | 15.0 | 15.1 | 13.9 | 13.5 | 16.9 | 20.0 | 18.0 | 17.8 | 17.1 | 16.0 | 23.8 | 19.4 | 19.7 | 14.9 | 19.7 | 17.7 | 14.1 |
| A-Dried Fruits | 16.2 | 17.0 | 17.8 | 15.3 | 15.3 | 18.4 | 21.5 | 20.4 | 16.9 | 16.5 | 16.8 | 20.1 | 19.8 | 18.2 | 15.4 | 22.0 | 15.0 | 16.2 |
| **A-Cooked Vegetables** | 18.6 | 23.0 | 23.2 | 21.2 | 22.5 | 16.3 | 24.2 | 14.7 | 16.7 | 21.0 | 24.2 | 12.5 | 18.0 | 14.5 | 16.5 | 21.0 | 34.4 | 24.5 |
| **A-Yeasty** | 18.5 | 23.4 | 19.3 | 23.2 | 29.5 | 13.8 | 17.0 | 10.6 | 17.7 | 12.5 | 13.8 | 15.3 | 17.1 | 14.0 | 12.5 | 14.6 | 20.4 | 15.0 |
| A-Oaky | 27.1 | 24.8 | 25.3 | 25.2 | 26.4 | 27.5 | 27.3 | 32.1 | 27.7 | 24.9 | 25.2 | 26.6 | 26.3 | 23.6 | 22.5 | 29.6 | 23.3 | 22.9 |
| **A-Tobacco** | 17.3 | 22.7 | 24.1 | 15.4 | 26.7 | 22.0 | 22.5 | 16.8 | 17.3 | 17.9 | 20.4 | 14.6 | 19.4 | 17.4 | 15.8 | 17.6 | 20.4 | 18.8 |
| A-Pepper | 25.9 | 20.1 | 23.0 | 21.9 | 24.3 | 22.7 | 22.2 | 19.2 | 23.0 | 23.6 | 20.6 | 22.2 | 21.8 | 24.2 | 23.7 | 19.8 | 19.8 | 19.3 |
| A-Spices | 25.8 | 15.0 | 23.1 | 20.5 | 24.4 | 24.3 | 22.5 | 24.9 | 21.2 | 22.5 | 19.8 | 21.0 | 26.0 | 24.7 | 19.9 | 21.9 | 14.7 | 16.7 |
| A-Liquorice | 16.5 | 11.8 | 10.6 | 12.0 | 11.9 | 12.3 | 12.6 | 9.9 | 12.4 | 11.8 | 14.7 | 10.3 | 13.6 | 13.3 | 14.5 | 9.3 | 11.4 | 15.5 |
| **A-Savoury** | 19.0 | 25.1 | 23.2 | 23.2 | 28.8 | 17.2 | 20.4 | 14.4 | 15.5 | 21.3 | 27.1 | 17.9 | 17.2 | 16.7 | 20.6 | 25.2 | 27.6 | 24.4 |
| A-Green | 11.9 | 11.8 | 14.2 | 13.1 | 13.6 | 14.6 | 13.4 | 12.5 | 12.2 | 16.3 | 16.7 | 15.1 | 12.9 | 18.8 | 16.6 | 17.4 | 14.8 | 13.5 |
| A-Grassy | 13.2 | 18.0 | 15.8 | 16.7 | 16.7 | 18.0 | 17.4 | 15.6 | 14.2 | 15.8 | 16.7 | 21.3 | 18.6 | 17.8 | 18.5 | 17.0 | 20.0 | 13.8 |
| A-Earthy | 29.1 | 26.9 | 21.9 | 25.5 | 22.5 | 19.2 | 21.8 | 11.0 | 18.4 | 16.6 | 21.8 | 16.6 | 18.6 | 14.1 | 19.4 | 18.9 | 20.8 | 14.5 |
| A- Mallee leaf | 13.8 | 12.2 | 15.8 | 15.6 | 12.3 | 13.7 | 13.8 | 13.0 | 14.1 | 13.8 | 13.2 | 11.8 | 10.8 | 17.4 | 21.1 | 11.4 | 13.5 | 13.5 |
| **A-Minty** | 11.2 | 10.0 | 7.8 | 9.0 | 8.0 | 10.3 | 9.6 | 9.9 | 13.5 | 9.0 | 10.5 | 9.0 | 10.2 | 11.9 | 21.8 | 9.3 | 8.3 | 9.3 |
| **A-Violets** | 12.0 | 12.4 | 11.1 | 12.5 | 11.2 | 19.1 | 15.9 | 16.8 | 18.3 | 15.6 | 11.4 | 15.7 | 15.6 | 17.0 | 18.1 | 12.6 | 12.4 | 16.1 |
| **A-Floral** | 12.8 | 16.7 | 10.4 | 11.3 | 8.5 | 16.5 | 12.6 | 22.3 | 13.9 | 17.2 | 14.4 | 17.0 | 13.7 | 14.5 | 13.0 | 13.5 | 12.1 | 14.9 |
| **A-Chocolate/Vanilla** | 15.7 | 20.2 | 12.6 | 13.8 | 22.8 | 19.4 | 18.0 | 27.5 | 16.0 | 18.2 | 15.5 | 14.1 | 12.2 | 12.2 | 17.7 | 18.7 | 10.1 | 16.9 |
| F-Overall Flavour | 45.2 | 46.6 | 45.8 | 45.6 | 48.6 | 47.1 | 48.4 | 51.1 | 46.0 | 46.7 | 50.6 | 47.2 | 47.7 | 48.1 | 46.6 | 51.1 | 43.0 | 47.0 |
| **F-Overall Fruity Flavour** | 31.4 | 33.1 | 29.0 | 28.7 | 33.9 | 34.6 | 36.8 | 44.2 | 32.3 | 34.7 | 35.6 | 37.3 | 38.2 | 36.9 | 34.4 | 38.8 | 30.8 | 35.7 |
| F-Dark Fruits | 28.1 | 30.6 | 28.5 | 26.3 | 32.5 | 29.8 | 31.0 | 36.3 | 29.0 | 30.9 | 30.7 | 31.5 | 35.6 | 29.1 | 30.0 | 36.1 | 27.0 | 35.3 |
| F-Red Fruits | 20.8 | 18.5 | 17.9 | 21.7 | 19.6 | 20.2 | 21.1 | 28.1 | 21.1 | 21.2 | 21.5 | 25.8 | 21.3 | 22.1 | 19.9 | 23.7 | 20.0 | 21.3 |
| F-Jammy | 18.8 | 19.7 | 15.4 | 19.3 | 14.9 | 23.3 | 26.2 | 29.0 | 16.9 | 21.7 | 21.3 | 19.5 | 22.6 | 24.1 | 22.5 | 22.1 | 26.6 | 19.2 |
| **F-Dried Fruits** | 17.5 | 15.0 | 17.9 | 15.7 | 20.0 | 16.8 | 22.1 | 26.2 | 18.6 | 19.3 | 17.9 | 19.7 | 21.3 | 19.0 | 17.8 | 19.6 | 16.5 | 22.5 |
| **F-Cooked Vegetables** | 14.9 | 18.0 | 18.6 | 15.5 | 17.8 | 15.1 | 19.6 | 11.1 | 15.9 | 14.7 | 18.8 | 14.3 | 19.2 | 16.4 | 15.9 | 18.9 | 23.8 | 16.8 |
| **F-Yeasty** | 16.9 | 17.2 | 16.7 | 19.7 | 23.8 | 15.4 | 14.7 | 9.9 | 16.1 | 13.6 | 15.1 | 16.7 | 15.4 | 14.8 | 13.5 | 13.4 | 16.7 | 10.4 |
| F-Oaky | 34.3 | 29.0 | 29.9 | 26.0 | 28.6 | 28.0 | 29.1 | 33.4 | 30.7 | 28.9 | 30.5 | 26.6 | 28.1 | 29.7 | 29.1 | 29.0 | 25.2 | 22.7 |
| F-Tobacco | 16.7 | 20.4 | 21.0 | 18.5 | 24.0 | 22.3 | 22.3 | 17.2 | 19.7 | 17.3 | 20.3 | 14.2 | 17.7 | 22.8 | 16.6 | 16.4 | 18.8 | 16.4 |
| F-Pepper | 25.2 | 23.7 | 18.8 | 22.0 | 25.9 | 23.3 | 24.4 | 18.2 | 22.3 | 25.0 | 22.7 | 22.9 | 19.2 | 23.0 | 26.0 | 22.0 | 22.4 | 20.6 |
| F-Spices | 23.2 | 19.9 | 17.2 | 19.6 | 21.1 | 21.0 | 22.4 | 19.2 | 18.2 | 18.3 | 19.3 | 16.1 | 19.3 | 20.5 | 19.3 | 18.4 | 16.1 | 17.8 |
| F-Liquorice | 15.2 | 11.8 | 14.7 | 13.4 | 13.7 | 16.0 | 13.3 | 12.1 | 16.4 | 14.4 | 17.4 | 12.7 | 19.4 | 14.1 | 16.9 | 15.9 | 12.2 | 18.0 |
| **F-Savoury** | 20.0 | 21.2 | 21.8 | 20.8 | 24.1 | 18.3 | 19.7 | 15.3 | 21.4 | 19.6 | 20.9 | 20.4 | 14.6 | 17.1 | 22.1 | 22.3 | 24.6 | 20.1 |
| **F-Green** | 13.9 | 12.5 | 11.5 | 16.9 | 15.1 | 15.7 | 14.7 | 12.7 | 15.6 | 18.7 | 15.9 | 13.2 | 12.0 | 17.3 | 19.6 | 19.2 | 15.0 | 14.3 |
| F-Grassy | 14.7 | 18.0 | 16.6 | 18.0 | 17.6 | 14.1 | 16.0 | 13.8 | 15.2 | 15.1 | 12.1 | 17.0 | 15.2 | 16.7 | 16.7 | 17.9 | 18.4 | 15.2 |
| F-Earthy | 20.8 | 17.9 | 18.8 | 19.7 | 21.4 | 19.2 | 19.6 | 13.6 | 15.3 | 16.0 | 17.8 | 16.0 | 18.2 | 13.9 | 18.6 | 15.8 | 18.3 | 14.5 |
| **F- Mallee leaf** | 13.4 | 13.9 | 13.4 | 13.6 | 10.8 | 12.2 | 16.5 | 10.9 | 14.4 | 13.9 | 10.6 | 12.2 | 14.0 | 17.8 | 17.6 | 10.8 | 13.3 | 13.1 |
| **F-Minty** | 9.2 | 10.8 | 7.6 | 8.8 | 9.2 | 8.3 | 8.8 | 10.3 | 13.8 | 7.8 | 7.4 | 11.2 | 10.4 | 11.1 | 15.6 | 10.0 | 8.6 | 8.9 |
| F-Violets | 12.1 | 9.9 | 8.7 | 15.0 | 11.0 | 10.5 | 13.4 | 13.9 | 15.5 | 13.1 | 10.0 | 12.5 | 14.0 | 16.2 | 14.3 | 13.5 | 12.0 | 14.5 |
| F-Floral | 12.2 | 15.0 | 11.9 | 12.3 | 9.9 | 16.1 | 12.4 | 18.0 | 15.0 | 16.9 | 14.3 | 14.9 | 11.7 | 11.7 | 12.0 | 16.1 | 12.6 | 12.4 |
| **F-Chocolate/Vanilla** | 11.6 | 12.4 | 10.7 | 12.4 | 10.7 | 14.1 | 12.0 | 22.6 | 14.4 | 14.4 | 12.1 | 14.5 | 11.1 | 9.4 | 10.4 | 11.9 | 10.1 | 11.7 |
| MF-Astringency | 40.1 | 46.2 | 46.1 | 46.8 | 43.4 | 43.9 | 45.7 | 41.4 | 42.1 | 42.6 | 46.9 | 41.5 | 45.5 | 46.0 | 47.3 | 41.4 | 44.7 | 43.0 |
| MF-Alcohol | 46.1 | 46.9 | 43.7 | 46.4 | 44.3 | 40.8 | 43.3 | 48.8 | 42.7 | 45.4 | 49.6 | 42.8 | 44.4 | 44.3 | 49.5 | 44.8 | 46.5 | 48.3 |
| MF-Body | 35.5 | 37.3 | 38.5 | 32.6 | 36.1 | 39.5 | 37.8 | 40.4 | 34.4 | 33.7 | 40.0 | 39.0 | 34.8 | 37.6 | 36.8 | 40.0 | 34.5 | 38.1 |
| T-Acidity | 37.2 | 36.5 | 35.5 | 44.1 | 35.8 | 32.0 | 36.2 | 34.9 | 33.7 | 38.0 | 41.0 | 36.6 | 30.4 | 36.6 | 47.6 | 34.0 | 40.1 | 33.3 |
| **T-Sweetness** | 26.7 | 26.9 | 25.5 | 25.9 | 28.0 | 31.1 | 29.0 | 38.2 | 29.7 | 26.9 | 27.5 | 28.5 | 32.0 | 28.3 | 24.3 | 33.2 | 29.3 | 28.6 |

**Table S5. contd.**

| | Samples | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Attributes | a27 | a28 | a29 | a3 | a35 | a36 | a5 | a6 | a7 | a8 | a9 | b1 | b12 | b13 | b15 | b19 | b2 | b3 |
| A-Overall Aroma | 49.0 | 48.4 | 46.1 | 44.2 | 48.2 | 46.8 | 47.4 | 47.7 | 44.1 | 46.4 | 44.6 | 46.2 | 44.4 | 43.8 | 46.3 | 46.0 | 46.7 | 43.0 |
| **A-Overall Fruity Aroma** | **31.7** | **31.0** | **33.8** | **28.2** | **26.9** | **35.0** | **34.9** | **32.4** | **29.3** | **33.7** | **27.8** | **30.3** | **30.8** | **29.0** | **27.0** | **24.4** | **27.0** | **29.1** |
| A-Dark Fruits | 30.8 | 27.8 | 28.8 | 27.5 | 27.3 | 29.3 | 26.7 | 29.2 | 28.5 | 31.0 | 25.5 | 26.9 | 20.4 | 28.5 | 23.0 | 22.7 | 24.4 | 24.6 |
| **A-Red Fruits** | **15.7** | **22.5** | **17.6** | **19.2** | **16.0** | **23.3** | **21.5** | **18.8** | **16.9** | **22.1** | **17.7** | **18.5** | **21.6** | **17.8** | **20.3** | **16.3** | **18.5** | **18.1** |
| A-Jammy | 12.9 | 20.2 | 17.1 | 16.1 | 16.0 | 18.1 | 17.1 | 20.0 | 21.5 | 22.0 | 16.4 | 18.3 | 18.9 | 19.3 | 16.9 | 15.2 | 16.4 | 16.7 |
| A-Dried Fruits | 18.4 | 17.5 | 17.3 | 16.8 | 16.5 | 18.6 | 20.9 | 16.8 | 23.7 | 22.9 | 19.8 | 20.0 | 17.8 | 19.6 | 20.6 | 19.0 | 18.7 | 17.8 |
| **A-Cooked Vegetables** | **19.2** | **16.2** | **24.5** | **13.7** | **19.2** | **18.8** | **16.7** | **24.8** | **25.9** | **12.0** | **23.8** | **17.1** | **15.9** | **18.2** | **23.5** | **17.1** | **18.9** | **15.9** |
| **A-Yeasty** | **20.7** | **15.3** | **20.4** | **14.3** | **11.1** | **10.1** | **16.4** | **13.9** | **19.3** | **15.2** | **18.0** | **14.5** | **14.9** | **12.0** | **18.8** | **17.3** | **15.6** | **14.8** |
| A-Oaky | 29.4 | 23.3 | 23.0 | 23.9 | 24.9 | 23.7 | 25.8 | 24.1 | 26.3 | 21.1 | 24.0 | 25.1 | 24.8 | 26.9 | 26.5 | 25.7 | 26.9 | 22.9 |
| **A-Tobacco** | **21.2** | **13.8** | **19.0** | **17.2** | **14.7** | **12.9** | **17.3** | **19.2** | **18.5** | **16.2** | **16.5** | **17.2** | **14.0** | **17.8** | **19.6** | **16.2** | **16.7** | **15.4** |
| A-Pepper | 22.8 | 25.4 | 21.3 | 20.0 | 25.2 | 22.9 | 26.0 | 22.5 | 22.8 | 21.3 | 24.9 | 24.7 | 20.5 | 22.9 | 23.6 | 21.0 | 20.5 | 19.0 |
| A-Spices | 18.5 | 27.8 | 22.3 | 23.7 | 25.7 | 14.5 | 21.1 | 19.2 | 20.5 | 27.3 | 20.5 | 21.5 | 22.0 | 24.2 | 21.0 | 24.3 | 26.2 | 17.9 |
| A-Liquorice | 10.8 | 13.4 | 12.4 | 11.4 | 12.3 | 12.9 | 14.9 | 11.6 | 11.0 | 11.0 | 15.8 | 11.7 | 12.8 | 13.3 | 11.3 | 15.2 | 11.4 | 12.0 |
| **A-Savoury** | **20.9** | **15.1** | **26.5** | **15.7** | **18.8** | **17.3** | **17.4** | **21.0** | **26.6** | **17.3** | **22.7** | **17.7** | **18.0** | **16.7** | **24.1** | **18.5** | **20.0** | **16.0** |
| A-Green | 17.7 | 12.3 | 13.8 | 15.7 | 15.1 | 19.0 | 16.3 | 25.0 | 15.9 | 15.2 | 18.1 | 15.1 | 11.7 | 17.4 | 13.5 | 14.2 | 13.8 | 14.4 |
| A-Grassy | 19.4 | 14.8 | 17.4 | 17.0 | 20.1 | 20.7 | 15.0 | 19.9 | 19.9 | 17.7 | 17.7 | 18.2 | 13.4 | 15.0 | 15.8 | 21.5 | 15.8 | 18.4 |
| A-Earthy | 21.5 | 16.6 | 23.1 | 12.6 | 13.9 | 16.4 | 14.5 | 15.4 | 18.7 | 12.1 | 16.7 | 13.6 | 16.0 | 18.7 | 21.3 | 17.2 | 15.9 | 16.0 |
| A- Mallee leaf | 14.9 | 18.0 | 13.0 | 11.8 | 13.7 | 18.9 | 13.5 | 14.4 | 13.0 | 15.2 | 14.6 | 13.9 | 13.1 | 17.4 | 14.1 | 17.9 | 13.6 | 14.0 |
| **A-Minty** | **12.1** | **12.3** | **9.8** | **8.9** | **12.9** | **9.2** | **11.4** | **9.8** | **9.2** | **12.4** | **10.2** | **10.8** | **11.0** | **11.1** | **10.3** | **11.9** | **9.5** | **9.9** |
| **A-Violets** | **13.5** | **17.4** | **13.2** | **15.3** | **10.9** | **15.1** | **16.5** | **13.7** | **16.0** | **15.5** | **15.1** | **17.2** | **19.0** | **18.8** | **17.3** | **20.9** | **15.2** | **14.7** |
| **A-Floral** | **14.4** | **17.2** | **19.7** | **17.6** | **14.8** | **18.9** | **13.7** | **14.0** | **13.1** | **17.6** | **13.8** | **22.4** | **19.4** | **11.6** | **16.8** | **17.4** | **16.2** | **15.5** |
| **A-Chocolate/Vanilla** | **11.4** | **13.4** | **17.4** | **16.8** | **16.8** | **10.4** | **14.4** | **17.5** | **14.0** | **14.6** | **11.0** | **11.6** | **18.5** | **15.7** | **23.6** | **15.3** | **17.6** | **12.3** |
| F-Overall Flavour | 49.2 | 46.6 | 49.1 | 44.3 | 47.8 | 49.7 | 49.8 | 46.0 | 49.5 | 47.1 | 46.9 | 47.0 | 46.9 | 48.8 | 47.4 | 48.1 | 48.5 | 43.4 |
| **F-Overall Fruity Flavour** | **35.5** | **39.4** | **37.9** | **37.1** | **34.3** | **40.3** | **37.6** | **39.0** | **38.5** | **38.2** | **37.3** | **35.6** | **34.5** | **38.6** | **40.2** | **36.0** | **37.5** | **30.5** |
| F-Dark Fruits | 27.4 | 35.2 | 36.5 | 30.4 | 28.3 | 34.0 | 30.8 | 35.7 | 32.1 | 33.6 | 31.4 | 28.7 | 26.7 | 32.9 | 31.1 | 31.7 | 33.7 | 28.3 |
| F-Red Fruits | 21.2 | 27.8 | 24.4 | 21.6 | 25.6 | 24.7 | 21.0 | 22.0 | 25.1 | 23.2 | 23.5 | 20.9 | 19.3 | 19.8 | 24.9 | 21.5 | 23.6 | 25.9 |
| F-Jammy | 26.3 | 30.3 | 23.4 | 26.2 | 18.9 | 21.4 | 27.8 | 25.8 | 21.3 | 21.0 | 23.3 | 25.2 | 18.8 | 23.6 | 24.5 | 19.3 | 19.3 | 20.7 |
| **F-Dried Fruits** | **16.1** | **20.2** | **23.8** | **16.2** | **17.2** | **23.5** | **16.2** | **15.1** | **22.4** | **23.8** | **21.3** | **23.9** | **19.3** | **23.0** | **21.5** | **19.9** | **22.9** | **18.5** |
| **F-Cooked Vegetables** | **19.8** | **15.2** | **14.1** | **15.3** | **16.9** | **12.8** | **13.7** | **20.3** | **17.5** | **16.3** | **14.4** | **12.5** | **17.1** | **14.6** | **15.5** | **17.7** | **14.7** | **15.5** |
| **F-Yeasty** | **18.5** | **15.1** | **17.9** | **14.2** | **13.4** | **10.2** | **13.9** | **13.5** | **15.6** | **12.2** | **11.1** | **16.4** | **15.4** | **13.2** | **13.3** | **15.9** | **17.2** | **14.8** |
| F-Oaky | 27.2 | 28.6 | 25.8 | 29.3 | 28.3 | 23.3 | 30.2 | 23.8 | 27.2 | 23.6 | 23.9 | 25.4 | 26.8 | 27.8 | 26.7 | 26.9 | 26.3 | 29.5 |
| F-Tobacco | 22.0 | 13.0 | 19.1 | 18.4 | 20.5 | 12.9 | 18.2 | 15.5 | 20.2 | 16.1 | 15.0 | 17.4 | 15.4 | 18.3 | 18.5 | 18.1 | 20.9 | 14.6 |
| F-Pepper | 23.6 | 23.1 | 23.0 | 20.0 | 22.8 | 24.9 | 28.3 | 22.6 | 24.9 | 21.7 | 22.6 | 24.0 | 20.4 | 26.8 | 25.6 | 27.6 | 21.2 | 19.7 |
| F-Spices | 17.3 | 19.4 | 21.6 | 19.9 | 23.3 | 17.5 | 23.9 | 17.6 | 21.0 | 19.2 | 21.1 | 18.4 | 19.9 | 19.6 | 19.8 | 20.0 | 22.6 | 22.4 |
| F-Liquorice | 16.0 | 17.0 | 16.2 | 15.3 | 15.7 | 16.0 | 20.1 | 14.4 | 16.1 | 13.7 | 19.2 | 15.6 | 15.4 | 15.5 | 14.5 | 19.3 | 13.7 | 16.1 |
| **F-Savoury** | **20.3** | **19.0** | **23.2** | **16.0** | **17.7** | **14.9** | **21.0** | **20.6** | **21.9** | **20.0** | **19.7** | **19.6** | **17.7** | **20.7** | **20.6** | **21.5** | **21.3** | **15.0** |
| **F-Green** | **16.2** | **16.3** | **17.7** | **14.2** | **13.1** | **21.4** | **17.7** | **16.2** | **18.1** | **16.6** | **21.1** | **12.6** | **12.4** | **18.1** | **15.3** | **18.7** | **12.7** | **10.1** |
| F-Grassy | 15.6 | 13.5 | 16.9 | 15.6 | 17.1 | 19.8 | 19.4 | 16.9 | 17.2 | 17.7 | 17.5 | 14.2 | 14.0 | 14.5 | 13.7 | 18.1 | 16.2 | 15.2 |
| F-Earthy | 16.6 | 15.9 | 15.2 | 16.2 | 12.8 | 17.7 | 16.0 | 12.6 | 17.2 | 13.3 | 17.4 | 15.2 | 15.4 | 17.0 | 18.1 | 17.2 | 16.3 | 16.7 |
| **F- Mallee leaf** | **11.9** | **17.1** | **12.9** | **12.2** | **11.5** | **18.5** | **10.5** | **14.7** | **12.7** | **15.7** | **15.1** | **13.1** | **10.8** | **14.9** | **12.9** | **18.8** | **12.4** | **12.3** |
| **F-Minty** | **9.5** | **11.1** | **8.2** | **8.3** | **10.3** | **11.2** | **9.5** | **8.5** | **8.8** | **12.9** | **11.2** | **9.5** | **9.7** | **8.8** | **10.0** | **10.0** | **11.1** | **8.1** |
| F-Violets | 11.5 | 15.6 | 12.4 | 14.3 | 11.7 | 15.5 | 13.7 | 13.9 | 13.1 | 13.6 | 13.0 | 16.1 | 16.2 | 14.1 | 15.7 | 15.1 | 11.6 | 13.9 |
| F-Floral | 14.5 | 17.6 | 13.7 | 15.0 | 13.0 | 21.8 | 14.9 | 16.7 | 13.5 | 16.3 | 13.1 | 16.5 | 14.6 | 13.0 | 18.0 | 14.0 | 14.8 | 17.1 |
| **F-Chocolate/Vanilla** | **11.6** | **15.2** | **14.2** | **17.8** | **13.9** | **11.4** | **14.2** | **11.9** | **16.0** | **11.5** | **12.9** | **11.2** | **11.7** | **10.4** | **19.9** | **9.4** | **12.6** | **10.2** |
| MF-Astringency | 47.7 | 44.0 | 48.0 | 50.5 | 41.6 | 42.3 | 39.5 | 43.9 | 41.9 | 44.5 | 43.9 | 41.0 | 41.9 | 46.3 | 47.1 | 39.5 | 41.5 | 44.4 |
| MF-Alcohol | 49.6 | 44.3 | 45.8 | 46.9 | 45.1 | 45.2 | 45.1 | 46.3 | 44.8 | 45.1 | 45.7 | 47.5 | 41.5 | 46.1 | 45.9 | 47.0 | 45.2 | 47.5 |
| MF-Body | 39.6 | 38.9 | 39.6 | 40.5 | 35.2 | 39.4 | 37.7 | 36.0 | 37.8 | 37.7 | 35.2 | 39.2 | 35.0 | 36.7 | 40.0 | 38.1 | 36.9 | 35.1 |
| T-Acidity | 38.4 | 38.9 | 36.8 | 42.5 | 32.2 | 36.5 | 33.8 | 32.5 | 34.0 | 37.1 | 36.3 | 35.9 | 37.6 | 36.8 | 34.1 | 34.7 | 35.7 | 34.1 |
| **T-Sweetness** | **28.6** | **33.4** | **32.0** | **31.4** | **28.0** | **33.2** | **31.1** | **30.3** | **29.6** | **30.3** | **30.6** | **31.4** | **34.7** | **29.3** | **32.3** | **31.1** | **32.9** | **30.4** |

**Table S5. contd.**

| | Samples | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Attributes | b4 | b5 | b8 | c1 | c10 | c11 | c13 | c14 | c15 | c16 | c17 | c18 | c19 | c4 | c6 | c7 | LSD | p-value |
| A-Overall Aroma | 44.6 | 45.1 | 46.4 | 48.6 | 45.3 | 45.6 | 49.4 | 43.0 | 46.2 | 46.2 | 45.8 | 46.9 | 46.4 | 47.4 | 43.1 | 41.5 | 5.8 | 0.7828 |
| **A-Overall Fruity Aroma** | **30.3** | **27.2** | **29.4** | **27.9** | **33.0** | **26.9** | **25.2** | **27.3** | **30.0** | **31.0** | **36.1** | **29.7** | **31.4** | **31.3** | **23.8** | **25.7** | **8.2** | **0.0821** |
| A-Dark Fruits | 27.0 | 24.0 | 25.0 | 25.4 | 29.6 | 23.5 | 24.7 | 26.4 | 30.2 | 25.1 | 28.4 | 25.3 | 30.0 | 25.0 | 22.3 | 22.4 | 7.9 | 0.2480 |
| **A-Red Fruits** | **18.1** | **16.8** | **17.0** | **16.8** | **20.3** | **17.2** | **15.9** | **15.4** | **15.6** | **19.9** | **26.8** | **17.1** | **19.6** | **25.3** | **16.4** | **17.9** | **6.0** | **0.0016** |
| A-Jammy | 18.5 | 17.9 | 13.9 | 17.4 | 17.1 | 21.3 | 14.9 | 20.8 | 18.0 | 19.6 | 22.5 | 19.5 | 18.5 | 19.0 | 17.3 | 19.8 | 6.7 | 0.4495 |
| A-Dried Fruits | 17.1 | 16.4 | 23.2 | 20.4 | 21.5 | 18.7 | 14.6 | 18.8 | 14.6 | 23.5 | 23.8 | 18.2 | 19.5 | 20.4 | 18.6 | 16.8 | 6.6 | 0.3678 |
| **A-Cooked Vegetables** | **23.9** | **22.1** | **19.7** | **16.8** | **21.9** | **28.8** | **26.7** | **28.6** | **26.5** | **20.2** | **13.8** | **23.3** | **34.4** | **18.5** | **22.1** | **15.0** | **8.6** | **< 0.0001** |
| **A-Yeasty** | **18.3** | **13.7** | **11.4** | **13.5** | **17.2** | **24.7** | **19.4** | **23.1** | **17.0** | **18.7** | **12.3** | **17.6** | **15.3** | **13.6** | **16.6** | **17.6** | **7.1** | **< 0.0001** |
| A-Oaky | 22.0 | 22.1 | 23.8 | 24.1 | 24.9 | 25.9 | 27.1 | 22.8 | 24.8 | 22.8 | 17.8 | 22.0 | 22.0 | 25.5 | 25.2 | 23.7 | 6.2 | 0.2542 |
| **A-Tobacco** | **16.7** | **14.6** | **17.6** | **13.7** | **19.2** | **17.7** | **18.3** | **15.1** | **13.0** | **14.4** | **17.4** | **14.8** | **14.2** | **11.5** | **18.8** | **15.2** | **7.2** | **0.0761** |
| A-Pepper | 19.6 | 23.0 | 21.6 | 25.1 | 22.7 | 23.5 | 22.4 | 24.2 | 22.6 | 24.3 | 17.7 | 21.6 | 21.6 | 19.4 | 20.6 | 20.9 | 6.6 | 0.9443 |
| A-Spices | 19.6 | 20.4 | 20.9 | 25.0 | 20.0 | 19.4 | 24.0 | 20.8 | 15.6 | 21.8 | 19.3 | 11.2 | 16.7 | 21.6 | 19.6 | 23.7 | 9.0 | 0.2375 |
| A-Liquorice | 10.5 | 14.4 | 13.1 | 18.5 | 13.2 | 11.3 | 10.5 | 10.9 | 12.0 | 12.1 | 10.2 | 10.2 | 10.2 | 12.1 | 14.0 | 11.8 | 5.8 | 0.8768 |
| **A-Savoury** | **20.5** | **21.6** | **18.8** | **13.9** | **14.9** | **24.6** | **21.8** | **24.4** | **25.2** | **17.5** | **15.6** | **25.3** | **31.7** | **15.3** | **21.2** | **15.4** | **7.4** | **< 0.0001** |
| A-Green | 16.3 | 18.2 | 14.9 | 11.0 | 15.0 | 13.0 | 15.0 | 13.6 | 13.6 | 18.1 | 9.8 | 11.0 | 15.2 | 18.4 | 20.5 | 14.4 | 7.1 | 0.2527 |
| A-Grassy | 18.2 | 16.5 | 19.5 | 16.6 | 15.3 | 17.8 | 19.9 | 15.8 | 14.5 | 18.7 | 17.9 | 14.4 | 15.4 | 14.8 | 13.9 | 17.9 | 6.4 | 0.7800 |
| A-Earthy | 20.0 | 21.1 | 16.4 | 13.6 | 17.8 | 21.4 | 17.7 | 22.1 | 18.7 | 15.7 | 17.0 | 16.3 | 18.9 | 15.9 | 16.1 | 15.9 | 7.9 | 0.0038 |
| A- Mallee leaf | 20.3 | 13.2 | 14.0 | 14.4 | 11.2 | 12.2 | 15.6 | 13.7 | 14.3 | 15.0 | 15.2 | 13.4 | 11.9 | 14.7 | 19.1 | 13.5 | 5.8 | 0.2336 |
| **A-Minty** | **8.3** | **9.0** | **10.4** | **9.1** | **9.9** | **7.9** | **10.8** | **9.9** | **8.0** | **9.7** | **11.0** | **8.0** | **9.7** | **13.3** | **12.4** | **13.7** | **4.7** | **0.0024** |
| **A-Violets** | **16.0** | **18.2** | **12.9** | **16.6** | **19.9** | **9.8** | **11.3** | **15.2** | **14.8** | **14.3** | **20.1** | **14.9** | **10.5** | **17.2** | **20.1** | **16.5** | **6.7** | **0.0811** |
| **A-Floral** | **12.0** | **13.7** | **13.5** | **15.1** | **15.7** | **9.7** | **12.1** | **16.4** | **13.8** | **12.1** | **21.3** | **11.7** | **13.9** | **21.0** | **16.1** | **14.0** | **7.1** | **0.0289** |
| **A-Chocolate/Vanilla** | **12.9** | **15.8** | **12.5** | **13.9** | **15.2** | **13.1** | **12.5** | **10.1** | **11.4** | **12.8** | **13.4** | **12.3** | **12.9** | **17.3** | **14.0** | **16.0** | **7.4** | **0.0016** |
| F-Overall Flavour | 43.6 | 48.0 | 48.8 | 46.9 | 49.9 | 46.2 | 47.7 | 43.3 | 43.4 | 48.3 | 46.5 | 46.2 | 47.5 | 48.4 | 44.8 | 41.8 | 5.2 | 0.1024 |
| **F-Overall Fruity Flavour** | **36.0** | **32.7** | **37.5** | **32.7** | **39.9** | **39.2** | **33.5** | **32.1** | **33.7** | **39.8** | **37.9** | **33.4** | **35.8** | **39.2** | **30.4** | **35.9** | **7.7** | **0.0630** |
| F-Dark Fruits | 29.2 | 29.5 | 30.3 | 30.9 | 36.1 | 36.8 | 27.6 | 28.6 | 28.8 | 31.5 | 32.1 | 29.4 | 33.7 | 30.9 | 25.8 | 28.4 | 8.5 | 0.6203 |
| F-Red Fruits | 22.2 | 22.2 | 19.0 | 21.2 | 22.5 | 22.3 | 24.2 | 22.4 | 18.2 | 25.8 | 27.7 | 22.6 | 22.5 | 30.1 | 19.6 | 21.8 | 6.6 | 0.1101 |
| F-Jammy | 23.8 | 19.4 | 19.7 | 18.8 | 25.0 | 26.2 | 23.2 | 23.2 | 18.6 | 23.5 | 23.6 | 20.8 | 15.7 | 23.6 | 14.9 | 23.2 | 9.2 | 0.2617 |
| **F-Dried Fruits** | **19.5** | **17.8** | **23.4** | **16.4** | **20.7** | **16.7** | **18.9** | **16.3** | **18.1** | **21.6** | **22.8** | **18.5** | **18.2** | **22.3** | **16.4** | **17.4** | **6.4** | **0.0328** |
| **F-Cooked Vegetables** | **18.5** | **18.3** | **18.8** | **15.6** | **15.8** | **19.7** | **20.5** | **18.4** | **22.7** | **13.6** | **14.8** | **19.5** | **21.0** | **14.7** | **15.0** | **18.0** | **6.2** | **0.0532** |
| **F-Yeasty** | **16.6** | **13.6** | **11.6** | **14.4** | **14.9** | **15.4** | **17.1** | **20.3** | **13.9** | **13.0** | **14.8** | **16.3** | **13.1** | **13.3** | **14.3** | **14.3** | **6.0** | **0.0620** |
| F-Oaky | 26.8 | 26.0 | 27.0 | 28.0 | 29.1 | 25.6 | 26.3 | 26.5 | 28.6 | 29.7 | 19.6 | 22.9 | 21.9 | 28.0 | 28.8 | 24.3 | 6.8 | 0.1285 |
| F-Tobacco | 14.2 | 13.0 | 17.3 | 15.8 | 19.5 | 16.3 | 18.7 | 15.9 | 16.3 | 18.2 | 20.3 | 13.9 | 13.5 | 14.5 | 19.5 | 14.0 | 7.1 | 0.1703 |
| F-Pepper | 20.9 | 23.9 | 26.0 | 22.4 | 22.7 | 18.2 | 22.4 | 23.7 | 25.8 | 25.0 | 17.4 | 21.9 | 22.5 | 21.9 | 25.2 | 19.4 | 6.1 | 0.1481 |
| F-Spices | 16.2 | 17.5 | 20.6 | 19.7 | 19.2 | 16.9 | 19.0 | 14.4 | 16.0 | 20.6 | 16.0 | 14.0 | 15.8 | 16.1 | 18.9 | 16.9 | 7.0 | 0.7980 |
| F-Liquorice | 16.1 | 14.9 | 16.7 | 16.5 | 15.3 | 15.0 | 17.6 | 8.5 | 16.9 | 18.3 | 9.5 | 15.5 | 11.9 | 15.1 | 19.2 | 12.7 | 6.7 | 0.5389 |
| **F-Savoury** | **16.4** | **23.4** | **17.8** | **18.3** | **15.3** | **22.7** | **22.0** | **16.9** | **24.2** | **16.3** | **15.4** | **25.5** | **25.5** | **15.5** | **20.4** | **16.3** | **6.4** | **0.0067** |
| **F-Green** | **15.7** | **19.0** | **13.9** | **11.7** | **11.9** | **15.1** | **18.9** | **14.7** | **12.1** | **13.3** | **11.8** | **15.4** | **16.9** | **19.4** | **15.6** | **15.2** | **6.5** | **0.0745** |
| F-Grassy | 16.2 | 16.1 | 16.3 | 14.9 | 15.3 | 15.2 | 17.1 | 17.1 | 15.8 | 16.5 | 15.8 | 16.4 | 14.3 | 14.8 | 16.4 | 15.5 | 6.0 | 0.9982 |
| F-Earthy | 14.8 | 17.3 | 14.8 | 14.6 | 14.8 | 16.7 | 18.8 | 19.3 | 16.0 | 16.5 | 13.8 | 18.3 | 14.1 | 13.5 | 16.3 | 13.1 | 6.7 | 0.8945 |
| **F- Mallee leaf** | **13.9** | **16.1** | **13.8** | **13.0** | **9.9** | **12.7** | **14.3** | **10.7** | **15.4** | **12.7** | **13.6** | **11.5** | **12.0** | **13.5** | **17.9** | **13.0** | **5.2** | **0.0610** |
| **F-Minty** | **8.7** | **11.7** | **10.8** | **7.9** | **10.5** | **8.0** | **9.6** | **9.4** | **7.6** | **9.7** | **8.3** | **7.5** | **9.3** | **10.6** | **11.3** | **7.4** | **3.9** | **0.0529** |
| F-Violets | 13.4 | 17.7 | 13.5 | 12.7 | 16.7 | 13.5 | 12.3 | 14.6 | 10.4 | 15.1 | 17.7 | 13.8 | 12.6 | 18.9 | 16.0 | 12.5 | 5.3 | 0.1719 |
| F-Floral | 10.5 | 14.6 | 13.2 | 15.0 | 14.5 | 11.3 | 10.5 | 14.8 | 11.4 | 17.0 | 19.2 | 12.0 | 13.5 | 19.8 | 16.8 | 15.0 | 6.7 | 0.3010 |
| **F-Chocolate/Vanilla** | **11.1** | **11.5** | **10.3** | **13.9** | **16.0** | **12.0** | **11.4** | **10.7** | **10.4** | **12.4** | **11.4** | **13.0** | **11.4** | **15.4** | **10.8** | **9.6** | **5.4** | **0.0025** |
| MF-Astringency | 42.1 | 43.4 | 43.2 | 49.5 | 44.8 | 39.0 | 45.5 | 42.1 | 45.6 | 48.5 | 40.0 | 42.6 | 40.8 | 39.6 | 44.8 | 46.4 | 7.5 | 0.3844 |
| MF-Alcohol | 45.5 | 47.0 | 43.3 | 42.1 | 43.0 | 45.3 | 47.6 | 44.1 | 44.8 | 49.7 | 42.6 | 45.2 | 44.8 | 41.3 | 48.4 | 46.5 | 5.9 | 0.4233 |
| MF-Body | 37.0 | 37.7 | 40.7 | 37.0 | 37.1 | 37.4 | 36.9 | 34.6 | 32.5 | 41.1 | 33.6 | 36.0 | 33.9 | 36.7 | 36.2 | 34.5 | 6.8 | 0.8287 |
| T-Acidity | 33.8 | 33.7 | 35.3 | 41.9 | 35.9 | 35.7 | 38.6 | 37.4 | 34.9 | 38.8 | 31.9 | 35.2 | 37.1 | 36.9 | 39.3 | 38.8 | 8.9 | 0.5412 |
| **T-Sweetness** | **29.5** | **25.4** | **30.3** | **27.0** | **30.9** | **28.2** | **31.8** | **29.1** | **24.3** | **31.1** | **32.9** | **26.8** | **28.7** | **29.5** | **25.7** | **28.1** | **6.4** | **0.0375** |

# Chapter 4

## Publication

Exploring consumer knowledge of wine typicity and the impact of region of origin information when tasting Cabernet Sauvignon wines

**Souza Gonzaga, L.**, Bastian, S. E. P., Capone, D. L., Danner, L., & Jeffery, D. W. (2021) Food Research International, 110719. DOI

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## Principal Author

| | | | |
|---|---|---|---|
| Name of Principal Author (Candidate) | Lira Souza Gonzaga | | |
| Contribution to the Paper | Sourced all the wine samples. Designed, prepared and conducted the sensory evaluation. Carried out statistical analysis of the data collected. Prepared the complete first draft of the manuscript and incorporated revisions. | | |
| Overall percentage (%) | 70% | | |
| Certification: | This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper. | | |
| Signature | | Date | 26/10/2021 |

## Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

| | | | |
|---|---|---|---|
| Name of Co-Author | Susan E. P. Bastian | | |
| Contribution to the Paper | Assisted with the study design and supervised the project. Discussed the results and provided critical feedback. Critically evaluated and revised the manuscript. | | |
| Signature | | Date | 26/10/2021 |

| | | | |
|---|---|---|---|
| Name of Co-Author | Dimitra L. Capone | | |
| Contribution to the Paper | Assisted with sample sourcing and preparation. Assisted with the study design and supervised the project. Discussed the results and provided critical feedback. Critically evaluated and revised the manuscript. | | |
| Signature | | Date | 26/10/2021 |

| | | | |
|---|---|---|---|
| Name of Co-Author | Lukas Danner | | |
| Contribution to the Paper | Assisted with the study design and data extraction. Discussed the results and provided critical feedback. Critically evaluated and revised the manuscript. | | |
| Signature | | Date | 26/10/2021 |

| | | | |
|---|---|---|---|
| Name of Co-Author | David W. Jeffery | | |
| Contribution to the Paper | Supervised and directed the project. Discussed the study design and results, and provided critical feedback. Critically evaluated and revised the manuscript. Acted as corresponding author. | | |
| Signature | | Date | 26/10/2021 |

Please cut and paste additional co-author panels here as required.

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# Consumer perspectives of wine typicity and impact of region information on the sensory perception of Cabernet Sauvignon wines

Lira Souza Gonzaga[a,b], Susan E.P. Bastian[a,b], Dimitra L. Capone[a,b], Lukas Danner[a,1], David W. Jeffery[a,b,*]

[a] Department of Wine Science and Waite Research Institute, The University of Adelaide, PMB 1, Glen Osmond, South Australia 5064, Australia
[b] Australian Research Council Training Centre for Innovative Wine Production, The University of Adelaide, PMB 1, Glen Osmond, South Australia 5064, Australia

A R T I C L E I N F O

*Keywords:*
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Regionality
Rate-all-that-apply
Hedonics
Consumer behavior

A B S T R A C T

Region of origin is used in marketing of wine and by consumers as a wine quality indicator. To better understand wine consumers' purchase decisions, sensory perception, and wine liking in connection with wine provenance, this study used regular wine consumers (n = 112) to evaluate two Cabernet Sauvignon wines from each of four wine producing regions through hedonic rating and rate-all-that-apply (RATA) testing in conjunction with pre- and post-tasting questionnaires. The majority of consumers rated the region of origin stated on the label as important for purchase intent and for deciding the price they were willing to pay for a wine. The questionnaire also revealed that consumers were familiar with the wine typicity concept, but seemed to consider it only as an extrinsic characteristic rather than an intrinsic aspect of the wine. By randomly dividing the consumers into two groups (n = 56 each), one having information on the origin of samples and the other tasting without such knowledge, it was demonstrated that origin information had a positive impact on hedonic scores. Sensory profiling revealed that origin information did not impact the sample sensory characterisation, and liking for both groups was related to 'full body', 'jammy', and 'dark fruits' attributes. Some regional profile features were apparent for the samples, such as 'minty' for Coonawarra and savoury attributes for Bordeaux. Overall, this work highlighted that consumers could differentiate wines from distinct regions on the basis of sensory characteristics.

## 1. Introduction

A typical product, or one that conveys typicity, can be defined as a product that is able to express a combination of traits that are characteristic of belonging to a distinctive group. This definition can be considered highly applicable to and well exemplified by wine, considering all the inputs that it undergoes, from the cultivation of grapes to the winemaking process. The stages of wine production involve natural geographical conditions, cultivar characteristics, and vineyard and winemaking cultural practices that can ultimately contribute to the typicity of wine. The concept of wine typicity is one that has become increasingly relevant to the wine industry over the past decade (Souza Gonzaga et al., 2021). Wine typicity is usually a result of unique chemical and sensorial profiles that express the connection between the wine and its origin, making it a distinct and identifiable product (Cadot et al., 2010; Cadot et al., 2012; Souza Gonzaga et al., 2021). It has recently been defined as follows:

> *"Wine typicity can be defined as a juxtaposition of unique traits that define a class of wines having common aspects of terroir involving bio-physical and human dimensions that make the wines recognisable, and in theory, unable to be replicated in another territory."* (Souza Gonzaga et al., 2021)

With information being readily available through the use of technology, consumers are becoming increasingly aware of what the world has to offer, expanding their preferences for international markets and becoming more interested in where and how a product originates (Angus & Westbrook, 2019). The importance of wine origin was reported by Kustos et al. (2020), who showed that consumers identified a fine Australian wine as one that encompasses the expression of its regionality. Additionally, consumers might use the "sense of place" connection of wine to support their purchase decision and to set their expectations around style (Stasi et al., 2011).

* Corresponding author at: Department of Wine Science and Waite Research Institute, The University of Adelaide, PMB 1, Glen Osmond, South Australia 5064, Australia.
*E-mail address:* david.jeffery@adelaide.edu.au (D.W. Jeffery).
[1] Present address: Sensory and Consumer Science, Agriculture and Food, CSIRO, 671 Sneydes Rd, Werribee, Victoria 3030, Australia.

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A number of methodologies are available to produce wine sensory profiles depending on the objectives of the work, and the time and sample setup required. For example, Ballester et al. (2005) developed methodology for typicity assessment that relies on an expert panel rating how typical a sample is during tasting. Although it can analyse typicity per se, it is still up for debate whether such typicity assessment can serve as an analytical sensory tool or whether it draws too much upon the preconceived notions that experts may have of the wines in question (Souza Gonzaga et al., 2021). In contrast to using experts, rate-all-that-apply (RATA) is a suitable quantitative sensory methodology for use with consumers because it can be performed with a product-naïve panel with no necessity for prior training, so it is considered a time effective test (Danner et al., 2018). In fact, given that RATA can utilise naïve consumers and is a rapid method, it may be performed in conjunction with a consumer liking test without risking any bias from the panel, as long as the hedonic test is performed for each sample prior to the analytical task of rating the intensity of applicable sensory attributes and the appropriate number of consumers is used (usually between 40 and 100 or more) (Gacula JR. & Rutenbeck, 2006; Jaeger et al., 2017; Lawless & Heymann, 2010). Dividing the consumers into groups from the total cohort can also be undertaken when investigating different conditions that can influence consumer perception and purchase drivers, as reviewed by Jaeger et al. (2017).

When conducting consumer research, characterising the participants and obtaining information about their purchasing behaviour is important to gain deeper understanding of the target consumer. This is mostly undertaken through self-reported surveys that can be executed as a stand-alone exercise or combined with a sensory evaluation (Dillman et al., 2014). Furthermore, consumers of a product category are not homogeneous, so segmentation is an important strategic tool for in depth analysis of their attitudes and to make further projections (Wedel & Kamakura, 2000). The lack of homogeneity also applies to regular red wine consumers, with the most sophisticated way to segment being based on psychographic characteristics of the consumers along with their involvement, such as by using the fine wine instrument (FWI) that was developed specifically for segmentation of Australian wine consumers (Johnson & Bastian, 2015).

It is advantageous for regional wine producers to comprehend any uniqueness of their wines' sensory profiles in order to effectively preserve or even enhance the expression of those qualities. Improving knowledge for producers is not enough, however, and consumer expectations and opinions need consideration to effectively promote regional wine profiles (Souza Gonzaga et al., 2021). Understanding consumer attitudes toward regional typicity and its sensory expression has distinct importance for Australia's Cabernet Sauvignon wine producers, given that it sits in second place in terms of most crushed red grape variety in Australia and most planted variety internationally (OIV-International Organisation of Vine and Wine, 2018; Wine Australia, 2020). Thus, this study sought to test the hypothesis that consumers seek origin information as a decision factor when purchasing a wine, and use it to set their expectations and liking perspectives regarding the sensory composition of regional Cabernet Sauvignon wines. This was realised via a pre-tasting survey with demographic questions, segmentation based on behaviour, sensory evaluation involving liking, familiarity, and rate-all-that-apply methodology, and a post-tasting survey with questions related to regionality and typicity of wine.

## 2. Material and methods

### 2.1. Sample selection

The samples analysed in this consumer study comprised a subset of wines selected based on the results of a previous study by Souza Gonzaga et al., 2020, which followed the selection criteria elucidated by Souza Gonzaga et al. (2019). Briefly, 16 wines were initially chosen from a set of 52 that complied with the following criteria: well-reviewed by relevant Australian wine writers; from vintage 2015; maximum retail price of AU$150; minimum of 60% of Cabernet Sauvignon in the blend for the wine from Bordeaux and minimum of 85% for the wines from Australia. Subsequently, a subset of 8 wines (two from each of four regions) was selected on the basis of regional representativeness through an informal tasting by wine experts ($n = 5$), according to the definition of expert proposed by Parr et al. (2002)), and one random wine from the initial 52 was selected to serve as a standard (ST). Wines were obtained from commercial producers (6 × 750 mL bottles of each wine). The wines coded coo1 and coo2 were from Coonawarra, yv1 and yv2 were from Yarra Valley, mr1 and mr2 were from Margaret River, and bor1 and bor2 were respectively from the Margaux and Pauillac, being Left Bank appellations of Bordeaux (sample codes can be related to the previous study of Souza Gonzaga et al., 2020 as follows: coo1 = coo22; coo2 = coo36; yv1 = yv4; yv2 = yv15; bor1 = bor8; bor2 = bor9; Margaret River wine codes remained the same).

### 2.2. Consumer sensory analysis

Wine consumers ($n = 112$) were recruited from an in-house consumer database (containing approximately 900 consumers), social media, and university mail-lists. They were selected based on three conditions: being 18 years of age or older; not having formal wine evaluation or winemaking training nor having an extensive history of wine involvement (i.e., not an expert as defined by Parr et al. (2002)); and being a consumer of red wine at least once a month. Even though consumers were recruited on the basis of red wine consumption of unspecified variety, the majority of the panel consumed Cabernet Sauvignon wine at least once a month (Appendix B, Table B.1). For the sensory evaluation, the consumers were split into two groups: 56 participants were informed of the region of origin of each wine prior to tasting whereas the remaining 56 participants were not provided with origin information. Both groups knew that they were tasting Cabernet Sauvignon wines as this information was stated during the recruitment phase. Other than this, no other information about the wines was provided.

Sensory analysis was conducted in individual sensory booths equipped with a computer terminal under white fluorescent lighting and at a temperature of 22–23 °C. Samples (20 mL) were served at room temperature (22–23 °C) in black stemmed ISO wine glasses that were randomly coded with a four-digit number and covered by a petri dish. Tasters had a forced 1-min break after each sample and a 10-min break after 4 samples, and were advised to cleanse their palate with deionised water and unsalted crackers if desired.

Before tasting, consumers were asked questions about their demographics and wine consumption behaviour and were instructed to complete the fine wine instrument (FWI) proposed by Johnson and Bastian (2015), which was used to psychographically segment the consumer panel by their fine wine behaviour. Questions related to importance of the region stated on the label for purchase decision and how much to pay for a wine were evaluated on a scale encompassing "Not important", "Slightly important", "Moderately important", "Important", and "Very important". Participants began with sample ST as a warm-up and to enable comparison between data obtained from both groups. For that reason, this sample was evaluated the same way across the groups without any region information. The remaining samples were presented one by one in a random order for each participant.

During the tasting, participants were first questioned about their overall liking of the wine using a 9-point scale (from "dislike extremely" to "like extremely"), how familiar they were with the sample using a 5-

**Table 1**
Opinions about wine purchase behaviour (pre-tasting survey) and typicity (post-tasting survey) according to fine wine instrument consumer segmentation. Values in bold are significantly different between the segments.

| | Wine Enthusiasts % (n = 45) | Aspirants % (n = 50) | No Frills % (n = 17) | Total % (n = 112) |
|---|---|---|---|---|
| **Q1. Factors that influence the decision making when purchasing a wine** | | | | |
| Price | 76 | 86 | 100 | 84 |
| Previous experiences | 84 | 84 | 71 | 82 |
| Grape variety[a] | **93a** | **72b** | **76ab** | 81 |
| Provenance/origin | 78 | 60 | 53 | 66 |
| Local producer | 60 | 38 | 47 | 48 |
| Recommendation from experts of the industry | 53 | 36 | 24 | 41 |
| Brand loyalty | 44 | 30 | 53 | 39 |
| Medals or awards[a] | **49a** | **38ab** | **12b** | 38 |
| Recommendation from wine writers[a] | **56a** | **24b** | **18b** | 36 |
| Recommendation from bottle shop staff | 31 | 36 | 24 | 32 |
| Tasting notes on the back of the bottle | 29 | 28 | 29 | 29 |
| Cellaring potential[a] | **42a** | **16b** | **18ab** | 27 |
| Packaging, label and closure type | 18 | 26 | 47 | 26 |
| History or heritage[b] | **36** | **22** | **6** | 25 |
| Advertising, marketing, brand recognition | 11 | 24 | 29 | 20 |
| Novelty | 18 | 16 | 18 | 17 |
| Typicity/typicality | 11 | 8 | 29 | 12 |
| Organic or Biodynamic certification | 16 | 8 | 6 | 11 |
| Alcohol content | 11 | 8 | 0 | 8 |
| Environmental impact[b] | **16** | **2** | **0** | 7 |
| **Q2. Do you know what wine typicity (typicality) means?** | | | | |
| Yes, but it is not important for my purchasing decision. | 24 | 22 | 35 | 25 |
| Yes. It is an important concept for my purchasing decision. | 24 | 22 | 0 | 20 |
| I've heard about it but do not know what it means. | 24 | 30 | 18 | 26 |
| No, I do not know what it means. | 27 | 26 | 47 | 30 |
| **Q3. Which words do you consider to be associated with wine typicity (typicality)?** | | | | |
| Grape variety | 71 | 72 | 71 | 71 |
| Regionality | 76 | 60 | 53 | 65 |
| Country of origin | 62 | 50 | 59 | 56 |
| Terroir[a] | **62a** | **34b** | **41ab** | 46 |
| Soil type | 44 | 42 | 47 | 44 |
| Climate | 44 | 44 | 41 | 44 |
| Winemaking practices | 38 | 24 | 35 | 31 |
| Fruit flavour[a] | **38a** | **16b** | **35ab** | 28 |
| Oak use | 31 | 18 | 41 | 27 |
| Viticultural practices | 24 | 18 | 35 | 23 |
| Complexity | 22 | 22 | 23 | 22 |
| Wine quality | 24 | 22 | 18 | 22 |
| Unsure | 16 | 18 | 12 | 16 |
| Brand | 18 | 14 | 6 | 14 |
| Price | 4 | 14 | 6 | 9 |
| Closure type | 4 | 0 | 6 | 3 |
| Mouthfeel, taste and aroma | 4 | 0 | 6 | 3 |

[a] Chi-square test for significance with z-test for multiple comparison of means ($\alpha = 0.05$). Values in a row sharing the same letter are not statistically different.
[b] Fisher's exact test for significance ($\alpha = 0.05$).

point scale (from "not familiar" to "very familiar"), and in the case of the informed group, how familiar they were with the region presented for each sample. After each hedonic evaluation, the same sample was tasted again and evaluated using rate-all-that-apply (RATA) methodology (Danner et al., 2018). In this way, samples were characterised by rating on a 7-point scale (from "extremely low" to "extremely high") only those attributes that applied from a list of 53 encompassing aroma, flavour and mouthfeel attributes (Appendix A, Table A.1) derived from a previous study (Souza Gonzaga et al., 2020). Term randomisation across participants was used to minimise the influence of term order. After the RATA tasting, a second questionnaire was presented with questions examining the meaning of typicity and words associated with the concept. All data were collected through Red Jade software (2016, Redwood City, USA). Informed consent was obtained from panellists and this study was approved by the Human Research Ethics Committee of the University of Adelaide (approval number: H-2019-031).

### 2.3. Statistical analysis

The consumers' demographics data and questions involving frequency data were analysed using chi-square test and z-test for post hoc pairwise comparisons with SPSS (IBM SPSS Statistics, Armonk, NY, version 25.0). All other statistical analyses were performed using XLSTAT (Addinsoft, New York, USA, version 2019.4.1). Fisher's exact test was used instead of chi-square test for questions with an expected count of less than five. Non-parametric questions related to importance were analysed with Kruskal-Wallis test with Dunn's procedure for multiple comparison of means. The tasting data were firstly analysed with repeated measures ANOVA using sample and participant condition (informed or uninformed) as fixed factors, including their two-way interactions. Tukey's honestly significant difference (HSD) post hoc test was used for multiple comparison of the means. The fine wine segmentation was performed according to the methodology established by Johnson and Bastian (2015) using agglomerative hierarchical clustering (AHC) with Ward's clustering method and Euclidean distance. Principal component analysis (PCA) was used to analyse the samples according to the means of significantly different RATA attributes ($\alpha = 0.05$). Liking and sample familiarity scores were included as supplementary variables in the analysis. Multiple factor analysis (MFA) was used to compare and correlate the significantly different RATA attributes ($\alpha = 0.05$) between the two groups of consumers, again with sample familiarity and liking as supplementary variables.

## 3. Results

### 3.1. Characterisation of panel demographics and wine-related behaviour

Information characterising the panel is presented in Table B.1 of Appendix B. Chi-square test results demonstrated in general that both groups had the same demographic profile. The only difference was the education level, where the informed group had more respondents who were high school graduate or equivalent. Overall, more than half of the consumers indicated that they consumed wine more than a few times a week. In terms of Cabernet Sauvignon wine, 46% of participants consumed it at least once a week with a dominant proportion of the remainder selecting at least once a month. Most were willing to pay between AU$16 and $25 for a bottle of wine (Appendix B, Table B.1). Based on the FWI, it was also possible to compare segmentation of consumers within the informed and uninformed groups. In that case, a similar segment distribution was noted: the informed group had 24 wine Enthusiasts, 25 Aspirants, and 7 No Frills, whereas the uninformed group had 21 Wine Enthusiasts, 25 Aspirants, and 10 No Frills.

The FWI was used to segment consumers for an examination of differences between resultant cluster responses regarding purchase behaviour and the typicity concept. The demographic profile of each FWI segment can be seen in Table B.2 of Appendix B. A significant

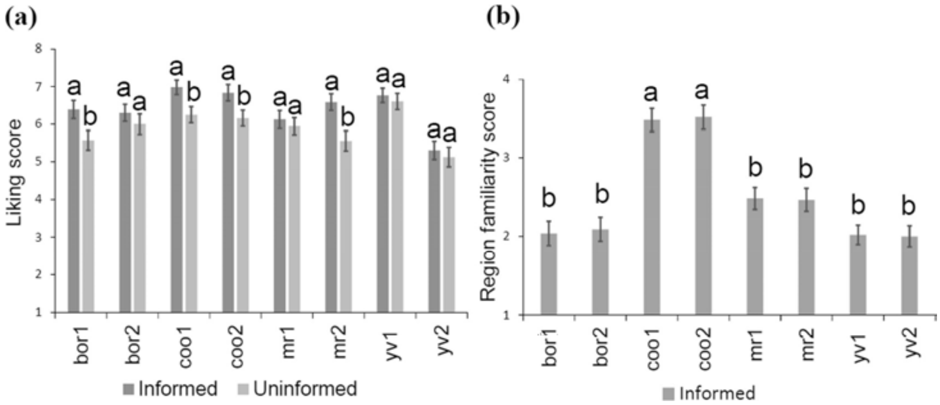


**Fig. 1.** Mean and standard error for (**a**) sample liking (9-point scale) for informed and uninformed consumer groups and (**b**) region familiarity (5-point scale) for the informed group only. Means not sharing a lower case letter for a given sample in panel (**a**) or between samples in panel (**b**) are statistically different (Tukey's honestly significant difference test, α = 0.05).

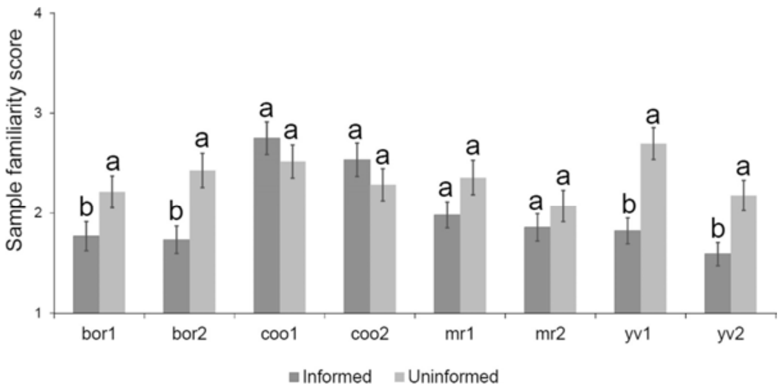


**Fig. 2.** Mean and standard error for sample familiarity scores between the informed and uninformed consumer groups. Means not sharing a lower case letter for a given sample are statistically different (Tukey's honestly significant difference test, α = 0.05).

difference (p = 0.03, chi-square) between the segments was only evident for wine consumption, where a significantly greater proportion of the No Frills segment (24%) consumed wine once a fortnight compared to Wine Enthusiasts (2%) and Aspirants (4%). The majority of the latter two segments consumed wine a few times a week (62% each) whereas the No Frills segment tended to drink wine less frequently on the whole. In terms of Cabernet Sauvignon wine, the vast majority of Wine Enthusiast respondents consumed it at least once a fortnight, whereas for Aspirants and No Frills consumers this broadened to at least once a month, with a high proportion of No Frills (41%) choosing "once a month" as a response (Appendix B, Table B.2). Across the three segments, the majority were willing to pay $16–$25 for a bottle of wine and only Wine Enthusiasts responded that they would pay $50 or more for a bottle (Appendix B, Table B.2).

When asked about the importance of the region when purchasing a wine, Wine Enthusiasts deemed this to be significantly more important (3.9 where 4 is "important") than Aspirants (3.3) and No Frills (2.8 where 3 is "moderately important") segments (p = 0.001, Kruskal-Wallis). Despite the divergence between the segments when asked about purchasing decision, no significant differences (p = 0.27) were detected regarding the price point decision based on the importance of region stated on the label, although the segments on average found it to range from "moderately important" for No Frills (3.0) and Aspirants (3.1) to "important" for Wine Enthusiasts (3.7).

The panel were also asked to select factors that were important for their purchase decision. Significant differences in frequency for the segments were observed for "Grape variety" (p = 0.025, chi-square test), "Medals or awards" (p = 0.027), "Recommendation from wine writers" (p = 0.001) and "Cellaring potential" (p = 0.010), as well as "History or heritage" (p = 0.047, Fisher's exact test) and "Environmental impact" (p = 0.035) (Table 1, Q1). "Recommendation from wine writers" was significantly higher for Wine Enthusiasts compared to Aspirants and No Frills. In a similar way, a greater proportion of Wine Enthusiasts selected "Medals and awards" compared to No Frills, and selected "Grape variety" and "Cellaring potential" more frequently than Aspirants. For "Environmental impact" and "History and heritage", Fisher's exact test showed these were selected by a higher proportion of Wine Enthusiasts than expected when compared to Aspirants and No Frills. "Price" was

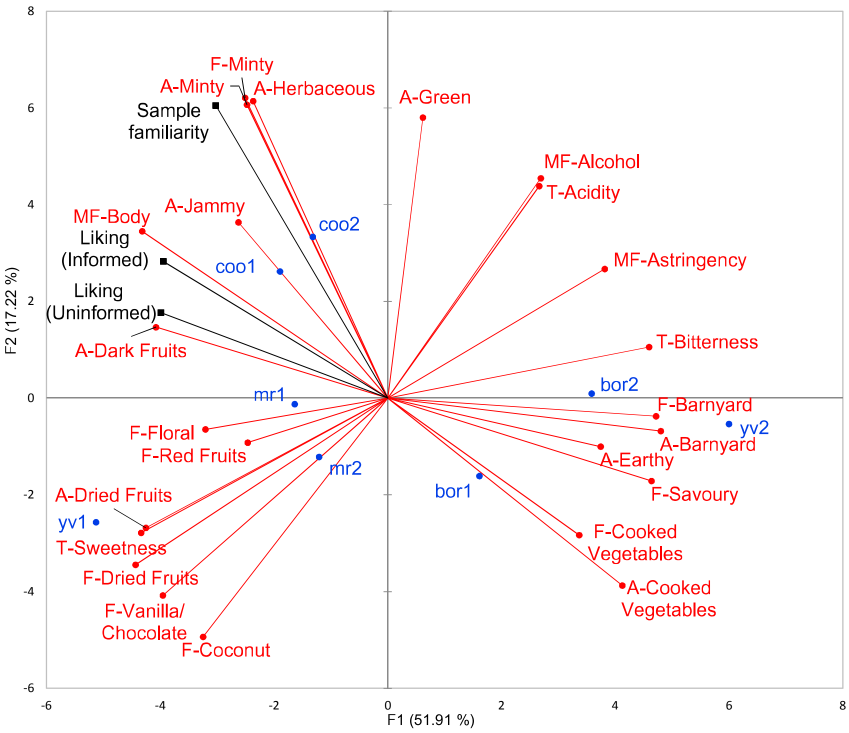


**Fig. 3.** Principal component analysis biplot for the significantly different attributes ($p < 0.05$) from combined RATA results of both consumer groups (red) for the eight Cabernet Sauvignon wines (blue). Liking score according to information level and sample familiarity score appear as supplementary variables (black). A- aroma; F- flavour; T- taste. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the top chosen factor influencing the purchase decision, representing a total of 84% of respondents. This was followed by "Previous experiences" with 82%, "Grape variety" with 81%, and "Provenance/Origin" with 66%. Within the segments, the most chosen factor for Wine Enthusiasts was "Grape Variety", representing 93%, whereas for Aspirants and No Frills, "Price" was the most selected (86% and 100%, respectively). "Environmental impact" was the least chosen answer with 7% response rate, preceded by "Alcohol content" with 8% and "Organic or biodynamic certification" with 11%.

The consumers were asked about their familiarity with the wine typicity concept, and although there were no significant differences between the segments, 45% of panellists were familiar with the term (Table 1, Q2). It was an important term for purchase decision for 20% of respondents, none of which were classified as No Frills (Table 1, Q2). A sizeable proportion of No Frills (47%) were not familiar with the typicity concept in contrast to Wine Enthusiasts and Aspirants, which were somewhat more evenly spread across the answers (Table 1, Q2).

The majority of the panel selected "Grape variety" (71%), "Regionality" (65%), and "Country of origin" (56%) as words that were associated with the concept of typicity (Table 1, Q3). There were no significant differences among the segments in terms of selection frequency for each of those particular words, with the proportion of Wine Enthusiasts being 71%, 76%, and 62% for "Grape variety", "Regionality", and "Country of origin", respectively, Aspirants being 72%, 60%, and 50%, and No Frills being 71%, 53%, and 59%. "Terroir" was fourth most selected word (46%) and had a significant difference ($p = 0.020$, chi-square) between segments, with Wine Enthusiasts (62%) more frequently choosing this word than Aspirants (34%). "Fruit flavour" was also significantly different ($p = 0.045$) between the segments and showed the same tendency as "Terroir", with Wine Enthusiasts (38%) associating this term with typicity more often than Aspirants (16%). "Soil type" and "Climate" were each selected by 44% of panellists whereas around a third of the overall panel or less thought that "Winemaking practices", "Viticultural practices", "Complexity", "Fruit flavour" and "Oak use" were words that related to typicity. Even fewer selected remaining words such as "Wine quality", "Brand", and "Price", and only 3% of panellists considered "Mouthfeel, taste and aroma" and "Closure type" as words associated with wine typicity, whereas 18% of panellists (12–18% across the segments) were unsure about which words related to typicity (Table 1, Q3).

Sample ST (i.e., the standard wine) was analysed separately to evaluate the comparability of the uninformed and informed groups. Repeated measures ANOVA showed that the liking score for the ST wine was not significantly different between the two consumer groups ($p = 0.678$), and of the 53 rated attributes (data not shown), only 4 were significant. These were 'red fruits' ($p = 0.011$), 'spices' ($p = 0.033$), 'green' ($p = 0.013$), and 'cooked vegetables' ($p = 0.019$).

### 3.2. *Effect of region information on hedonic and familiarity scores*

Analysis of variance showed that liking score was significantly different ($p < 0.0001$) between the samples with overall means varying between 5.2 and 6.7 (Appendix B, Table B.3). Sample yv2 was at the lower end of the scores and samples yv1, coo1, coo2, and bor2 were on the higher end according to Tukey's HSD test (Appendix B, Table B.3). Repeated measures ANOVA also demonstrated that having prior information regarding region of origin significantly increased ($p = 0.007$) the liking score independently of the samples, with the sample × information interaction not being significant ($p = 0.205$; Appendix A, Table A.1). Although in general, information improved liking of all samples, the informed group had significantly higher liking scores than the uninformed group for both Coonawarra samples (coo1 and coo2), for Bordeaux sample bor1, and for Margaret River sample mr2 (Fig. 1a). The means varied between 7.0 and 5.3 for the informed group and 6.6 and 5.1 for the uninformed group (Appendix B, Table B.3). Region familiarity scores (informed condition only), which had a significant moderate positive correlation with liking score ($r = 0.430$, $p < 0.0001$), were also significantly higher ($p < 0.0001$) for the Coonawarra samples in comparison with the rest (Fig. 1b).

As well as scoring overall liking, both groups were asked to score how familiar they were with the sample they were tasting. Sample familiarity was significantly different across samples ($p < 0.0001$, Appendix A, Table A.1) and mean values varied between 1.9 and 2.6, with sample yv2 on the lower end of the scores and coo1 on the higher end (Appendix B, Table B.4). According to the analysis of variance, sample familiarity was statistically different ($p = 0.036$, Fig. 2 and Table A.1 of Appendix A) between the two groups of panellists although the result was dependent on the sample, with a significant sample × information interaction ($p < 0.0001$, Appendix A, Table A.1). Fig. 2 shows that the informed consumer panel (region of origin known) had lower sample familiarity scores for both Bordeaux wines (bor2 with $p = 0.002$ and bor1 with $p = 0.041$) and both Yarra Valley wines (yv1 with $p < 0.0001$ and yv2 with $p = 0.002$), but did not differ for the remainder. Region of origin information had a positive impact for Coonawarra wines (differences in means of around 0.2) but a negative impact for the remainder of the wines (differences in means between −0.9 and −0.4).

### 3.3. *Effect of region information and hedonic scores on the panel sensory profiling*

Repeated measures ANOVA demonstrated that although the liking score was different between the groups, the information condition did not seem to impact their sample profiling, based on the lack of significant difference among the 53 sensory attributes ($p \geq 0.060$, Appendix A, Table A.1). Further supporting this assertion, MFA results showed agreement between the sample profiling of the two groups (Appendix B, Fig. B.1) with an RV coefficient of 0.868. Furthermore, Fig. 3 shows that the liking vectors for both groups (informed and uninformed) were plotted in close proximity and were associated with the same set of sensory descriptors.

RATA profiles also underwent repeated measures ANOVA, revealing that 24 of 53 attributes were statistically different ($p \leq 0.050$) between the samples (Appendix A, Table A.1). PCA of significant attributes (with liking and sample familiarity scores as supplementary variables) is shown in Fig. 3, where F1 explains 51.91% of the variance in the data and F2 explains another 17.22% (Fig. 3). The samples from Coonawarra, Margaret River and one from Yarra Valley (yv1) were plotted along the negative side of F1 while samples from Bordeaux and one from Yarra Valley (yv2) were plotted along the positive side of F1 (Fig. 3). F2 mainly segregated Coonawarra wines on the positive side from the others. Within a region, Bordeaux wines were separated along F2 to the greatest extent, although they were still in close proximity to each other.

The liking scores for both groups and the sample familiarity were all presented in the upper left quadrant along with 'minty', 'herbaceous', 'jammy', and 'dark fruits' aromas as well as 'minty' flavours and body, along with samples coo1 and coo2 (Fig. 3). The lower left quadrant contains 'dried fruits' aroma and flavour, 'floral', 'red fruits', 'vanilla/chocolate', and 'coconut' flavours, and sweetness along with samples mr1, mr2, and yv1. On the right of Fig. 3, mouthfeel attributes of astringency and alcohol, 'green' flavours, and bitter and acid taste were plotted in the upper quadrant along with sample bor2, whereas the lower quadrant had 'barnyard' and 'cooked vegetables' aromas and flavours, 'earthy' aroma, and 'savoury' flavour for samples bor1 and yv2.

## 4. Discussion

The results from the ST sample demonstrated that both consumer groups (informed and uninformed) evaluated the sample similarly, indicating that the data sets can be comparable and correlated. As such, any impact on liking, familiarity, and sensory profiles generated by the cohort in this study can be solely attributed to the region information and not to the differences in evaluation between the groups. The comparability of the groups is reaffirmed by their similar demographic characteristics (Appendix B, Table B.1).

### 4.1. *Factors important for consumer purchase decisions*

The FWI was chosen for the psychographic segmentation because it is a tool that was specifically developed to understand consumers who vary both in their interest in high quality fine wine and their knowledge about the Australian wine market (Danner et al., 2020; Johnson & Bastian, 2015). When asked about the importance of the region stated on the wine label for their purchase decisions, Wine Enthusiasts indicated that the region was more important compared to Aspirants and No Frills consumers. This may demonstrate that the importance of region when purchasing a wine is positively related to consumers' wine knowledge, degree of fine wine behaviour, and wine involvement. In general, region of origin had a level of importance for purchase decision for most of the panellists (i.e., "moderately important" to "important"), as well as for deciding how much to pay for a wine, although for the latter there were no significant differences between consumer segments. In fact, as Kustos et al. (2019) demonstrated, even though provenance appeared as a valuable factor for Australian consumers, Wine Enthusiasts seemed to have broader knowledge of the concept compared to the other segments. Other studies have shown that consumers indeed place trust in wine's provenance as an expression of quality, thus positively influencing their price point decision (D'Alessandro & Pecotich, 2013; Hollebeek et al., 2007; Schamel, 2006; Spielmann, 2015). For New World wine consumers, regionality was considered as one of the factors of a fine wine according to a study by Kustos et al. (2019).

The responses in Table 1 for Q1 show that typicity was not only a concept known by a high number of consumers but it might also be important for their purchase behaviour. According to Boncinelli et al. (2016), the extrinsic typicity (i.e., local or international origin) associated with a wine is also an aspect considered by consumers to be related with high quality. Additionally, Table 1, Q1 demonstrates that consumers have some knowledge of the connection between wine typicity concept and place of origin by associating wine typicity with "Grape variety", "Terroir", "Country of origin", and "Regionality". However, this concept seemed to be considered as a more extrinsic aspect of a wine, considering that intrinsic sensory attributes ("Mouthfeel, taste and aroma") were not associated with typicity by the majority of the panel. Boncinelli et al. (2016) demonstrated that the importance of typicity aspects of a wine for the consumer were not associated with its perceived sensory composition, but rather the preconceived notions around that specific wine category. For that reason, increasing the relationship between the wine and its provenance and increasing the consumer's involvement with wine through wine tourism could positively influence their purchase decision and aggregate more value to the wine (Boncinelli et al., 2016; Famularo et al., 2010).

Purchase decision seemed to be influenced mostly by "Price", "Provenance/origin", "Grape variety", and "Previous experiences" (Table 1, Q1). Factors such as "Grape variety", "Cellaring potential", "Medals or awards", "History or heritage", "Environmental impact", and "Recommendation from wine writers" seemed to be more important for consumers with higher involvement with wine. In fact, it has been previously reported that grape variety, personal recommendations, and region of origin (in that order) are important influences for Australian wine consumer decision-making (Kustos et al., 2019).

It is noteworthy that "Brand loyalty" was not one of the major factors impacting the wine purchase decision, with a response rate of 39%. This differentiates the present results from those reported by Atkin and Johnson (2010) and Johnson and Bruwer (2007), in which brand came in second and first, respectively, in terms of being a wine quality indicator that may impact the purchase decision for US consumers. The difference may be explained on the basis that Australian consumers perceive most Australian brands to be trustworthy, so choosing a different brand is a relatively risk free proposition. Australian consumers may also be more willing to seek new experiences and increase their knowledge (Bianchi et al., 2014).

### 4.2. Impact of wine origin information on consumer liking

Of the samples that were significantly different between the conditions, those that had their provenance disclosed (i.e., informed condition) were more preferred than the samples that were tasted without such knowledge, demonstrating that region of origin information may have had a positive impact over hedonic results (Fig. 1a). Accordingly, region of origin was reported to be one of the top five factors used as a quality indicator for wine consumers (Atkin & Johnson, 2010; Johnson & Bruwer, 2007) and also positively impacted the price point decision (Vecchio et al., 2019). Higher liking scores for the Coonawarra samples could be explained by how familiar the informed group were with region as shown in Fig. 1b, and by the moderate positive correlation ($r = 0.430$) between region familiarity and liking scores. In other words, consumers reported a higher preference for samples coming from Coonawarra because they were more familiar with the region in question. Indeed, region of origin can be a major factor for decision making when consumer familiarity with the region exists (Perrouty et al., 2006). It is noteworthy that there could also be an influence of consumer expectation, which plays a role in sensory perception of wine as shown by Ashton (2014) with California and New Jersey wines and by Siegrist and Cousin (2009) in terms of positive and negative information about wine.

Curiously, familiarity with the sensory traits of the samples appeared to be inversely related with region of origin information. That is, consumers who tasted the samples under the uninformed condition were more familiar on the whole with the taste and aroma of the wines, with the exception of the Coonawarra and Margaret River samples (Fig. 2). The uninformed panel presumably did not have any expectation around the sensory profiles of the samples as a function of region, leading to the perception that they were more familiar with the wines as a consequence. However, it is worth pointing out that the interaction between information condition and samples was significant. This could be the result of the difference in impact of the Coonawarra samples when compared to the remainder, even though no significant differences were evident for the Coonawarra samples (coo2 with $p = 0.283$ and coo1 with $p = 0.317$). The fact that no significant differences were found between the two consumer groups for the Coonawarra and Margaret River samples could potentially be explained on the basis of the panel composition. As the majority of the consumers were from South Australia, they were possibly more familiar with both of these regions.

### 4.3. Sensory profiling of the samples

Reviewing the ANOVA results for the attributes against the consumer groups (informed and uninformed), it was interesting to note that although the information impacted significantly on liking score, it did not appear to have much influence on wine aroma and flavour attributes, considering that none of the attributes were significant at $\alpha = 0.05$ (Appendix A, Table A.1). In other words, both groups profiled the wine sensory traits in the same way (as verified by MFA, Appendix B, Fig. B.1), so the difference in liking score between the groups (which were actually closely related according to Fig. 3) can be attributed to whether they had information on the origin of the wine or not (as discussed in Section 4.2). The opposite was seen when analysing different tasting environments (e.g., restaurant, sensory booth, home, etc.), whereby liking did not change across the environments, but differences in the sensory traits were perceived (Torrico et al., 2020) and different consumer emotions were evoked (Danner et al., 2016).

It was previously demonstrated that consumers are capable of discriminating wine from a typical warm region and a typical cool region through emotional responses (Coste et al., 2018). The PCA results of the present work (Fig. 3) show that consumers can also be used to discriminate regional profiles, since it is clear that with the exception of Yarra Valley wines, samples from the same region were plotted in close proximity. In general, Margaret River and Coonawarra wines shared more similarities when compared to Bordeaux samples, based on the two Australian regions being plotted on the same side of F1. It could be proposed that this distinction was a result of an assessment between wines coming from an Old World and a New World wine producing country, with distinctiveness for each around production method and environmental conditions of the region as well as intended style (Baciocco et al., 2014; Hervé & Jean-Pierre, 2006).

The distinctiveness could also be associated with differences in blend composition, whereby the Bordeaux wines had a lower proportion of Cabernet Sauvignon compared to the Australian counterparts. Coonawarra samples were characterised by a fuller body mouthfeel, 'jammy', 'minty', and 'herbaceous' aromas and 'minty' flavour (Fig. 3), which contrasted with the savoury style and lack of fruity characters found in the Bordeaux samples, such as 'barnyard' and 'cooked vegetables' flavours and aromas, 'earthy' aroma, and 'savoury' flavour. Considering the set of wines was from the 2015 vintage, such an influence from developed (tertiary) characters can be expected as a result of chemical transformations that occur during wine ageing (Ugliano, 2013). Additionally, descriptors like 'barnyard' can be related to occurrence of *Brettanomyces* spp. yeast during fermentation or ageing, generating volatile compounds that can impact the final product (Wedral et al., 2010). The 'minty' aroma found for Coonawarra wines accorded with the results of Robinson et al. (2011), despite the differences in vintage and sensory methodology used in each case. The only region in the present study that did not seem to yield a consensus about the sensory characterisation was Yarra Valley, in which one of the samples (yv2) seemed to be more akin to an Old World wine style (plotted close to the Bordeaux samples) whereas the other Yarra Valley wine (yv1) was deemed to be of a style that more closely aligned with the other Australian Cabernet Sauvignon producing regions. The difference between the Yarra Valley wines might be attributable to winemaking practices, choice of oak, or maturation regime, for example.

Margaret River was related to floral and fruit-forward characters such as 'dark fruits' and 'dried fruits' aromas, and 'red fruits' and 'floral' flavours. Margaret River also had the presence of 'coconut' and 'vanilla/

chocolate' aromas that can be associated with contact with oak during winemaking. Although not strictly attributable to the region, decisions regarding oak use are part of the terroir concept and will generate sensory characters that not only depend on the process itself (e.g., barrel maturation or oak chip incorporation during fermentation) but also on the oak material (e.g., type and origin) and its treatment (e.g., seasoning, toasting level) (Crump et al., 2015; Francis et al., 1992).

The regional characterisation found through this sensory evaluation with consumers reaffirms previous studies, in which the greater overall distinction on a regional basis occurred between wines from Bordeaux and the Australian examples, with the Australian wines sharing a range of sensory attributes (Souza Gonzaga, Capone, Bastian, Danner, & Jeffery, 2019, 2020). From the combination of all the results, some sensory descriptors seemed to stand out as a good marker for the regions analysed, such as 'floral' and 'red fruits' for Margaret River wines, 'savoury', 'cooked vegetables', and 'barnyard' for Bordeaux wines, and 'minty', 'full body', and 'herbaceous' for Coonawarra wines (Souza Gonzaga, Capone, Bastian, Danner, & Jeffery, 2019, 2020).

### 4.4. Gaps requiring further research

Further research is necessary to better understand how consumers may describe the sensory profile of wines in the same way while at the same time differing in liking, which was positively influenced by prior information about region. This could confirm whether there is an assimilation effect or it is a result of the difference between performing a more holistic test (hedonics) and a more analytical evaluation (RATA). It would be interesting to study whether this effect is carried over when analysing different tasting contexts and consumer emotions. Research is also necessary to understand the origin of the sensory attributes from each region, their chemical drivers, and how vineyard practices and winery processes can impact them, so that the industry is able to enhance desirable characteristics and avoid the undesirable ones according to consumer opinions and involvement with wine. Ultimately, that may conceivably require the production of different styles of regional wine for different consumer segments. Finally, as this study was executed in South Australia, it was inevitable that this could influence the results in terms of consumer familiarity with the wines. Whether this is an important aspect or not will require further study and it would be worthwhile determining if such results could be replicated in another location or by including different cultures.

## 5. Conclusion

Wine typicity is a concept not only important for the wine industry but also for the consumers' purchase decision. It is evident that typicity is not a foreign term for many of the consumers who participated in this study: they seem to have a broad idea of the meaning of the concept and its connection with wine and its 'sense of place'. It appeared, however, that the consumers surveyed in this study may have associated typicity with an extrinsic construct rather than to inherent characteristics such as aroma, flavour, and mouthfeel of the wine. Additional qualitative research with open-ended questions would be useful to further understand the meaning of typicity for consumers. It was clear that information about provenance (e.g., on a bottle of wine) may positively influence a consumer's purchase decision but also the price they are willing to pay, although this should be tested with research involving real purchases. Conjoint analysis in future studies could also provide better insight into how extrinsic factors can influence consumer behaviour and purchase intent. This study demonstrated that having prior information about region of origin can increase the consumer hedonic score. Interestingly, provenance information did not seem to impact the overall characterisation of the samples, revealing that although the informed consumer group scored a higher preference for the wine when they knew of its origin, that information did not seem to impact their sensory profiling of the wines compared to the uninformed group. Additionally, sensory familiarity impacted differently on each sample, with region information having an inverse effect compared to liking score, with the exception of Coonawarra samples.

Regional profiles emerged from the RATA results, showing that segregation of wines based on sensory characteristics of each region is a possibility, as identified previously. This statement needs to be taken with some caution, however, because the outcomes may not be solely considered as representative of a specific region due to the limited number of samples. Nonetheless, it was apparent that the consumer cohort was familiar with samples that presented 'minty' and 'herbaceous' aromas and flavours, and that they preferred wine that had fuller body mouthfeel, 'dark fruits', and 'jammy' aromas and flavours. It was also possible to demonstrate that consumers could conceivably use sensory traits to identify and differentiate wines from distinct regions.

## CRediT authorship contribution statement

**Lira Souza Gonzaga:** Conceptualisation, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Susan E.P. Bastian:** Conceptualisation, Funding acquisition, Methodology, Resources, Supervision, Writing – review & editing. **Dimitra L. Capone:** Conceptualisation, Methodology, Supervision, Writing – review & editing. **Lukas Danner:** Methodology, Supervision, Writing – review & editing. **David W. Jeffery:** Conceptualisation, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing – review & editing.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Repeated measures ANOVA results

See Table A.1.

**Table A1**
Repeated measures ANOVA results for liking, sample familiarity, and RATA attributes scores of Cabernet Sauvignon wines from different regions in relation to information condition and sample. Values in bold are significantly different (α = 0.05). A- Aroma, F- Flavour, MF- Mouthfeel, and T- Taste.

| | Information | | Sample | | Sample × Information | |
|---|---|---|---|---|---|---|
| Attribute | F | p-value | F | p-value | F | p-value |
| Liking | 7.695 | **0.007** | 10.350 | **<0.0001** | 1.393 | 0.205 |
| Sample familiarity | 4.520 | **0.036** | 10.698 | **<0.0001** | 7.085 | **<0.0001** |
| A-Barnyard | 2.993 | 0.086 | 7.896 | **<0.0001** | 0.720 | 0.655 |
| A-Coconut | 0.323 | 0.571 | 0.658 | 0.708 | 0.661 | 0.706 |
| A-Confectionery | 0.617 | 0.434 | 1.330 | 0.233 | 1.799 | 0.084 |
| A-Cooked vegetables | 2.116 | 0.149 | 4.735 | **<0.0001** | 0.349 | 0.931 |
| A-Dark fruits | 0.004 | 0.949 | 2.788 | **0.007** | 0.526 | 0.815 |
| A-Dried fruits | 0.359 | 0.550 | 2.130 | **0.038** | 0.616 | 0.743 |
| A-Earthy | 0.312 | 0.577 | 2.570 | **0.013** | 1.450 | 0.182 |
| A-Eucalyptus | 0.142 | 0.707 | 1.939 | 0.061 | 0.307 | 0.951 |
| A-Floral | 0.012 | 0.913 | 1.403 | 0.201 | 0.851 | 0.545 |
| A-Grassy | 0.041 | 0.840 | 1.375 | 0.213 | 0.763 | 0.619 |
| A-Green | 1.474 | 0.227 | 3.670 | **0.001** | 1.746 | 0.095 |
| A-Herbaceous | 0.069 | 0.793 | 2.800 | **0.007** | 0.835 | 0.558 |
| A-Jammy | 0.049 | 0.825 | 2.041 | **0.048** | 0.559 | 0.789 |
| A-Liquorice | 1.459 | 0.230 | 1.208 | 0.296 | 1.036 | 0.404 |
| A-Minty | 0.068 | 0.794 | 3.624 | **0.001** | 0.888 | 0.515 |
| A-Oaky | 0.334 | 0.565 | 1.959 | 0.058 | 0.455 | 0.867 |
| A-Pepper | 0.302 | 0.583 | 1.243 | 0.276 | 1.246 | 0.275 |
| A-Oaky | 0.334 | 0.565 | 1.959 | 0.058 | 0.455 | 0.867 |
| A-Pepper | 0.302 | 0.583 | 1.243 | 0.276 | 1.246 | 0.275 |
| A-Red fruits | 2.481 | 0.118 | 1.724 | 0.100 | 0.786 | 0.599 |
| A-Savoury | 2.534 | 0.114 | 1.142 | 0.335 | 0.390 | 0.908 |
| A-Spices | 0.681 | 0.411 | 0.738 | 0.640 | 1.039 | 0.402 |
| A-Tobacco | 0.132 | 0.717 | 1.713 | 0.103 | 1.453 | 0.181 |
| A-Vanilla/chocolate | 0.315 | 0.576 | 1.472 | 0.174 | 0.906 | 0.501 |
| A-Violets | 0.235 | 0.629 | 1.525 | 0.155 | 0.628 | 0.733 |
| F-Barnyard | 2.854 | 0.094 | 3.938 | **<0.0001** | 0.975 | 0.448 |
| F-Coconut | 0.036 | 0.850 | 2.137 | **0.038** | 1.083 | 0.373 |
| F-Confectionery | 3.013 | 0.085 | 1.242 | 0.277 | 2.565 | **0.013** |
| F-Cooked vegetables | 2.283 | 0.134 | 3.447 | **0.001** | 1.770 | 0.090 |
| F-Dark fruits | 0.467 | 0.496 | 1.186 | 0.308 | 1.507 | 0.161 |
| F-Dried fruits | 1.514 | 0.221 | 2.887 | **0.006** | 0.667 | 0.700 |
| F-Earthy | 1.392 | 0.241 | 1.968 | 0.057 | 0.950 | 0.467 |
| F-Eucalyptus | 0.118 | 0.732 | 1.063 | 0.386 | 1.082 | 0.373 |
| F-Floral | 0.183 | 0.670 | 2.019 | **0.050** | 0.150 | 0.994 |
| F-Grassy | 0.030 | 0.863 | 1.742 | 0.096 | 1.453 | 0.181 |
| F-Green | 0.803 | 0.372 | 1.352 | 0.223 | 0.539 | 0.805 |
| F-Herbaceous | 0.102 | 0.750 | 0.970 | 0.452 | 1.002 | 0.429 |
| F-Jammy | 0.826 | 0.366 | 1.431 | 0.189 | 1.312 | 0.242 |
| F-Liquorice | 1.993 | 0.161 | 0.824 | 0.567 | 0.296 | 0.955 |
| F-Minty | 0.360 | 0.550 | 2.855 | **0.006** | 0.366 | 0.922 |
| F-Oaky | 0.400 | 0.528 | 1.435 | 0.188 | 0.608 | 0.750 |
| F-Pepper | 2.042 | 0.156 | 0.569 | 0.781 | 0.971 | 0.451 |
| F-Red fruits | 2.057 | 0.154 | 4.136 | **<0.0001** | 0.331 | 0.940 |
| F-Savoury | 0.819 | 0.368 | 2.757 | **0.008** | 0.641 | 0.722 |
| F-Spices | 0.026 | 0.871 | 0.673 | 0.695 | 0.827 | 0.565 |
| F-Tobacco | 0.001 | 0.969 | 1.428 | 0.190 | 1.614 | 0.128 |
| F-Vanilla/chocolate | 1.087 | 0.300 | 2.784 | **0.007** | 0.806 | 0.582 |
| F-Violets | 1.006 | 0.318 | 1.714 | 0.102 | 0.839 | 0.555 |
| MF-Alcohol | 0.740 | 0.391 | 2.890 | **0.005** | 0.925 | 0.486 |
| MF-Astringency | 0.127 | 0.722 | 5.179 | **<0.0001** | 0.686 | 0.684 |
| MF-Body | 0.126 | 0.723 | 4.047 | **<0.0001** | 2.167 | **0.035** |
| T-Acidity | 0.525 | 0.470 | 3.799 | **<0.0001** | 0.697 | 0.674 |
| T-Bitterness | 0.009 | 0.925 | 3.811 | **<0.0001** | 1.469 | 0.175 |
| T-Sweetness | 0.312 | 0.577 | 6.215 | **<0.0001** | 0.893 | 0.512 |
| Flavour length | 3.602 | 0.060 | 0.913 | 0.496 | 2.149 | **0.037** |

## Appendix B. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodres.2021.110719.

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## APPENDIX B

## SUPPLEMENTARY INFORMATION FOR

# Consumer perspectives of wine typicity and impact of region information on the sensory perception of Cabernet Sauvignon wines

Lira Souza Gonzaga[a,b], Susan E. P. Bastian[a,b], Dimitra L. Capone[a,b], Lukas Danner[a], David W. Jeffery[a,b,*]

[a] Department of Wine Science and Waite Research Institute, The University of Adelaide, PMB 1, Glen Osmond, South Australia 5064, Australia

[b] Australian Research Council Training Centre for Innovative Wine Production, The University of Adelaide, PMB 1, Glen Osmond, South Australia 5064, Australia

* Corresponding author.

*Email address*: david.jeffery@adelaide.edu.au (D.W. Jeffery)

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**Table B.1**
Demographic characterisation of the consumer panel that evaluated Cabernet Sauvignon wines from different regions either without (uninformed) or with (informed) origin information. Values in bold are significantly different between the two groups.

| | Uninformed % (n = 56) | Informed % (n = 56) | Total % (n=112) |
|---|---|---|---|
| **Age Range** | | | |
| 18-34 | 32 | 16 | 24 |
| 35-49 | 23 | 23 | 23 |
| 50-64 | 20 | 36 | 28 |
| Over 65 | 25 | 25 | 25 |
| **Gender** | | | |
| Male | 43 | 45 | 44 |
| Female | 57 | 54 | 55 |
| Prefer not to specify | 0 | 2 | 1 |
| **Education Level** | | | |
| High School Graduate or Equivalent[a] | **7** | **29** | 18 |
| Trade, Technical or Vocational Training | 11 | 5 | 8 |
| Diploma, Advanced Diploma | 11 | 14 | 13 |
| Bachelor's Degree | 30 | 25 | 28 |
| Doctorate or Master Degree | 41 | 27 | 34 |
| **Household Income** | | | 0 |
| Under $50,000 | 43 | 27 | 35 |
| $50,000 to $99,999 | 34 | 32 | 33 |
| $100,000 to $199,999 | 16 | 36 | 26 |
| $200,000 and over | 7 | 5 | 6 |
| **Wine consumption** | | | |
| Daily | 16 | 13 | 14 |
| A few times a week | 54 | 63 | 58 |
| Once a week | 21 | 16 | 19 |
| Once a fortnight | 5 | 7 | 6 |
| Once a month | 5 | 0 | 3 |
| Once every 2 months | 0 | 0 | 0 |
| Once every 6 months | 0 | 0 | 0 |
| Once a year | 0 | 0 | 0 |
| **Cabernet Sauvignon wine consumption** | | | |
| Daily | 0 | 0 | 0 |
| A few times a week | 20 | 16 | 18 |
| Once a week | 25 | 32 | 28 |
| Once a fortnight | 21 | 29 | 25 |
| Once a month | 21 | 21 | 21 |
| Once every 2 months | 9 | 0 | 4 |
| Once every 6 months | 4 | 2 | 3 |
| Once a year | 0 | 0 | 0 |
| **How much are you willing to pay for your bottle of wine?** | | | |
| $15 or less | 13 | 14 | 13 |
| $16-$25 | 63 | 54 | 58 |
| $26-$49 | 23 | 25 | 24 |
| $50-$70 | 0 | 7 | 4 |
| $71-$99 | 2 | 0 | 1 |
| $100 or more | 0 | 0 | 0 |

[a]Chi-square test for significance ($p = 0.03$) with z-test for comparison of means ($\alpha = 0.05$).

**Table B.2**
Demographic characterisation of the consumer panel that evaluated Cabernet Sauvignon wines from different regions with segmentation based on the fine wine instrument. Values in bold are significantly different between the segments.

| | Wine Enthusiasts % (n= 45) | Aspirants % (n=50) | No Frills % (n= 17) | Total % (n=112) |
|---|---|---|---|---|
| **Age Range** | | | | |
| 18-34 | 11 | 30 | 41 | 24 |
| 35-49 | 20 | 24 | 29 | 23 |
| 50-64 | 36 | 24 | 18 | 28 |
| Over 65 | 33 | 22 | 12 | 25 |
| **Gender** | | | | |
| Male | 53 | 36 | 41 | 44 |
| Female | 47 | 62 | 59 | 55 |
| Prefer not to specify | 0 | 2 | 0 | 1 |
| **Education Level** | | | | |
| High School Graduate or Equivalent | 16 | 22 | 12 | 18 |
| Trade, Technical or Vocational Training | 7 | 10 | 6 | 8 |
| Diploma, Advanced Diploma | 13 | 10 | 18 | 13 |
| Bachelor's Degree | 24 | 32 | 24 | 28 |
| Doctorate or Master Degree | 40 | 26 | 41 | 34 |
| **Household Income** | | | | 0 |
| Under $50,000 | 31 | 36 | 41 | 35 |
| $50,000 to $99,999 | 31 | 36 | 29 | 33 |
| $100,000 to $199,999 | 31 | 24 | 18 | 26 |
| $200,000 and over | 7 | 4 | 12 | 6 |
| **Wine consumption** | | | | |
| Daily | 20 | 10 | 12 | 14 |
| A few times a week | 62 | 62 | 35 | 58 |
| Once a week | 13 | 22 | 24 | 19 |
| Once a fortnight[a] | **2b** | **4b** | **24a** | 6 |
| Once a month | 0 | 0 | 6 | 3 |
| Once every 2 months | 0 | 2 | 0 | 0 |
| Once every 6 months | 2 | 0 | 0 | 0 |
| Once a year | 0 | 0 | 0 | 0 |
| **Cabernet Sauvignon wine consumption** | | | | 0 |
| Daily | 0 | 0 | 0 | |
| A few times a week | 22 | 18 | 6 | 18 |
| Once a week | 36 | 26 | 18 | 29 |
| Once a fortnight | 27 | 24 | 24 | 25 |
| Once a month | 13 | 22 | 41 | 21 |
| Once every 2 months | 0 | 8 | 6 | 4 |
| Once every 6 months | 2 | 2 | 6 | 3 |
| Once a year | 0 | 0 | 0 | 0 |
| **How much are you willing to pay for your bottle of wine?** | | | | |
| $15 or less | 7 | 16 | 24 | 13 |
| $16-$25 | 60 | 56 | 59 | 58 |
| $26-$49 | 22 | 28 | 18 | 24 |
| $50-$70 | 9 | 0 | 0 | 4 |
| $71-$99 | 2 | 0 | 0 | 1 |
| $100 or more | 0 | 0 | 0 | 0 |

[a]Chi-square test for significance ($p = 0.03$) with z-test for multiple comparison of means ($\alpha = 0.05$). Values in a row sharing the same letter are not statistically different.

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**Table B.3**
Mean values for liking of Cabernet Sauvignon wines from different regions showing overall liking and scores segregated between the groups (uninformed and informed). The p-values are based on information condition with significant differences for a given wine shown in bold (repeated measures ANOVA).

| Samples | Overall mean liking (n = 112)[a] | Mean liking by condition | | |
|---|---|---|---|---|
| | | Informed (n = 56) | Uninformed (n = 56) | p-value |
| bor1 | 6.0ab | 6.4 | 5.6 | **0.024** |
| bor2 | 6.2a | 6.3 | 6.0 | 0.393 |
| coo1 | 6.6a | 7.0 | 6.2 | **0.012** |
| coo2 | 6.5a | 6.8 | 6.2 | **0.028** |
| mr1 | 6.0ab | 6.1 | 5.9 | 0.589 |
| mr2 | 6.1ab | 6.6 | 5.6 | **0.004** |
| yv1 | 6.7a | 6.8 | 6.6 | 0.579 |
| yv2 | 5.2b | 5.3 | 5.1 | 0.619 |

[a]Repeated measures ANOVA ($p < 0.0001$) with Tukey HSD test for multiple comparison of means ($\alpha = 0.05$). Values in a column sharing the same letter are not statistically different.

**Table B.4**
Mean values for overall sample familiarity of Cabernet Sauvignon wines from different regions. Values sharing the same letter are not statistically different (Tukey HSD test, $\alpha = 0.05$). See Table A.1 of Appendix A for the repeated measures ANOVA result for sample familiarity.

| Sample | Sample familiarity |
|---|---|
| coo1 | 2.6a |
| coo2 | 2.4ab |
| yv1 | 2.2abc |
| mr1 | 2.2abc |
| bor2 | 2.1bc |
| bor1 | 2.0bc |
| mr2 | 2.0bc |
| yv2 | 1.9c |

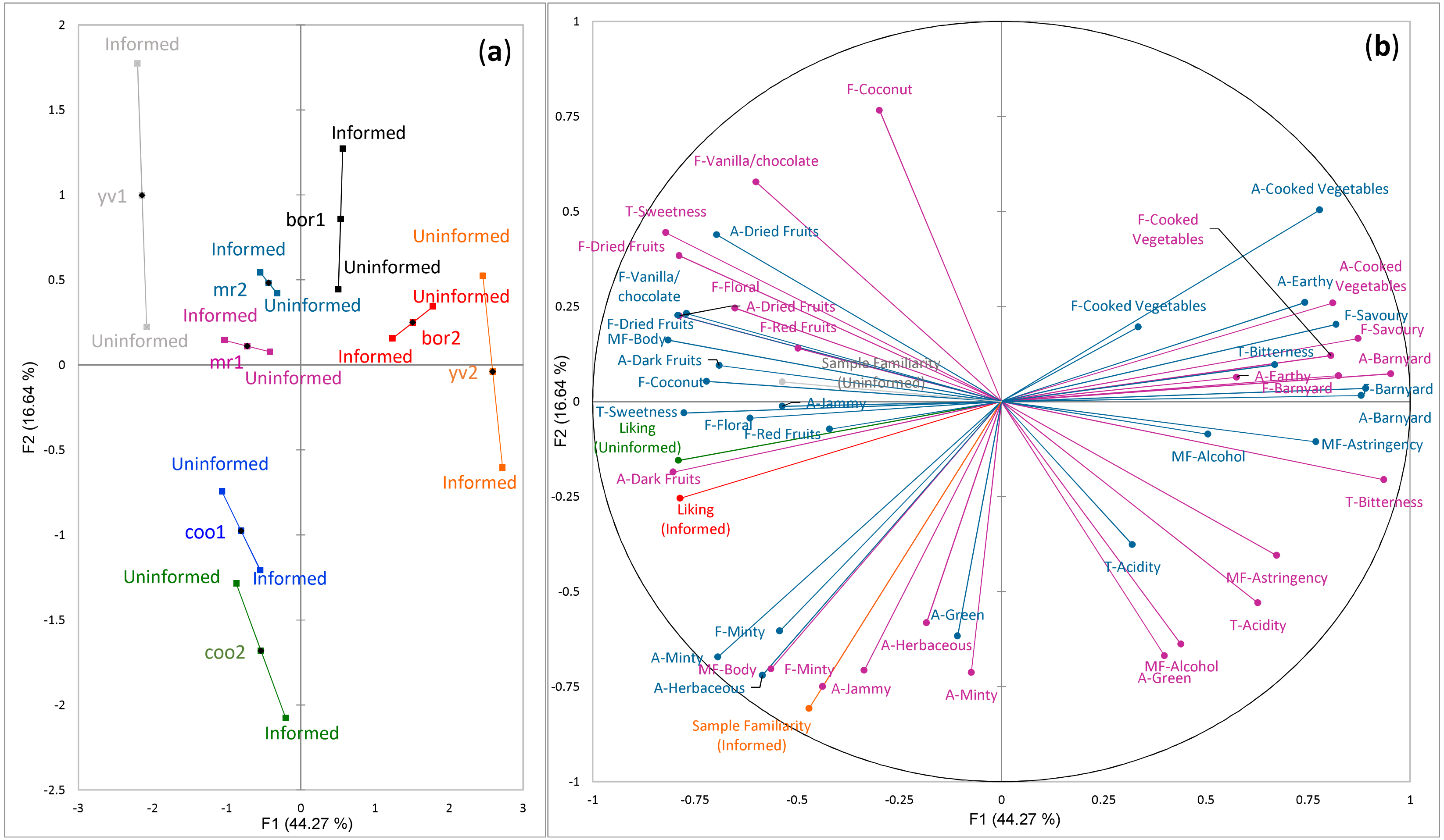


**Fig. B.1.** Multiple factor analysis plots of Cabernet Sauvignon wines with significantly different (α = 0.05, ANOVA) RATA attributes of the two consumer panel groups (informed and uninformed) showing (**a**) projected points of the samples positioned about the mid-point in relation to the two datasets, where the length of the line is inversely related to the strength of the agreement, and (**b**) descriptors arising from the informed panel (in purple) and the uninformed panel (in blue). Sample familiarity (informed in orange and uninformed in grey) and liking scores (informed in red and uninformed in green) were plotted as supplementary variables.

# Chapter 5

## Publication

Modelling Cabernet-Sauvignon wine sensory traits with spectrofluorometric data

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# Statement of Authorship

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## Principal Author

| | | | |
|---|---|---|---|
| Name of Principal Author (Candidate) | Lira Souza Gonzaga | | |
| Contribution to the Paper | Sourced all the wine samples. Designed, prepared and conducted the sensory evaluation. Carried out statistical analysis of the data collected. Prepared the complete first draft of the manuscript and incorporated revisions. | | |
| Overall percentage (%) | 70% | | |
| Certification: | This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper. | | |
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## Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

| | | | |
|---|---|---|---|
| Name of Co-Author | Susan E. P. Bastian | | |
| Contribution to the Paper | Assisted with the study design and supervised the project. Discussed the results and provided critical feedback. Critically evaluated and revised the manuscript. | | |
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| | | | |
|---|---|---|---|
| Name of Co-Author | Dimitra L. Capone | | |
| Contribution to the Paper | Assisted with sample sourcing and preparation. Assisted with the study design and supervised the project. Discussed the results and provided critical feedback. Critically evaluated and revised the manuscript. | | |
| Signature | | Date | 26/10/2021 |

| | | | |
|---|---|---|---|
| Name of Co-Author | Ruchira K. R. Ranaweera | | |
| Contribution to the Paper | Assisted with the data extraction on the spectrofluorometric analysis. Assisted with the statistical analysis of the data. Discussed the results and provided critical feedback. Critically evaluated and revised the manuscript. | | |
| Signature | | Date | 26/10/2021 |

| | | | |
|---|---|---|---|
| Name of Co-Author | David W. Jeffery | | |
| Contribution to the Paper | Supervised and directed the project. Discussed the study design and results, and provided critical feedback. Critically evaluated and revised the manuscript. Acted as corresponding author. | | |
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Please cut and paste additional co-author panels here as required.

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# Modelling Cabernet-Sauvignon wine sensory traits from spectrofluorometric data

Lira Souza Gonzaga[1,2], Susan E. P. Bastian[1,2], Dimitra L. Capone[1,2], Ranaweera K. R. Ranaweera[1] and David W. Jeffery[1,2]*

[1] Department of Wine Science and Waite Research Institute, The University of Adelaide, PMB 1, Glen Osmond, South Australia 5064, Australia
[2]Australian Research Council Training Centre for Innovative Wine Production, The University of Adelaide, PMB 1, Glen Osmond, South Australia 5064, Australia

**corresponding author*: david.jeffery@adelaide.edu.au

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ABSTRACT

Understanding how wine compositional traits can be related to sensory profiles is an important and ongoing challenge. Enhancing knowledge in this area could assist producers to select practices that deliver wines of the desired style and sensory specifications. This work reports the use of spectrofluorometry in conjunction with chemometrics for prediction, correlation, and classification based on sensory descriptors obtained using a rate-all-that-apply sensory assessment of Cabernet-Sauvignon wines (n = 26). Sensory results were first subjected to agglomerative hierarchical cluster analysis, which separated the wines into five clusters represented by different sensory profiles. The clusters were modelled in conjunction with excitation-emission matrix (EEM) data from fluorescence measurements using extreme gradient boosting discriminant analysis. This machine learning technique was able to classify the wines into the pre-defined sensory clusters with 100 % accuracy. Parallel factor analysis of the EEMs identified four main fluorophore components that were tentatively assigned as catechins, phenolic aldehydes, anthocyanins, and resveratrol (C1, C2, C3, and C4, respectively). Association of these four components with different sensory descriptors was possible through multiple factor analysis, with C1 relating to 'dark fruits' and 'savoury', C2 with 'barnyard', C3 with 'cooked vegetables' and 'vanilla/chocolate', and C4 with 'barnyard' and a lack of C1 descriptors. Partial least squares regression modelling was undertaken with EEM data and sensory results, with a model for perceived astringency being able to predict the panel scores with 68.1 % accuracy. These encouraging outcomes pave the way for further studies that relate sensory traits to fluorescence data and move research closer to the ultimate goal of predicting wine sensory expression from a small number of compositional factors.

KEYWORDS

Rate-all-that-apply, cluster analysis, excitation-emission matrix, partial least squares regression, machine learning, chemometrics

**Supplementary data can be downloaded through: https://oeno-one.eu/article/view/4805**

## INTRODUCTION

Wine is a luxury product with a highly complex composition that can be affected by the environment in which the grapes are grown as well as techniques applied in the vineyard and winery. The intrinsic complexity of wine has necessitated the development of various techniques to obtain an in-depth understanding of grape and wine metabolites and control points during production that can shape the final product. Relating compositional and technological factors with the sensory expression of a wine, which is a determining factor for the overall consumer experience, remains an ongoing focus of research. Being able to link chemical and sensory information with the practices and techniques that wine endures during production would ultimately equip practitioners with the ability to make more precise decisions for producing targeted wine styles.

Multiple methodologies are available for sensory profiling of wine, but their suitability will depend upon the requirements of the study. Rate-all-that-apply (RATA) is a quantitative sensory methodology that is rapid and effective for wine sensory characterisation (Danner *et al.,* 2018), as shown by its successful use in different studies (Franco-Luesma *et al.,* 2016; Mezei *et al.,* 2021; Nguyen *et al.,* 2020). Similarly to sensory profiling, a range of analytical approaches are available to define wine chemical composition that underpins sensory traits. A common approach has therefore been to combine sensory data with a number of chemical analysis techniques to predict and classify wine sensory characters (Niimi *et al.,* 2018), explore distinctiveness (Geffroy *et al.,* 2016), comprehend the impact of storage and packaging conditions (Hopfer *et al.,* 2013), and understand quality drivers (Gambetta *et al.,* 2016; Hopfer *et al.,* 2015). Many studies rely on analytical methodologies that are time-consuming, expensive, and relatively intricate (e.g., HPLC or GC with mass spectrometry), requiring personnel with specialised skills. There is room, however, for more accessible approaches (usually spectroscopy-based) that can provide chemical information more simply and rapidly. As reviewed by Ranaweera *et al.* (2021a), there are various spectroscopic approaches and each differs in terms of compounds measured, sensitivity, and advantages/disadvantages, among other aspects. The choice of methodology should therefore be defined according to the needs and objectives of the study.

As a spectroscopic technique, spectrofluorometry has often been applied to the analysis of food products because of its time- and cost-effective nature, and its high selectivity and sensitivity (Ranaweera *et al.,* 2021a). It can provide a unique three-dimensional excitation and emission matrix (EEM) that acts as a molecular fingerprint of a sample (Coelho *et al.,* 2015; Ranaweera *et al.,* 2021b). This technique can be a useful tool to authenticate, distinguish and classify different food products through a qualitative investigation of specific fluorescent substances (e.g., phenolic compounds, vitamins, and aromatic amino acids) present at different concentrations depending on the product (Karoui and Blecker, 2011). This methodology is also highly applicable to wine, which contains a myriad of fluorophores. Spectrofluorometry has been applied to wine for authentication and discrimination of samples based on variety, origin, or vintage (Ranaweera *et al.,* 2021b; Ranaweera *et al.,* 2021c; Sádecká and Jakubíková, 2020; Suciu *et al.,* 2019), to analyse oxidative changes and sulfur dioxide addition (Coelho *et al.,* 2015), and to quantitatively assess polyphenol content (Cabrera-Bañegil *et al.,* 2017).

In the quest for a rapid technique that could link wine composition and sensory properties, this study aimed to explore 1) the association between sensory descriptors obtained by RATA and the fluorescence EEM data recorded for Cabernet-Sauvignon wines from the Coonawarra Geographical Indication (GI), and 2) the dominant sensory traits of such regional wines. Specifically, the study tested the applicability of using EEMs with machine learning modelling for sample classification based on sensory profiles, investigated the relationship between the main fluorophores identified by parallel factor analysis (PARAFAC) and sensory descriptors using multiple factor analysis (MFA), and assessed partial least squares (PLS) regression models to predict sensory attributes.

## MATERIALS AND METHODS

### 1. Sample selection

Unreleased vintage 2020 Cabernet-Sauvignon wines were sought from commercial producers using fruit from the Coonawarra GI of South Australia. Most of the wines were monovarietal and had only undergone alcoholic and malolactic fermentation and racking, with minimal oak contact (≤5 months) and limited maturation time.

In total, 26 Cabernet-Sauvignon wine samples (6 × 750 mL bottles of each wine) were obtained from 8 wineries/vineyards within the GI (Supplementary data, Table S1).

**2. Sensory evaluation**

Prior to formal evaluation, the wines were tasted by experts as defined by Parr *et al.* (2002) consisting of academics and postgraduate oenology students (n = 6), who evaluated aroma, flavour, taste, and mouthfeel with a free text assessment followed by a discussion of the wines. This informal tasting was used to evaluate whether the sample set was appropriate for a naïve panel to assess (considering that they were not commercially-released wines), to ensure that the samples could be differentiated, and to decide on the sensory attributes that should be included in the formal RATA evaluations.

Naïve wine consumers (n = 60; 27 females and 33 males from 18 to 77 years of age) were recruited based on being 18 years of age or older and having consumed red wine at least once a month. Evaluations were conducted in a purpose-built sensory laboratory at the University of Adelaide's Waite Campus, in individual booths equipped with a computer, under white fluorescent lighting, and at room temperature (22–23 °C). Samples (20 mL) were served at room temperature in clear stemmed ISO wine glasses coded with a random four-digit number and covered by a petri dish.

Due to the number of samples and to avoid palate fatigue, assessments were divided into three sessions: 9 samples in the first, 9 samples in the second, and 8 samples in the last session. The samples were randomly presented monadically for each subject within a session and the same panel was used for all three sessions. RATA methodology was used to characterise samples by rating the intensity only of the attributes that applied from a list of 53 comprising aroma, flavour, taste, and mouthfeel descriptors (Supplementary data, Table S2) on a 7-point scale (from "extremely low" to "extremely high"). Between samples, the panellists were forced to have a 1-min break and could cleanse their palate with deionised water and unsalted crackers. A 5-min break was enforced at the mid-point of the tasting (between samples 4 and 5). Data were collected with RedJade software (2016, Redwood City, USA). Informed consent was obtained from panellists and this study was approved by the Human Research Ethics Committee of the University of Adelaide (approval number: H-2019-031).

**3. Chemicals**

HPLC grade absolute ethanol and analytical grade 37 % hydrochloric acid (HCl) were purchased from Chem-Supply (Port Adelaide, SA, Australia). High purity water was obtained from a Milli-Q purification system (Millipore, North Ryde, NSW, Australia).

**4. Spectrofluorometric analysis**

After sensory analysis, the remainder of each wine was subsampled into a 4 mL centrifuge tube that was completely filled and stored in a refrigerator at 4 °C until measurements were performed. After warming to room temperature, samples were centrifuged at 9300 × *g* for 10 min and diluted with 50 % aqueous ethanol that had been adjusted with HCl to pH 2 and vacuum filtered (0.45 µm PTFE membrane). The samples were diluted 150-fold (Ranaweera *et al.,* 2021c), and analysed in a Hellma type 1FL (1 cm path length) Macro Fluorescence cuvette (Sigma-Aldrich, Castle Hill, NSW, Australia). Samples were prepared in duplicate and two measurements of each sample were undertaken with a Horiba Scientific Aqualog® spectrophotometer (version 4.2, Quark Photonics, Adelaide, SA, Australia). The excitation wavelength ranged from 240 to 700 nm with an increment of 5 nm under medium gain and 0.2 s integration time and the emission wavelength ranged from 242 to 824 nm with an increment of 4.66 nm. Data acquisition was controlled with Origin software (version 8.6, OriginLab® Corporation, Massachusetts, USA) and EEMs were normalised using water Raman scattering units and corrected for the inner filter effects, solvent background, dark detector signals, and Rayleigh masking (Gilmore *et al.,* 2017).

**5. Basic analytical measurements of pH, TA, ethanol, and $SO_2$**

Sample pH and titratable acidity (TA) were obtained with a T50 auto-titrator (Mettler Toledo, Melbourne, VIC, Australia). Ethanol was measured in triplicate by HPLC analysis (Li *et al.,* 2017) of undiluted samples that were centrifuged at 9300 × *g* for 10 min. Separation was performed with an Aminex HPX-87H column (300 mm × 7.8 mm, BioRad, Hercules, California, USA) thermostatted at 60 °C using 2.5 mM $H_2SO_4$ as mobile phase with a flow rate of 0.5 $mLmin^{-1}$. Peaks were detected with a refractive index detector (RID-10A, Shimadzu, Kyoto, Japan) and quantified by comparison with standards prepared in model wine using ChemStation for

LC 3D Systems software (Agilent Technologies, Santa Clara, CA, USA). Free and total $SO_2$ concentrations were determined in duplicate using the method described by Iland *et al.* (2004).

**6. Statistical analysis**

The raw sensory data were firstly analysed through two-way analysis of variance (ANOVA) with panellists as a random factor and samples as a fixed factor to identify significantly different attributes between the samples. Attributes that presented a p-value $\leq 0.1$ were selected for agglomerative hierarchical cluster (AHC) analysis of all samples with an automatic entropy truncation and Euclidean distance using Ward's method or unweighted pair-group average (UPGMA). With a superior cophenetic correlation (0.676 for UPGMA *versus* 0.511 for Ward's method), UPGMA was chosen and truncation configured with a minimum of five classes. Correlation principal component analysis (PCA) was performed to identify sensory profiles that arose for different clusters based on the AHC analysis.

EEM data were unfolded using unfold multiway (mode 1) in Solo software (version 8.7.1, Eigenvector Research, Inc., Manson, WA, USA). For classification according to the clusters defined by AHC analysis, extreme gradient boosting discriminant analysis (XGBDA) was conducted (Ranaweera *et al.,* 2021c) using pre-processing with mean centring, PLS compression to yield a maximum of 25 latent variables (LVs), and decluttering with generalised least squares weighting at 0.2 for calibration and cross-validation (k = 10, Venetian blinds procedure). Confusion matrix score probabilities were used to assess the model effectiveness. PARAFAC was performed with a non-negativity constraint in all modes imposed and the model was validated by split-half analysis (Murphy *et al.,* 2013).

Loadings for the components determined by PARAFAC were analysed in conjunction with the sensory data (significantly different attributes, $\alpha = 0.1$) through MFA. Separately, a calibration model was created with PLS1 regression of sensory scores for perceived wine astringency and the EEM data to predict astringency ratings. The model was optimised through assessment of LVs, root mean square error of calibration (RMSEC), root mean square error of cross-validation (RMSECV, Venetian blinds with 10 splits), and root mean square error of prediction (RMSEP).

ANOVA, PCA, AHC, and MFA were performed with XLSTAT (version 2019.4.1, Addinsoft, New York, USA). XGBDA, PARAFAC, and PLS regression analysis were conducted with Solo software (version 8.7.1).

## RESULTS AND DISCUSSION

Unreleased Cabernet-Sauvignon wines sought for the study went through minimal post-fermentation processes (e.g., fining, maturation, blending) and were bottled at early stages of production so that the impact of the Coonawarra GI could be assessed with minimal influence of downstream winemaking operations. Basic analytical measurements were within the normal range for red wines at such a stage of production. The total and free $SO_2$ content ranged from 0.4 to 70.8 $mgL^{-1}$ and 0.4 to 33.4 $mgL^{-1}$, respectively, TA ranged from 5.6 to 7.5 $gL^{-1}$, pH values ranged from 3.40 to 3.87, and ethanol concentration ranged from 12.9 % to 15.3 % (Supplementary data, Table S1).

**1. RATA sensory profiling and clustering of wines**

Of the 53 sensory attributes rated by panellists using RATA methodology, 20 were significantly different ($\alpha = 0.1$) according to ANOVA and comprised 8 aromas, 8 flavours, 3 tastes, and 1 mouthfeel attribute (Supplementary data, Table S3). The means of the 20 descriptors were analysed through a correlation PCA (Figure 1) following the AHC analysis (Supplementary data, Figure S1). The first factor (F1) in Figure 1A accounted for 30.6 % of the data variance and the second factor (F2) explained a further 19.6 %. Cluster 1 (shown in red, 7 wines) appeared on the right side of F1 and spread across both segments of F2, with 5 samples in the upper half and 2 in the lower half. Cluster 2 (green, 14 samples) mostly presented near the origin, with 11 samples on the left and 3 samples on the right of F1, and a more or less even spread across F2. Cluster 3 (cyan, 2 samples) was found on the left side of F1 and upper half of F2, and Cluster 4 (pink, 1 sample) was separated from the rest in the bottom right portion of the plot. Squared cosine values for samples in Cluster 5 (data not shown) indicated a higher representation on F3, in the lower half as seen in Figure 1B.

In terms of the sensory descriptors, 'barnyard' flavour and aroma, and bitterness and astringency were plotted on the right side of F1 and lower part of F2; 'minty', 'cooked vegetables', 'dark fruits', 'tobacco', and 'earthy' aromas and flavours, 'oaky' and 'savoury' aromas, and acidity were plotted

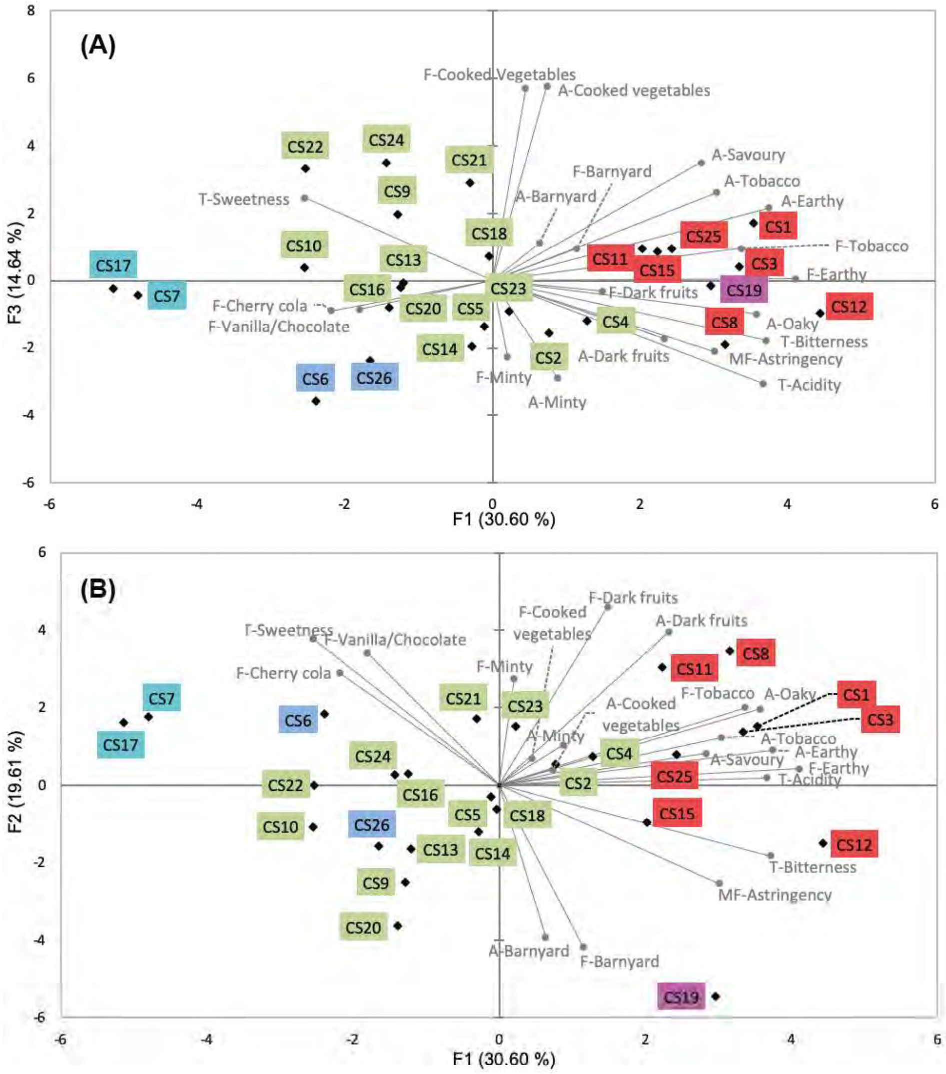


**FIGURE 1.** Principal component analysis biplots of Cabernet-Sauvignon wines (n = 26) using significantly different (α = 0.1) RATA attributes, showing (A) F1 *versus* F2 and (B) F1 *versus* F3.

Colour coding represents the clusters resulting from the agglomerative hierarchical cluster analysis (Supplementary data, Figure S1), with samples in the same cluster bearing the same colour. Cluster 1, red; Cluster 2, green; Cluster 3, cyan; Cluster 4, pink; Cluster 5, blue. A-, aroma; F-, flavour; MF-, mouthfeel; T-, taste.

on the right side of F1 and upper half of F2; and 'vanilla/chocolate' and 'cherry cola' flavours, and sweetness were plotted on the left side of F1 and upper half of F2 (Figure 1A). The aroma and flavour of 'cooked vegetables' were better represented in the upper half of F3 (Figure 1B).

The clusters defined by AHC analysis (Supplementary data, Figure S1) could be explained through different sensory profiles as shown in Figure 1. Cluster 1 was characterised by savoury characters including 'earthy' and 'tobacco', along with 'oaky' and 'dark fruits' aromas, and higher acidity, whereas Cluster 2 on the opposite side was generally characterised by a lack of those characters. Considering that these were young wines, the results might indicate the presence of some oak contact during fermentation for most samples in Cluster 1 as opposed to no oak contact for samples in Cluster 2 (Crump *et al.,* 2015).

Cluster 3 was associated with higher sweetness and 'cherry cola' flavour and low bitterness and astringency. Cluster 4 was characterised by 'barnyard' aroma and flavour, relatively low 'vanilla/chocolate' and 'cherry cola' flavours, a higher bitter taste and astringent mouthfeel, and a lack of sweetness. Cluster 5 was especially related to 'cherry cola' and 'vanilla/chocolate' flavours (Figure 1B), as opposed to the savoury profile found for Cluster 1 (Figure 1A). Sensory profiles have similarly been used in the past for regional classification of Australian Cabernet-Sauvignon wines (Souza Gonzaga *et al.,* 2019; Souza Gonzaga *et al.,* 2020) and Australian Shiraz and Chardonnay wines (Kustos *et al.,* 2020). Those studies with commercial wines reported that some distinctive sensory traits can be more important and more associated with a specific wine-producing region, with the current work on unreleased wines also indicating the existence of perceived differences within a GI according to Figure 1.

The main differences reported previously for Cabernet-Sauvignon wines were the duality between 'green' and 'fruity' related characters and between 'oak' related traits and 'eucalyptus' or 'minty' attributes (Heymann and Noble, 1987; Souza Gonzaga *et al.,* 2020). In the present study, the contrast was between 'barnyard', astringency and bitterness attributes, and 'cherry cola', 'vanilla/chocolate', and sweetness. Oak-related and savoury attributes and the 'minty' trait were found in the same quadrant, not in direct contrast, and the same was evident for fruity and vegetal characters (Figure 1A). Considering the samples were dominated by or exclusively produced from Cabernet-Sauvignon (Supplementary data, Table S1) and were all from the same GI, albeit from different vineyards and wineries, the disparity in the sensory profiles of the present work might be associated with differences in the winemaking processes, as seen previously by Kustos *et al.* (2020) with Australian Chardonnay and Shiraz wines. Additionally, the wines in the present study had a minimal influence of oak (i.e., less than 5 months) or other maturation treatments compared to commercially released red wines, which might have allowed sensory traits that could be attributed to aspects of terroir (e.g., soil, topography, and vineyard management practices) to be more perceivable, such as the 'minty' and fruity attributes.

Some samples in Cluster 2 indicated that 'minty' flavour was an important characteristic, although in general not much difference was seen between the samples (Figure 1A). A 'minty' character has been reported previously for Coonawarra Cabernet-Sauvignon wines, which might indicate this as a dominant trait for the Coonawarra region (Robinson *et al.,* 2011; Souza Gonzaga *et al.,* 2019; Souza Gonzaga *et al.,* 2020). Characters described as 'minty' and 'eucalyptus' in Cabernet-Sauvignon wines have been associated with the presence of eucalyptol (i.e., 1,8-cineole) and hydroxycitronellol, and although 'eucalyptus' aroma and flavour were not statistically significant ($\alpha = 0.1$) in the present work (Supplementary data, Table S3), studies have shown that they might be interchangeable and indistinguishable by a sensory panel (Capone *et al.,* 2012; Robinson *et al.,* 2011; Souza Gonzaga *et al.,* 2020). The current study did not explore the presence of volatile compounds so the link between 'minty' and 'eucalyptus' from both sensory and chemical viewpoints is open for further examination. Among the possibilities, the occurrence of 1,8-cineole in wine has been related to the presence of *Eucalyptus* trees within the vineyard environment (Capone *et al.,* 2012), whereas some studies report the presence of 'minty' traits associated with an aged profile of Bordeaux red wines specifically under the influence of the proportion of Cabernet-Sauvignon in the blend (Picard *et al.,* 2015; Picard *et al.,* 2016b). Mint aroma in that case has been associated with the presence of piperitone (Picard *et al.,* 2016a). Considering that the present study examined young Cabernet-Sauvignon wines, it seemed unlikely that piperitone or other limonene-derived compounds (Picard *et al.,* 2017) were responsible for the presence of the 'minty' attribute, although further investigation is required to clarify the role of various monoterpenoids in the perception of mint-related characters.

**2. Classification of sensory clusters based on spectrofluorometric analysis**

To examine whether sensory information could be classified using spectrofluorometric data, the results from AHC (Supplementary data, Figure S1) were modelled in conjunction with the EEMs of the wine samples through machine learning with the XGBDA algorithm. Various algorithms and machine learning tools exist for wine classification based on EEM data, such as soft independent modelling of class analogy and support vector machine, but XGBDA performs well when analysing a complex heterogeneous matrix with uneven class distribution (Babajide Mustapha and Saeed, 2016). The analysis was undertaken after PLS compression, used to improve the stability of the model by making it less disposed to overfitting. The class CV prediction demonstrated in Figure 2 shows each cluster (denoted using different symbols and colours) that was predefined by AHC. The model attempted to predict the class (cluster) to which each sample belonged, based on the relationship of the sensory profiles and EEM data. Figure 2 and the confusion matrix obtained from cross-validation (data not shown) highlighted that all clusters were 100 % correctly classified with a discrete segregation between the classes in the cross-validated model. This result indicated that the underlying composition of the wines encompassed in the fluorescence fingerprints might be driving the sensory differences of the clusters determined from RATA evaluation.

Classification methods using fluorescence spectroscopy have been previously applied for wine varietal, vintage and origin authentication (Ranaweera *et al.,* 2021b; Ranaweera *et al.,* 2021c; Sádecká and Jakubíková, 2020; Suciu *et al.,* 2019), which tends to yield similar or even better performance compared to other spectroscopic methods like UV-vis, near-infrared, mid-infrared, synchronous fluorescence, or Raman (Mandrile *et al.,* 2016; Riovanto *et al.,* 2011; Tan *et al.,* 2016). Ultimately, studies involving spectrofluorometry and chemometrics have demonstrated the approach as a valid tool for authenticating wine, and along with the present work, highlight the extent to which this type of data can be used to understand important traits related to wine chemical and sensory properties.

### 3. Using PARAFAC to identify main fluorophoric compounds

Attempting to shed light on the relationship between fluorescence data and sensory properties, PARAFAC was performed on the EEM data to identify the main fluorophores present in the samples. The percentage of core consistency of the data can be applied in combination with split-half analysis to assess the model suitability, especially with high complexity matrices such as wine (Airado-Rodríguez *et al.,* 2011; Murphy *et al.,* 2013). The split-half analysis compares the similarity between each half of

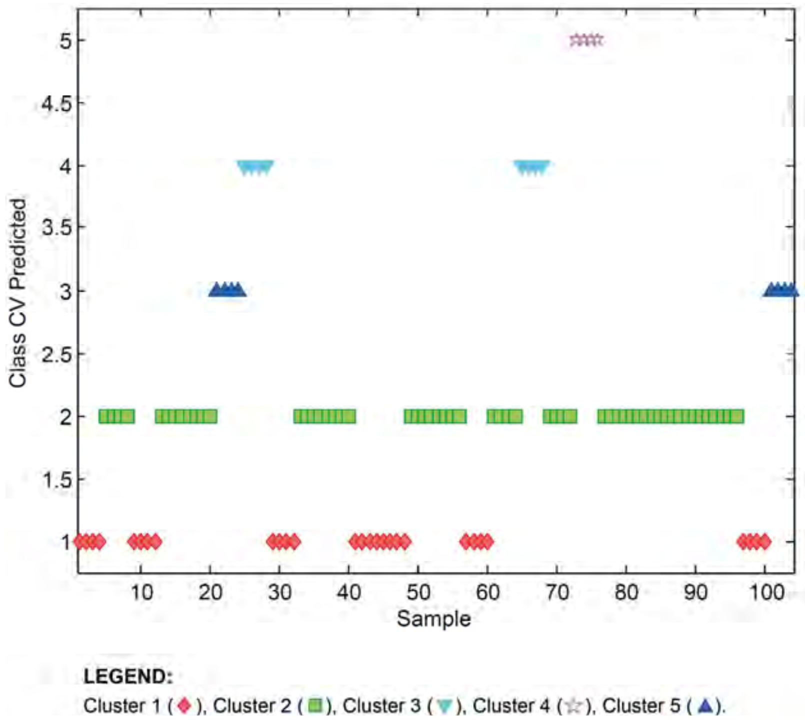


**FIGURE 2.** Class CV predicted for classification of RATA clusters arising from AHC based on XGBDA modelling for the set of Cabernet-Sauvignon wines (n = 26).

the data set, and like with core consistency, a higher percentage is desirable when deciding on the number of components for the model (Murphy *et al.,* 2013). Using all samples in the first PARAFAC model generated a core consistency of less than 0 % and a split-half result of less than 19 %. Investigating further, analysis of residuals of the samples showed that three (CS2, CS7 and CS26) of the 26 wines were outliers and presented equally high residuals for the four determinations (i.e., duplicate readings of duplicate samples) compared to the other samples. Based on the available data, no possible reason was identified that could explain the three samples as outliers. Although sample CS7 was the only sample produced with 100 % uninoculated alcoholic and malolactic fermentation, which might indicate a possible factor, that was not the case for the other two outlier samples. Nonetheless, PARAFAC modelling was performed again without the outlier samples, this time yielding a core consistency of 61 % and split half analysis of 93.7 % for the four main fluorescent components (Figure 3).

From PARAFAC it was possible to identify the maximum intensities ($\lambda_{ex}$ and $\lambda_{em}$) for the four components as demonstrated in Figure 3, and therefore to tentatively assign chemical compound classes that are naturally present in wine (Airado-Rodríguez *et al.,* 2011; Airado-Rodríguez *et al.,* 2009). Such spectral data can typically be related to fluorophoric compounds such as vitamins (Christensen *et al.,* 2006) and especially phenolic compounds (Schueuermann *et al.,* 2018). For PARAFAC component 1, maximum intensities of $\lambda_{ex}$ = 275 nm and $\lambda_{em}$ = 310 nm were tentatively

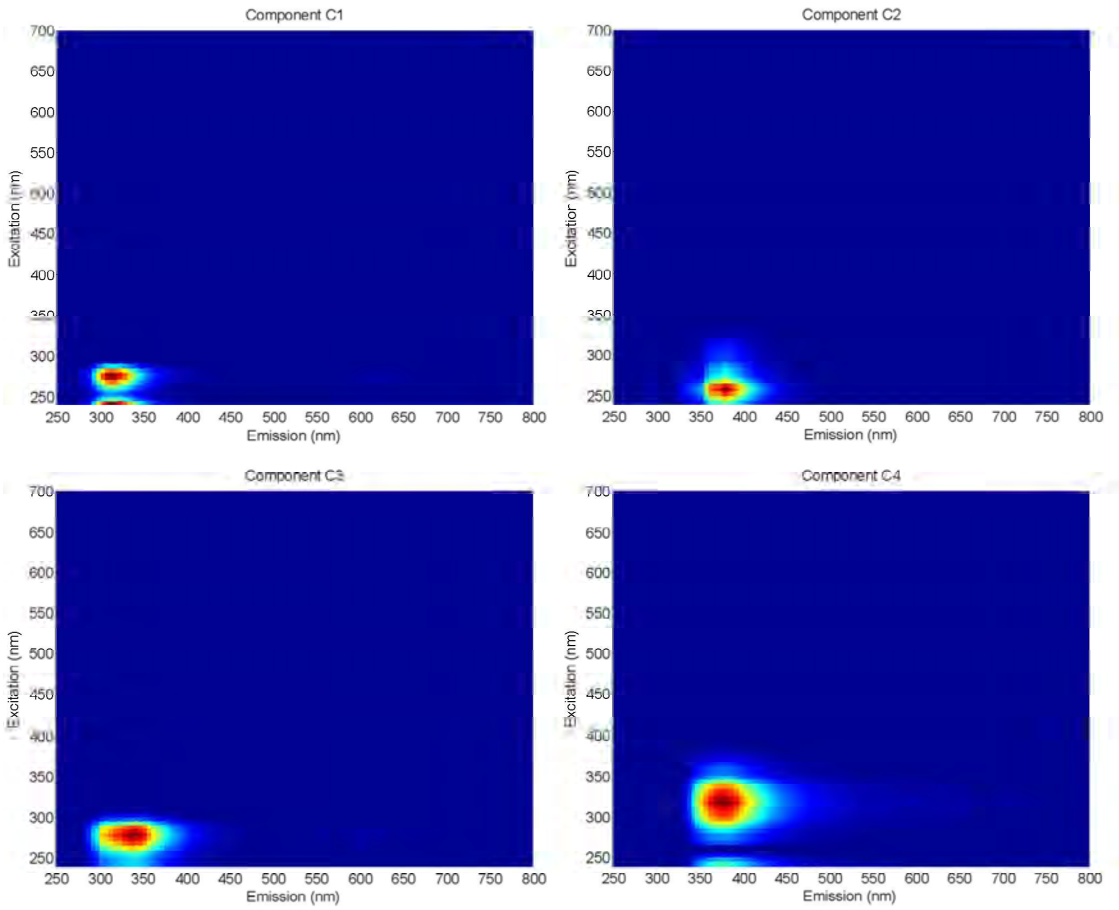


**FIGURE 3.** Contour plots for excitation and emission wavelengths identified from the PARAFAC model, indicating the four main fluorescent components (i.e., C1, C2, C3, C4) present in the sample set.

identified as compounds associated with catechin (including tannin). Component 2 peak intensities were $\lambda_{ex}$ = 255 nm and $\lambda_{em}$ = 375 nm and can be proposed to result from phenolic aldehyde related compounds. Component 3 peak intensities were $\lambda_{ex}$ = 270 nm and $\lambda_{em}$ = 335 nm and were considered to be associated with anthocyanins. Finally, component 4 peak intensities were $\lambda_{ex}$ = 315 nm and $\lambda_{em}$ = 375 nm and tentatively assigned to stilbenoids such as *trans*-resveratrol.

Ranaweera *et al.* (2021c) and Airado-Rodríguez *et al.* (2009) proposed similar assignments for PARAFAC model components in red wine, which are reasonable considering the main compounds (i.e., catechins, anthocyanins, and other phenolics) expected to be abundant in red wine. It is noteworthy that compound classes assigned from the PARAFAC modelling (i.e., phenolics) were not necessarily driving the sensory characters themselves, but could act as indirect markers that indicated compositional aspects of the wines that were not essentially measured by fluorescence. For example, different gene copies responsible for the biosynthesis of important wine compounds such as anthocyanins in grape berry can belong to multicopy families, having an expression profile coinciding with other specific flavonoids that may impact wine sensory profile by correlation rather than causation (Kuhn *et al.,* 2013). In contrast, there could be a direct relationship with compounds associated with aspects such as the taste and mouthfeel of the wine, as explained in more detail in the next section.

**4. Relation between PARAFAC components and RATA results according to MFA**

Considering the compound classes tentatively identified by PARAFAC modelling of EEM data can impact wine sensory profile (either directly or by implying an indirect correlation), the relative loadings of the four classes were analysed in conjunction with RATA results through MFA. Means of the significantly different (α = 0.1) descriptors and means of the four compound class loadings from 23 wines (excluding CS2, CS7 and CS26) were used for the analysis (Figure 4). MFA yielded an RV coefficient of 0.232 between both sets of data, an RV coefficient of 0.751 between PARAFAC data and the MFA model, and an RV coefficient of 0.816 between the RATA data and the MFA model.

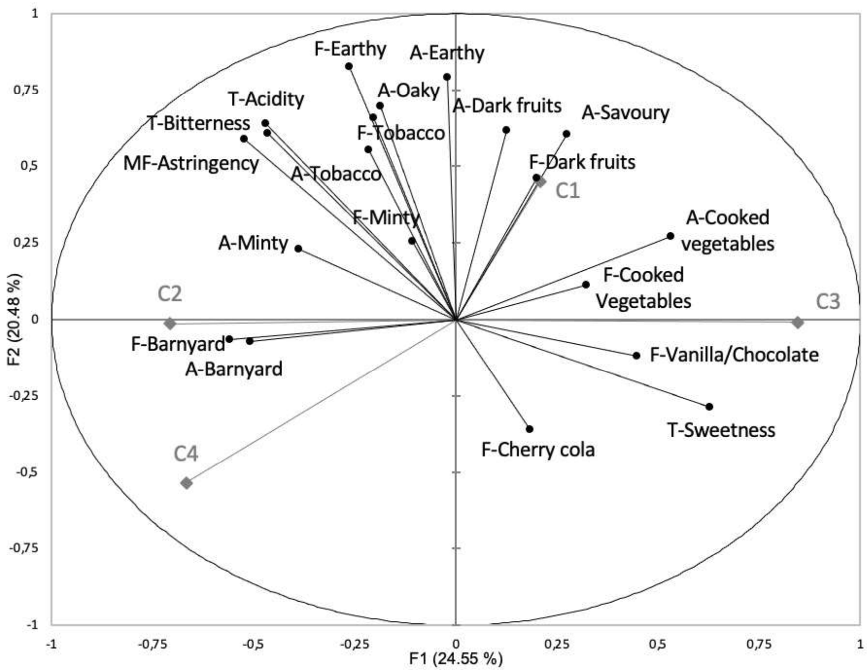


**FIGURE 4.** Multiple factor analysis biplot of the four components from PARAFAC (in grey, ◆) using significantly different (α = 0.1) descriptors from RATA evaluation (in black, ●) for 23 Cabernet-Sauvignon wine samples (excluding CS2, CS7 and CS26).

The MFA biplot explained 45 % of the variance in the data, with 24.6 % represented by F1 and 20.5 % by F2. PARAFAC C1 was plotted on the right side of F1 and the upper portion of F2, C2 and C3 were explained entirely along F1, with C3 on the right side and C2 on the left side, and C4 was plotted on the left side of F1 and lower part of F2, more or less opposite to C1 (Figure 4).

Catechin monomers associated with C1 are usually extracted from grape skin and seed and can increase the bitter taste of wine (Fischer and Noble, 1994) whereas polymers of catechin (e.g., tannins), extracted from the same sources, are related with astringency (Waterhouse *et al.,* 2016a). Figure 4 shows C1 was associated with 'dark fruits' and 'cooked vegetables' aromas and flavours and 'savoury' aroma, which is likely to be an indirect relationship as mentioned in the previous section. Analysing the RV coefficients, the correlation between bitterness and C1 was not significant ($p = 0.313$), thus indicating that there might not be an association. In contrast, the correlation between astringency and C1 was significant ($p = 0.006$) and had an RV coefficient of 0.315, demonstrating a moderate association. This implied that polymers had a greater influence on the expression of C1 than monomers, which would be reasonable given their relative concentrations in red wine.

Phenolic aldehydes assigned to C2 can be influenced by the origin of wood (usually oak) incorporated either during fermentation or maturation and can vary in concentration depending on ageing time — such compounds can be responsible for some oak-related aroma traits (e.g., vanillin) in wine (del Alamo Sanza *et al.,* 2004). Other oak compounds (e.g., volatile phenols, hydrolysable tannins) that may influence sensory traits would undoubtedly be extracted as well. C2 was related to 'barnyard' aroma and flavour and 'minty' aroma. Anthocyanins assigned to C3 are pigments present in red grape skins that are important to the colour of red wine (He *et al.,* 2012). Anthocyanins might also be responsible for an increase in the 'fullness' of a wine (Vidal *et al.,* 2004), as well as perceived astringency and bitterness (Ferrero-del-Teso *et al.,* 2020; Paissoni *et al.,* 2018). Additionally, as explained in the section dealing with PARAFAC, genes involved in the biosynthesis of anthocyanins in grapes are expressed through pathways that coincide with the biosynthesis of other flavonoids and volatile compounds (Czemmel *et al.,* 2012; Kuhn *et al.,* 2013). This could explain why anthocyanins could act as markers for compounds that impart aroma or flavour (Ristic *et al.,* 2010) but lack a fluorophore themselves. From the MFA, C3 was linked to 'cooked vegetables' aroma and flavour, 'vanilla/chocolate' flavour, and sweetness. Lastly, stilbenoids assigned to C4 are compounds that can be found in grape berry skins and are extracted into wine during fermentation (Waterhouse *et al.,* 2016b). Stilbenoids, especially *trans*-resveratrol, are responsible for the antioxidant characteristics of red wine and its association with the prevention of age-related diseases in consumers (Pawlus *et al.,* 2012). According to Gaudette and Pickering (2011), *trans*-resveratrol seems to have minimal impact on the sensory qualities of wine (when spiked at less than 200 $mgL^{-1}$). Figure 4 shows that C4 was associated with 'barnyard' aroma and flavour, which is likely to be another example of an indirect relationship between the fluorophoric component and the sensory data.

It is worth noting that the associations between sensory traits and tentative compound types found through PARAFAC do not allow for strict conclusions. It is possible, considering the complexity of what is being modelled, that some relationships may arise due to chance, and more in-depth research is necessary to better understand and explain the proposed relationships.

### 5. Regression model for astringency prediction

Considering that most of the compounds detected by spectrofluorometric analysis can directly affect basic mouthfeel and taste attributes in wine, PLS regression was performed with the two mouthfeel and three taste attributes described by the sensory evaluation of the 26 wines. Astringency was the only attribute that could be well modelled from the EEM data without overfitting, based on the model parameters. An optimal model was generated with eight LVs, giving RMSEC = 0.085, RMSECV = 0.132, RMSEP = 0.222, $R^2$ calibration = 0.936, $R^2$ cross-validation = 0.848, and $R^2$ prediction = 0.681. The model was thus able to explain 84.8 % of the variance in the samples and able to predict the results with 68.1 % accuracy (Figure 5). Furthermore, the low value for RMSECV indicated that the error associated with the prediction of astringency was around 2 % in relation to the sensory scale used (7-point), demonstrating that the model appeared to be suitable. This outcome showed that spectrofluorometric data had reasonable capabilities for predicting a perceived mouthfeel attribute rating for this data set, which was

  

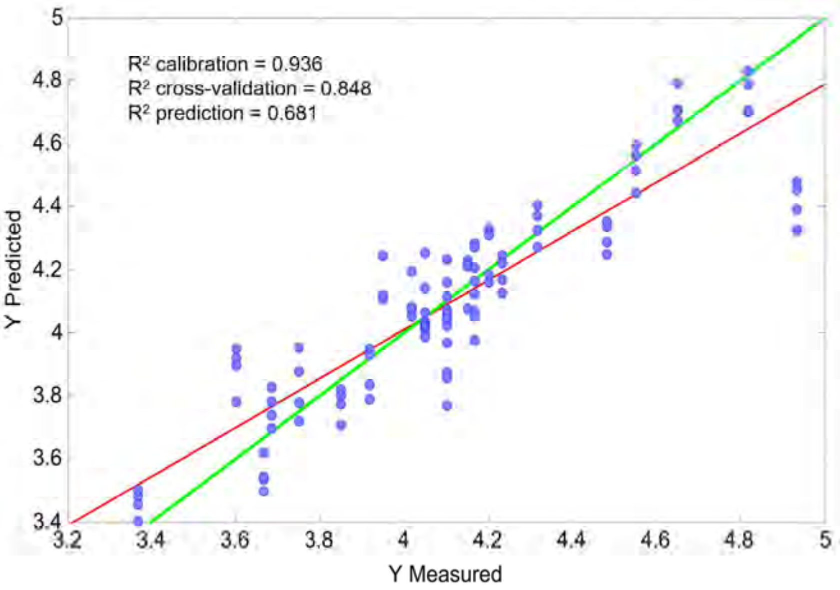


**FIGURE 5.** Correlation between the predicted and measured ratings for perceived astringency according to partial least squares regression modelling for Cabernet-Sauvignon wines (n = 26).

The green line shows the 1:1 correlation and the red line is the model fit.

encouraging given the simplicity of the approach and the complexity of what was being modelled.

The chemical composition of Cabernet-Sauvignon wines has also previously been used for sensory profile prediction, with regression models described by Niimi *et al.* (2018) explaining between 44.2 % and 69.1 % of the variance in the sample set, and 56.5 % for astringent mouthfeel. In that work, the model for predicting perceived astringency score involved anthocyanin concentration and colour measures, both of which can be determined using the A-TEEM approach and used in combination with a multi-block analysis (Ranaweera *et al.,* 2021c) to add information beyond that encompassed in the EEM data alone. Notably, the present study is the first known attempt to correlate and predict wine sensory profiles from EEM readings, and although the outcomes are positive, further work with additional samples will be necessary to improve and extend the modelling. Furthermore, different spectroscopic methods have been validated before for determining phenolic compound concentrations in a way that is less time consuming and more cost-effective than other options, and such approaches could become a valuable tool for assisting winemakers in monitoring and controlling phenolic composition (Cozzolino *et al.,* 2008; Cozzolino *et al.,* 2004; Dambergs *et al.,* 2012; Janik *et al.,* 2007; Ranaweera *et al.,* 2021c). Fluorescence spectroscopy in particular can quantify compounds that are present in the sample at a lower concentration than other spectroscopic methods (Gilmore and Chen, 2020), thus providing an attractive option for additional development in future.

## CONCLUSIONS

This study aimed to explore the association between sensory traits and spectrofluorometric data of unreleased, commercially produced 2020 Coonawarra Cabernet-Sauvignon wines. It combined cluster analysis of sensory profiles obtained using RATA with fluorescence data by using a machine learning algorithm, and examined the prediction of sensory ratings from fluorophoric compounds via regression modelling. Thus, five distinctive clusters arose that could be well explained by the sensory results of the RATA evaluation. Cluster 1 wines were characterised by savoury-related characters, Cluster 2 by 'minty' traits and a lack of the savoury-related attributes, Cluster 3 by 'cherry cola' flavour and low bitterness and astringency, Cluster 4 by higher sweetness and 'barnyard' aroma and flavour, and Cluster 5 by 'vanilla/chocolate' flavour.

  

Additionally, the EEM data analysed through XGBDA were able to predict with 100 % accuracy the clusters that arose from the sensory profiling, demonstrating that there might be a good association between the EEMs and sensory ratings (whether direct or indirect). After excluding three outlier samples, PARAFAC analysis showed that four main fluorophores could be segregated to explain the data set, with compound classes tentatively associated with the intensity readings being catechins (C1), phenolic aldehydes (C2), anthocyanins (C3) and stilbenoids (C4). MFA was used to identify associations between the PARAFAC components and the sensory ratings, revealing that C1 was associated with 'dark fruits' and 'savoury' characters, C2 was associated with 'barnyard', C3 was related to 'cooked vegetables' and 'vanilla/chocolate', and C4 was related with 'barnyard' but more characterised by the lack of attributes associated with C1. However, the nature of any relationship between the proposed compound classes and perceived sensory attributes requires further study. PLS regression resulted in a suitable model that was able to predict perceived astringency score with 68.1 % accuracy, although no suitable model was found for the other sensory attributes. Overall, the correlation of sensory profiles with spectrofluorometric data was quite an optimistic feat, yet the results from this study were promising. This work may inspire further research that is designed to better understand the chemical drivers of sensory traits and the most influential factors throughout wine production using a rapid technique like spectrofluorometry, perhaps with the inclusion of a small selection of compositional variables.

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Waterhouse, A. L., Sacks, G. L., & Jeffery, D. W. (2016b). *Introduction to Phenolics*. In Understanding Wine Chemistry (pp. 99-104). Wiley. https://doi.org/10.1002/9781118730720.ch11

**SUPPLEMENTARY DATA**

Souza Gonzaga, L., Bastian, S., Capone, D., Ranaweera, R., & Jeffery, D. (2021). Modelling Cabernet-Sauvignon wine sensory traits from spectrofluorometric data. *OENO One, 55*(4)
https://doi.org/10.20870/oeno-one.2021.55.4.4805

**TABLE S1**. Wine sample code with winery, blend components, oak contact information, and basic analytical measurements. Values for free and total $SO_2$, pH and TA are the means of duplicate measurements, and those for ethanol are from triplicate measurements.

| Sample code | Winery | Composition of blend | Type of oak contact | pH | TA ($gL^{-1}$) | Free $SO_2$ ($mgL^{-1}$) | Total $SO_2$ ($mgL^{-1}$) | Ethanol % v/v |
|---|---|---|---|---|---|---|---|---|
| CS1 | A | 100 % Cabernet-Sauvignon | Initial barrel maturation[1] | 3.61 | 7.0 | 22.0 | 42.0 | 14.7 |
| CS2 | A | 79 % Cabernet-Sauvignon, 21 % Petit Verdot | Initial barrel maturation | 3.55 | 7.2 | 30.4 | 52.4 | 15.2 |
| CS3 | A | 86 % Cabernet-Sauvignon, 14 % Petit Verdot | Initial barrel maturation | 3.58 | 7.2 | 26.0 | 48.0 | 14.8 |
| CS4 | A | 100 % Cabernet-Sauvignon | Initial barrel maturation | 3.54 | 7.4 | 33.6 | 70.8 | 15.3 |
| CS5 | B | 100 % Cabernet-Sauvignon | No contact | 3.50 | 7.0 | 0.4 | 0.4 | 15.1 |
| CS6 | B | 100 % Cabernet-Sauvignon | Initial barrel maturation | 3.48 | 7.5 | 1.2 | 8.0 | 15.3 |
| CS7 | C | 100 % Cabernet-Sauvignon | Initial barrel maturation | 3.87 | 6.5 | 4.4 | 9.2 | 14.7 |
| CS8 | C | 100 % Cabernet-Sauvignon | Oak chips during fermentation | 3.40 | 7.0 | 13.6 | 20.8 | 15.2 |
| CS9 | D | 100 % Cabernet-Sauvignon | Initial barrel maturation | 3.67 | 5.9 | 13.2 | 21.2 | 14.7 |
| CS10 | D | 100 % Cabernet-Sauvignon | Initial barrel maturation | 3.55 | 5.9 | 20.0 | 33.2 | 13.7 |
| CS11 | D | 100 % Cabernet-Sauvignon | Initial barrel maturation | 3.63 | 5.9 | 21.6 | 26.4 | 14.9 |
| CS12 | E | 100 % Cabernet-Sauvignon | Initial barrel maturation | 3.73 | 5.6 | 29.2 | 46.8 | 14.5 |
| CS13 | E | 100 % Cabernet-Sauvignon | Initial barrel maturation | 3.82 | 5.6 | 23.6 | 37.2 | 14.3 |
| CS14 | F | 100 % Cabernet-Sauvignon | Initial barrel maturation | 3.46 | 6.1 | 20.0 | 39.2 | 12.9 |
| CS15 | G | 100 % Cabernet-Sauvignon | Initial barrel maturation | 3.55 | 6.1 | 29.2 | 46.4 | 14.6 |
| CS16 | H | 100 % Cabernet-Sauvignon | Oak chips during fermentation | 3.73 | 7.0 | 20.0 | 39.6 | 14.4 |
| CS17 | H | 100 % Cabernet-Sauvignon | Oak chips during fermentation | 3.53 | 6.8 | 16.8 | 26.8 | 13.7 |
| CS18 | H | 100 % Cabernet-Sauvignon | Oak chips during fermentation | 3.60 | 7.2 | 23.6 | 39.6 | 14.3 |
| CS19 | H | 100 % Cabernet-Sauvignon | Oak chips during fermentation | 3.58 | 6.9 | 23.2 | 45.2 | 13.7 |
| CS20 | H | 100 % Cabernet-Sauvignon | Oak chips during fermentation | 3.59 | 6.7 | 22.0 | 40.8 | 13.8 |
| CS21 | H | 100 % Cabernet-Sauvignon | Oak chips during fermentation | 3.63 | 6.5 | 14.8 | 26.8 | 15.1 |
| CS22 | H | 100 % Cabernet-Sauvignon | Oak chips during fermentation | 3.74 | 6.4 | 18.8 | 26.8 | 14.1 |
| CS23 | H | 100 % Cabernet-Sauvignon | Oak chips during fermentation | 3.55 | 6.6 | 18.0 | 31.6 | 15.1 |
| CS24 | H | 100 % Cabernet-Sauvignon | Oak chips during fermentation | 3.58 | 6.5 | 23.2 | 37.2 | 14.2 |
| CS25 | H | 100 % Cabernet-Sauvignon | Oak chips during fermentation | 3.50 | 6.9 | 16.0 | 25.6 | 14.1 |
| CS26 | H | 100 % Cabernet-Sauvignon | Oak chips during fermentation | 3.67 | 7.44 | 20.0 | 34.0 | 13.8 |

[1] Initial barrel maturation was ≤ 5 months

SUPPLEMENTARY DATA

Souza Gonzaga, L., Bastian, S., Capone, D., Ranaweera, R., & Jeffery, D. (2021).
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https://doi.org/10.20870/oeno-one.2021.55.4.4805

**TABLE S2**. Aroma/flavour, taste, and mouthfeel attributes used for the RATA evaluation with respective description available to panellists during tasting.

| Attribute | Description |
|---|---|
| **Aroma/flavour** | |
| Dark fruits | blackcurrant, blackberry, mulberry, plum, blueberry |
| Red fruits | strawberry, raspberry |
| Confectionery | lollies |
| Jammy | preserved or cooked fruit |
| Dried fruits | raisin, prune, sultana |
| Spices | clove, cinnamon, nutmeg, mixed spice, mulled wine, liquorice, anise |
| Savoury | meaty, soy sauce, black olives, salami |
| Green | green pepper, capsicum, asparagus, green beans |
| Tobacco | smoky, cigar |
| Earthy | mushroom, truffle, forest floor |
| Minty | spearmint, mint, peppermint |
| Eucalyptus | menthol, VapoRub ointment |
| Violets | blue flowers |
| Oaky | woody, pencil shaving, toasty, cedar, coconut |
| Cooked Vegetables | pickles, cabbage, canned beans or mixed veggies |
| Grassy | stalky, leafy, cut grass, herbaceous, tomato leaf |
| Floral | roses, perfume, musk |
| Vanilla/Chocolate | vanilla and chocolate |
| Dried herbs | oregano |
| Barnyard | band-aid, medicinal, horse-like, stables |
| Cherry cola | sarsaparilla |
| Brine | oyster shell, sea spray, sardine oil |
| Yeasty | bread, doughy |
| **Taste** | |
| Bitterness | bitter taste |
| Acidity | tart, sour taste |
| Sweetness | sweet taste |
| **Mouthfeel** | |
| Body | weight of the wine when you swirl it in your mouth, thickness, mouth feeling |
| Astringency | drying, roughing and puckering sensation |
| Alcohol | warmth or burning sensation |
| Length of flavour | how persistent was the wine flavour in the mouth after expectoration |

**SUPPLEMENTARY DATA**

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**TABLE S3**. Mean values of each sensory attribute along with p-values according to ANOVA (significant differences with α = 0.1 are shown in bold) for Cabernet-Sauvignon wines from Coonawarra (n = 26; refer to Table S1 for wine codes).

| Attributes | CS1 | CS2 | CS3 | CS4 | CS5 | CS6 | CS7 | CS8 | CS9 | CS10 | CS11 | CS12 | CS13 | CS14 | CS15 | CS16 | CS17 | CS18 | CS19 | CS20 | CS21 | CS22 | CS23 | CS24 | CS25 | CS26 | p-value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **A-Barnyard** | **0.83** | **0.48** | **0.87** | **1.10** | **1.07** | **0.67** | **0.82** | **0.68** | **1.42** | **1.07** | **0.70** | **1.03** | **0.85** | **0.73** | **0.75** | **0.73** | **0.65** | **0.77** | **1.40** | **1.23** | **0.92** | **0.70** | **0.43** | **0.80** | **0.95** | **0.78** | **0.004** |
| A-Brine | 0.67 | 0.55 | 0.43 | 0.38 | 0.37 | 0.52 | 0.43 | 0.48 | 0.45 | 0.68 | 0.77 | 0.58 | 0.43 | 0.47 | 0.77 | 0.48 | 0.28 | 0.48 | 0.85 | 0.80 | 0.55 | 0.52 | 0.48 | 0.52 | 0.53 | 0.18 | 0.233 |
| A-Cherry cola | 0.90 | 1.00 | 0.85 | 0.82 | 1.53 | 1.62 | 1.12 | 1.37 | 0.70 | 1.07 | 1.18 | 1.02 | 1.03 | 1.17 | 0.90 | 1.07 | 1.08 | 1.08 | 0.93 | 0.98 | 1.10 | 1.07 | 1.18 | 1.13 | 1.17 | 1.20 | 0.440 |
| A-Confectionery | 1.22 | 1.50 | 1.38 | 1.23 | 1.85 | 1.90 | 1.48 | 1.67 | 1.22 | 1.25 | 1.47 | 1.57 | 1.28 | 1.33 | 1.58 | 1.55 | 1.22 | 1.15 | 1.70 | 1.53 | 1.15 | 1.43 | 1.57 | 1.92 | 1.15 | 1.75 | 0.268 |
| **A-Cooked Vegetables** | **0.93** | **0.57** | **0.93** | **0.67** | **0.68** | **0.47** | **0.57** | **0.58** | **1.12** | **0.80** | **0.92** | **0.82** | **0.88** | **0.55** | **1.02** | **0.73** | **0.60** | **0.67** | **0.60** | **0.53** | **1.22** | **1.15** | **0.78** | **1.17** | **1.07** | **0.77** | **0.021** |
| **A-Dark fruits** | **3.63** | **3.32** | **3.75** | **3.43** | **3.05** | **3.55** | **3.07** | **3.95** | **3.02** | **3.17** | **3.65** | **3.52** | **3.32** | **3.35** | **3.37** | **3.43** | **3.25** | **3.17** | **2.83** | **2.88** | **3.38** | **2.90** | **3.47** | **2.97** | **3.17** | **3.00** | **0.063** |
| A-Dried fruits | 1.92 | 2.00 | 2.30 | 1.98 | 2.25 | 2.10 | 1.68 | 2.30 | 1.57 | 2.08 | 2.15 | 2.05 | 1.75 | 2.30 | 2.02 | 1.73 | 1.90 | 2.15 | 1.77 | 1.72 | 2.17 | 1.75 | 2.28 | 1.92 | 2.02 | 1.88 | 0.692 |
| A-Dried herbs | 1.05 | 0.87 | 1.02 | 0.95 | 0.82 | 0.58 | 1.15 | 0.90 | 0.82 | 0.62 | 0.92 | 1.03 | 0.73 | 0.73 | 0.72 | 1.02 | 0.75 | 0.78 | 1.22 | 1.00 | 0.77 | 1.15 | 0.90 | 0.68 | 1.10 | 0.75 | 0.453 |
| **A-Earthy** | **2.10** | **1.33** | **1.93** | **1.47** | **1.20** | **1.00** | **1.12** | **1.67** | **1.20** | **1.22** | **1.58** | **1.73** | **1.10** | **1.08** | **1.97** | **1.27** | **1.22** | **1.38** | **1.57** | **1.27** | **1.35** | **1.35** | **1.37** | **1.45** | **1.75** | **1.25** | **0.004** |
| A-Eucalyptus | 1.07 | 1.07 | 1.17 | 1.07 | 1.32 | 1.13 | 1.58 | 1.02 | 0.88 | 0.78 | 0.78 | 0.85 | 0.82 | 0.97 | 1.00 | 0.78 | 0.68 | 0.77 | 0.97 | 1.12 | 0.67 | 0.75 | 0.90 | 0.70 | 0.92 | 0.85 | 0.115 |
| A-Floral | 1.48 | 1.27 | 1.97 | 1.40 | 1.77 | 2.07 | 1.65 | 1.40 | 1.38 | 1.53 | 1.30 | 1.42 | 1.28 | 1.02 | 1.37 | 1.28 | 1.38 | 1.37 | 1.30 | 1.62 | 1.30 | 1.17 | 1.65 | 1.42 | 1.62 | 1.52 | 0.301 |
| A-Grassy | 1.38 | 1.10 | 1.38 | 1.18 | 1.03 | 0.98 | 1.05 | 1.53 | 1.23 | 1.00 | 1.75 | 1.13 | 1.22 | 1.02 | 1.17 | 1.02 | 0.97 | 1.20 | 1.75 | 1.08 | 1.40 | 1.35 | 1.23 | 1.35 | 1.40 | 1.05 | 0.198 |
| A-Green | 1.08 | 1.02 | 1.27 | 1.27 | 1.28 | 0.88 | 1.40 | 1.28 | 0.83 | 1.10 | 1.10 | 1.07 | 0.82 | 1.35 | 1.10 | 1.27 | 1.03 | 1.17 | 1.17 | 1.25 | 1.40 | 1.48 | 1.18 | 1.33 | 1.15 | 1.20 | 0.754 |
| A-Jammy | 2.47 | 1.82 | 1.80 | 1.97 | 2.23 | 2.37 | 1.90 | 2.52 | 1.70 | 2.05 | 2.10 | 2.18 | 1.95 | 1.85 | 2.40 | 2.07 | 1.73 | 2.08 | 1.40 | 1.73 | 2.18 | 2.02 | 2.37 | 2.12 | 2.07 | 1.87 | 0.140 |
| **A-Minty** | **0.87** | **1.23** | **1.52** | **1.28** | **1.08** | **1.35** | **1.18** | **1.13** | **0.80** | **0.92** | **1.28** | **0.88** | **0.75** | **1.20** | **0.97** | **0.92** | **0.87** | **0.68** | **1.17** | **1.03** | **0.95** | **0.87** | **0.90** | **1.03** | **1.47** | **1.62** | **0.010** |
| **A-Oaky** | **1.88** | **1.83** | **1.93** | **1.88** | **1.72** | **1.60** | **1.38** | **2.25** | **1.70** | **1.43** | **1.92** | **2.20** | **1.60** | **1.90** | **1.57** | **1.80** | **1.48** | **1.75** | **1.65** | **1.25** | **1.62** | **1.40** | **1.65** | **1.53** | **1.98** | **1.30** | **0.069** |
| A-Red fruits | 2.88 | 2.13 | 2.87 | 2.35 | 2.47 | 2.52 | 2.20 | 2.83 | 2.43 | 2.45 | 2.60 | 2.82 | 2.37 | 2.82 | 2.45 | 2.08 | 2.70 | 2.57 | 2.02 | 2.50 | 1.90 | 2.17 | 2.82 | 2.47 | 2.28 | 2.37 | 0.104 |
| **A-Savoury** | **1.72** | **1.38** | **1.50** | **1.25** | **1.10** | **0.60** | **0.85** | **1.30** | **1.23** | **1.50** | **1.30** | **1.30** | **0.97** | **0.97** | **1.35** | **1.20** | **0.85** | **0.93** | **1.30** | **0.82** | **1.43** | **1.25** | **1.30** | **1.32** | **1.22** | **0.87** | **0.013** |
| A-Spices | 2.22 | 2.37 | 2.23 | 2.03 | 2.12 | 1.83 | 2.05 | 1.95 | 1.33 | 1.68 | 2.12 | 2.32 | 1.92 | 2.18 | 1.97 | 1.50 | 1.58 | 2.00 | 1.75 | 1.82 | 1.95 | 1.85 | 1.93 | 1.93 | 1.83 | 1.87 | 0.237 |
| **A-Tobacco** | **1.18** | **0.93** | **1.20** | **0.78** | **0.78** | **0.53** | **0.83** | **1.20** | **0.75** | **0.67** | **1.28** | **1.07** | **0.77** | **0.88** | **0.72** | **0.65** | **0.70** | **1.05** | **1.13** | **0.92** | **1.03** | **1.10** | **0.93** | **0.90** | **1.17** | **0.48** | **0.024** |
| A-Vanilla/Chocolate | 0.87 | 1.18 | 1.02 | 0.92 | 1.27 | 1.07 | 0.97 | 1.05 | 0.65 | 0.70 | 0.77 | 0.98 | 0.62 | 0.78 | 0.85 | 0.78 | 1.03 | 0.92 | 0.65 | 0.72 | 0.83 | 0.68 | 1.22 | 0.68 | 0.80 | 0.72 | 0.347 |
| A-Violets | 0.62 | 0.73 | 1.10 | 1.00 | 0.88 | 1.28 | 1.20 | 0.73 | 0.83 | 0.85 | 0.87 | 0.88 | 0.80 | 0.92 | 0.73 | 1.08 | 1.22 | 0.90 | 0.90 | 0.92 | 0.67 | 0.95 | 0.88 | 0.87 | 1.17 | 1.08 | 0.581 |
| A-Yeasty | 0.57 | 0.60 | 0.55 | 0.43 | 0.58 | 0.67 | 0.35 | 0.75 | 0.35 | 0.42 | 0.63 | 0.75 | 0.47 | 0.37 | 0.88 | 0.58 | 0.62 | 0.45 | 0.57 | 0.28 | 0.57 | 0.48 | 0.63 | 0.57 | 0.48 | 0.45 | 0.387 |
| **F-Barnyard** | **0.57** | **0.58** | **0.82** | **0.62** | **0.92** | **0.52** | **0.57** | **0.57** | **0.95** | **0.65** | **0.50** | **0.67** | **0.63** | **0.88** | **0.68** | **0.48** | **0.47** | **0.65** | **1.60** | **0.95** | **0.65** | **0.85** | **0.37** | **0.62** | **0.87** | **0.48** | **< 0.0001** |
| F-Brine | 0.60 | 0.45 | 0.48 | 0.65 | 0.65 | 0.53 | 0.45 | 0.88 | 0.58 | 0.38 | 0.48 | 0.57 | 0.37 | 0.43 | 0.95 | 0.40 | 0.53 | 0.47 | 0.82 | 0.68 | 0.40 | 0.48 | 0.43 | 0.62 | 0.57 | 0.38 | 0.151 |
| **F-Cherry cola** | **0.87** | **0.85** | **0.88** | **1.03** | **1.35** | **1.65** | **1.32** | **1.17** | **0.73** | **0.85** | **1.12** | **0.65** | **0.77** | **1.10** | **0.80** | **0.82** | **1.30** | **0.98** | **0.77** | **0.93** | **1.10** | **1.45** | **1.10** | **1.25** | **1.25** | **1.18** | **0.007** |
| F-Confectionery | 1.33 | 1.30 | 1.27 | 1.20 | 1.60 | 2.08 | 1.28 | 1.43 | 0.97 | 1.23 | 1.48 | 1.22 | 1.37 | 1.13 | 1.22 | 1.25 | 1.65 | 1.37 | 1.02 | 1.27 | 1.05 | 1.43 | 1.48 | 1.57 | 1.27 | 1.27 | 0.212 |
| **F-Cooked Vegetables** | **0.77** | **0.40** | **0.95** | **0.60** | **0.47** | **0.53** | **0.60** | **0.57** | **0.88** | **0.45** | **0.92** | **0.55** | **0.62** | **0.55** | **0.83** | **0.75** | **0.65** | **0.90** | **0.68** | **0.58** | **0.95** | **1.07** | **0.50** | **1.15** | **0.93** | **0.55** | **0.026** |
| **F-Dark fruits** | **3.78** | **3.53** | **3.47** | **3.70** | **3.52** | **3.92** | **3.50** | **3.97** | **3.38** | **3.22** | **4.02** | **3.63** | **3.27** | **3.18** | **3.47** | **3.75** | **3.33** | **3.45** | **2.88** | **3.13** | **3.85** | **3.25** | **3.60** | **3.25** | **3.65** | **2.93** | **0.008** |
| F-Dried fruits | 1.90 | 1.80 | 1.72 | 1.92 | 2.12 | 1.82 | 1.78 | 2.17 | 1.73 | 2.10 | 1.90 | 2.23 | 1.97 | 1.77 | 2.00 | 1.85 | 1.60 | 1.93 | 1.52 | 1.75 | 2.13 | 2.02 | 2.23 | 1.93 | 2.33 | 2.12 | 0.720 |
| F-Dried herbs | 0.90 | 0.93 | 0.83 | 1.02 | 0.77 | 0.97 | 0.87 | 0.95 | 0.98 | 0.90 | 0.90 | 0.95 | 0.88 | 0.67 | 1.00 | 1.10 | 0.85 | 0.55 | 0.98 | 1.05 | 0.75 | 0.98 | 1.02 | 0.82 | 1.10 | 0.82 | 0.976 |
| **F-Earthy** | **1.80** | **1.63** | **1.62** | **1.53** | **1.62** | **1.20** | **0.97** | **1.75** | **1.13** | **0.98** | **1.77** | **1.80** | **1.37** | **1.38** | **1.90** | **0.90** | **0.92** | **1.45** | **1.55** | **1.43** | **1.43** | **1.25** | **1.50** | **1.38** | **1.72** | **1.32** | **0.001** |
| F-Eucalyptus | 0.90 | 1.12 | 1.13 | 0.87 | 1.13 | 1.03 | 0.95 | 0.93 | 0.60 | 0.67 | 0.77 | 0.67 | 0.67 | 0.90 | 0.63 | 0.68 | 0.52 | 0.80 | 0.90 | 0.80 | 0.68 | 0.58 | 0.88 | 0.73 | 0.88 | 0.80 | 0.332 |
| F-Floral | 1.22 | 0.98 | 1.20 | 0.93 | 1.45 | 1.53 | 1.28 | 1.22 | 0.97 | 1.40 | 0.88 | 1.13 | 1.10 | 1.00 | 1.07 | 1.15 | 1.25 | 1.15 | 0.92 | 0.88 | 0.95 | 1.12 | 1.58 | 1.03 | 1.07 | 1.30 | 0.431 |
| F-Grassy | 1.30 | 1.12 | 1.20 | 1.43 | 1.05 | 0.98 | 1.07 | 1.32 | 0.97 | 1.07 | 1.18 | 1.23 | 0.82 | 0.88 | 1.33 | 1.05 | 0.77 | 1.10 | 1.12 | 1.28 | 1.20 | 0.95 | 1.28 | 1.17 | 1.45 | 0.88 | 0.496 |
| F-Green | 1.15 | 1.12 | 1.08 | 1.28 | 1.33 | 0.82 | 0.87 | 1.03 | 1.15 | 1.00 | 1.15 | 1.00 | 1.17 | 1.02 | 1.23 | 1.27 | 1.12 | 1.13 | 1.27 | 1.32 | 1.20 | 1.32 | 1.20 | 1.37 | 1.33 | 1.18 | 0.938 |
| F-Jammy | 2.33 | 2.00 | 1.82 | 1.90 | 2.13 | 2.13 | 2.15 | 2.22 | 1.48 | 1.75 | 2.20 | 1.88 | 1.53 | 1.82 | 2.15 | 1.82 | 1.78 | 1.77 | 1.88 | 1.77 | 2.45 | 2.13 | 2.20 | 2.30 | 1.78 | 1.72 | 0.161 |

**SUPPLEMENTARY DATA**

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**TABLE S3**. CONTD.

| Attributes | CS1 | CS2 | CS3 | CS4 | CS5 | CS6 | CS7 | CS8 | CS9 | CS10 | CS11 | CS12 | CS13 | CS14 | CS15 | CS16 | CS17 | CS18 | CS19 | CS20 | CS21 | CS22 | CS23 | CS24 | CS25 | CS26 | p-value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **F-Minty** | 0.78 | 0.97 | 1.32 | 1.28 | 1.22 | 1.10 | 1.27 | 1.12 | 0.80 | 0.75 | 1.02 | 0.67 | 0.68 | 1.05 | 0.82 | 0.83 | 0.85 | 0.68 | 0.85 | 0.68 | 0.97 | 0.85 | 0.85 | 0.85 | 1.10 | 1.10 | 0.063 |
| F-Oaky | 2.15 | 2.45 | 2.22 | 2.20 | 2.07 | 2.10 | 1.50 | 2.35 | 1.97 | 1.88 | 2.33 | 2.13 | 1.92 | 1.70 | 2.18 | 1.80 | 1.45 | 2.13 | 1.87 | 1.60 | 1.95 | 1.83 | 2.10 | 1.90 | 2.13 | 1.95 | 0.127 |
| F-Red fruits | 2.70 | 2.40 | 2.82 | 2.53 | 2.52 | 2.43 | 2.67 | 2.73 | 2.20 | 2.45 | 2.53 | 2.30 | 2.27 | 2.73 | 2.62 | 2.13 | 3.22 | 2.50 | 1.93 | 2.50 | 2.38 | 2.28 | 2.77 | 2.57 | 2.67 | 2.25 | 0.165 |
| F-Savoury | 1.52 | 1.38 | 1.47 | 1.63 | 1.08 | 1.02 | 1.12 | 1.45 | 1.42 | 1.40 | 1.38 | 1.25 | 1.05 | 1.08 | 1.52 | 1.08 | 0.77 | 1.43 | 1.30 | 1.32 | 1.40 | 1.32 | 1.57 | 1.55 | 1.63 | 0.93 | 0.141 |
| F-Spices | 2.40 | 2.25 | 2.30 | 2.35 | 2.30 | 2.12 | 2.42 | 2.45 | 1.87 | 1.85 | 2.42 | 2.43 | 1.55 | 1.98 | 1.90 | 2.10 | 1.80 | 2.13 | 2.20 | 1.90 | 2.48 | 2.00 | 2.27 | 2.10 | 1.73 | 2.10 | 0.105 |
| **F-Tobacco** | 1.13 | 0.92 | 1.05 | 1.20 | 0.97 | 0.72 | 0.72 | 1.13 | 0.60 | 0.62 | 1.12 | 0.88 | 0.72 | 0.70 | 0.75 | 0.73 | 0.50 | 0.97 | 1.05 | 0.60 | 1.08 | 0.70 | 0.90 | 1.05 | 1.15 | 0.82 | 0.099 |
| **F-Vanilla/Chocolate** | 0.73 | 0.78 | 0.83 | 0.68 | 0.70 | 0.90 | 0.98 | 1.18 | 0.88 | 1.00 | 0.73 | 0.60 | 0.80 | 0.43 | 0.50 | 0.73 | 1.33 | 0.63 | 0.40 | 0.57 | 0.80 | 0.82 | 0.98 | 0.47 | 0.75 | 0.68 | 0.010 |
| F-Violets | 0.55 | 0.82 | 0.78 | 0.65 | 1.02 | 1.03 | 1.10 | 0.77 | 0.53 | 0.75 | 0.63 | 0.62 | 0.68 | 0.75 | 0.60 | 0.60 | 1.07 | 0.63 | 0.73 | 0.93 | 0.62 | 0.70 | 0.93 | 0.85 | 0.85 | 1.03 | 0.248 |
| F-Yeasty | 0.42 | 0.37 | 0.43 | 0.27 | 0.48 | 0.30 | 0.65 | 0.50 | 0.60 | 0.45 | 0.47 | 0.48 | 0.20 | 0.58 | 0.50 | 0.47 | 0.32 | 0.57 | 1.00 | 0.75 | 0.38 | 0.48 | 0.42 | 0.45 | 0.47 | 0.37 | 0.103 |
| **T-Acidity** | 3.97 | 3.48 | 3.80 | 3.52 | 3.75 | 3.62 | 3.15 | 4.17 | 3.20 | 3.38 | 3.73 | 4.18 | 3.33 | 3.58 | 3.75 | 3.45 | 3.20 | 3.57 | 3.75 | 3.73 | 3.17 | 3.00 | 3.83 | 3.23 | 3.68 | 3.62 | < 0.0001 |
| **T-Bitterness** | 2.80 | 2.83 | 2.73 | 2.80 | 2.85 | 2.78 | 2.02 | 2.72 | 2.68 | 2.55 | 2.77 | 3.07 | 2.63 | 2.87 | 2.90 | 2.58 | 2.08 | 2.68 | 3.15 | 2.55 | 2.52 | 2.55 | 2.77 | 2.25 | 2.87 | 2.60 | 0.029 |
| **T-Sweetness** | 2.23 | 2.15 | 2.22 | 2.13 | 2.48 | 2.43 | 2.75 | 2.15 | 2.23 | 2.35 | 2.63 | 1.82 | 2.07 | 2.07 | 2.25 | 2.22 | 2.70 | 2.18 | 1.77 | 1.95 | 2.65 | 2.52 | 2.30 | 2.57 | 2.18 | 2.03 | 0.004 |
| MF-Alcohol | 3.87 | 3.78 | 3.88 | 3.92 | 3.93 | 4.17 | 3.58 | 3.80 | 4.00 | 3.75 | 3.90 | 3.70 | 3.75 | 3.77 | 3.80 | 3.92 | 3.67 | 3.62 | 3.50 | 3.67 | 3.85 | 3.78 | 3.75 | 3.53 | 3.62 | 3.60 | 0.447 |
| **MF-Astringency** | 3.85 | 4.10 | 4.48 | 4.05 | 4.15 | 4.17 | 3.37 | 4.17 | 4.20 | 3.67 | 4.10 | 4.93 | 4.32 | 3.95 | 4.55 | 4.05 | 3.60 | 4.02 | 4.82 | 4.05 | 3.92 | 3.68 | 4.23 | 3.75 | 4.10 | 4.65 | < 0.0001 |
| MF-Body | 3.65 | 3.77 | 4.02 | 3.95 | 4.17 | 3.97 | 3.82 | 3.73 | 3.77 | 3.58 | 3.80 | 3.83 | 3.62 | 3.72 | 3.80 | 3.97 | 3.57 | 3.70 | 3.75 | 3.57 | 3.92 | 3.70 | 3.92 | 3.55 | 3.68 | 3.73 | 0.272 |
| Length of flavour | 4.35 | 4.45 | 4.55 | 4.40 | 4.50 | 4.62 | 4.27 | 4.35 | 4.27 | 4.08 | 4.47 | 4.30 | 4.27 | 4.12 | 4.32 | 4.28 | 4.07 | 4.05 | 4.33 | 4.12 | 4.42 | 4.33 | 4.47 | 4.03 | 4.38 | 4.27 | 0.115 |

**SUPPLEMENTARY DATA**

Souza Gonzaga, L., Bastian, S., Capone, D., Ranaweera, R., & Jeffery, D. (2021). Modelling Cabernet-Sauvignon wine sensory traits from spectrofluorometric data. *OENO One*, *55*(4)
https://doi.org/10.20870/oeno-one.2021.55.4.4805

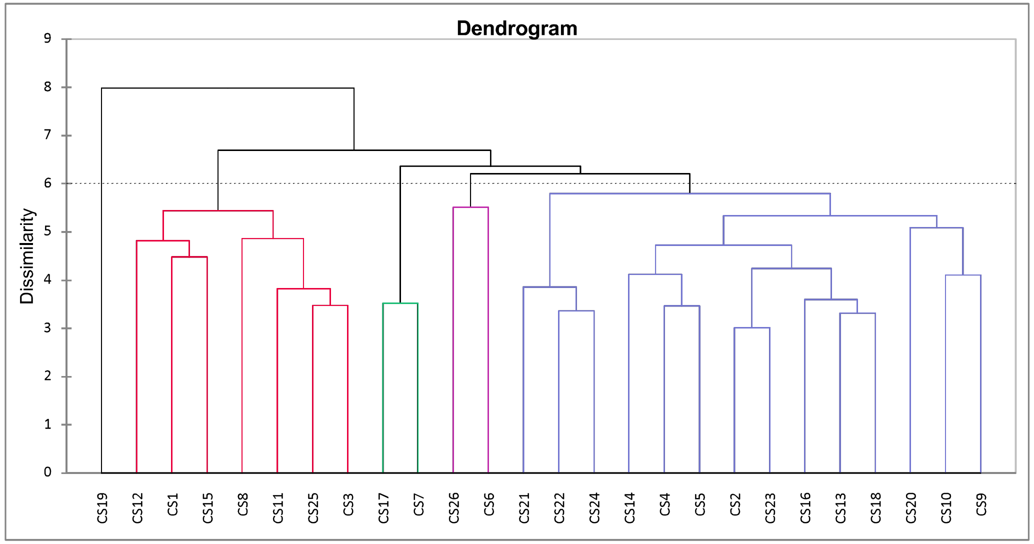


**FIGURE S1.** Agglomerative hierarchical clustering dendrogram plot of the five clusters segregating the Coonawarra Cabernet-Sauvignon wines (n = 26, refer to Table S1 for wine codes) evaluated with rate-all-that-apply (significantly different attributes as presented in Table S3, $\alpha = 0.1$). The dotted line shows the truncation according to the dissimilarity on the y-axis.

# Chapter 6

## Concluding Remarks & Future Perspectives

# 6.1 Concluding Remarks

The focus of this thesis was to better understand the sensory typicity of regional Australian Cabernet Sauvignon wines through different methods of sensory evaluations. An additional aspect was exploring the applicability of spectrofluorometric analysis to comprehend and predict sensory profiles of Cabernet Sauvignon wines from Coonawarra using unreleased commercial wines.

### 6.1.1. Understanding wine typicity

Typicity is a term that captures the expression of unique compositional traits in a food product that are shaped by the region of origin including, environmental, agricultural, industrial, and social conditions involved during production. Over the past 10 years, the concept of typicity has progressively grown in significance for food researchers, and this assertion applies similarly to the wine research field. Chapter 1 provides a systematic review of the subject in relation to wine, proposing a defined concept for wine typicity:

> "Wine typicity can be defined as a juxtaposition of unique traits that define a class of wines having common aspects of terroir involving biophysical and human dimensions that make the wines recognisable, and in theory, unable to be replicated in another territory".

When commercialising a product that has a strong connection with its origin such as wine, it is important to enhance consumer engagement and be able to effectively communicate information about typicity and origin in order to build a connection, increasing their trust and confidence. In accordance with the literature review in Chapter 1, the region of origin of a wine is used as a quality indicator and as a factor for the price that consumers are willing to pay for a bottle of wine. The expression of typicity is also an important factor for consumer when the expectations around a category of wine are built. Additionally, the literature review also revealed the importance for wine brands and wine producing regions to create a solid bond between their product and its provenance through strategies (e.g. wine tourism) that expand the involvement between consumers and the business.

### 6.1.2. Using content analysis of wine writers' online tasting notes to profile regional wines validated by industry expert sensory evaluation

In Chapter 2, content analysis was used as a novel approach to analysed a large data set of readily available wine writers' reviews and tasting notes to characterise regional Australian Cabernet Sauvignon wine. Another aim of the content analysis performed on the wine reviews, was to support the sample selection process. This ensured that wines purportedly characteristic of a region, were selected without the necessity to purchase and screen hundreds of wines using sensory evaluation being a cost effective and rapid tool. A web-scraping software was used to extract over 2,500 wine reviews publicly available from highly regarded wine writers. A content analysis with a text mining tool was used to create a lexicon and to analytically explore the data. Furthermore, an expert sensory assessment was performed and permitted validation and comparison of the findings above with data from an actual sensory evaluation on a selected set of wines. For the expert sensory assessment, a selected sample set of 84 commercial Cabernet

Sauvignon wines from different Australian geographical indications (Coonawarra, Margaret River, and Yarra Valley) and Bordeaux were selected to be free-handed evaluated by a panel of 11 industry experts. Distinctive regional profiles were observed using the content analysis approach on the tasting notes of both date sets (wine writers' reviews and expert panel), indicating that terroir, viticulture, and winemaking practices, that vary between GIs, can influence and distinguish the final composition of Cabernet Sauvignon wines.

The content analysis methodology was also useful to understand wine quality drivers using as a proxy overall quality scoring (100 points for wine writers' reviews and 20 points for expert panel) that were further divided into medal assignments. A clearer distinction was apparent between the high and low end of assigned medals for high industry involvement subjects that participated in this study. Based on multiple factor analysis (MFA), wine writers' and the industry expert panel displayed good agreement (RV = 0.826) when analysing wine quality, and considered 'complexity' and 'dark fruits' to be terms associated with high quality wine whereas 'green' related to lower quality examples. A moderate agreement (RV = 0.440) was noted when considering GI, but it did provide better understanding of the relationship between regional profile and quality parameters.

Overall, this study was able to established content analysis as an effective methodology to investigate analytical features, such as sensory characterisation in wine, using big data sets generated online. The proposed methodology could also assist wine sample selection for further in-depth sensory and chemical studies, thereby minimising the costs and optimising the time required for performing large scale research. The knowledge gained from this study also served as a foundation for selecting a sample set that could be further analysed through subsequent work (Chapter 3, 4, and 5) and provided insights for better understanding the drivers for the sensory typicity represented in the four GIs analysed.

### 6.1.3. Combining an industry expert sorting task and a descriptive analysis with trained panel to understand regional traits

With the objective of exploring the sensory traits responsible for the Australian Cabernet Sauvignon typicity the study conducted for Chapter 3 was composed of a free sorting task in combination with a variant of the rate-all-that-apply (RATA) exercise. The exercise was performed by an industry expert panel with a sample set of 84 commercial Cabernet Sauvignon wines that were selected from the study in Chapter 2. The wines studied were from Margaret River, Yarra Valley, Coonawarra, and Bordeaux and were all from the 2015 vintage. These results were compared with those of a sensory descriptive analysis (DA) performed by a trained panel on a subset of the wines (n=52). The free sorting task performed by the industry experts did not demonstrate region of origin as a clear driver for the wine segregation, potentially as a result of the high number of samples and/or by the open interpretation nature of the study. The fact that it was a free sorting task meant that the panellists were responsible for choosing their own sorting criteria. Nonetheless, it was interesting to explore the four main groups that experts used to categorise the wine and their related sensory traits. The first group comprised wines that presented a lack of 'fruity' characters and the presence of developed 'savoury' characters, the second group had the presence of 'fruity' and 'floral' attributes, the third group was defined by 'fresh green' terms such as 'green pepper' and 'herbaceous', and the fourth group was associated with developed 'vegetal' terms (e.g. 'cooked vegetables') and also lacked the 'floral' and 'fruity' characters.

By analysing the sensory results from the DA panel with the expert's RATA evaluation, it was clear that the biggest difference in sensory profile was seen between the Australian GIs and the Cabernet Sauvignon dominant red blends from Bordeaux. This indicated that differences in practices and natural conditions between the New World and Old World wine regions and targeted styles potentially have a large impact on sensory characteristics. Despite different methodologies being used to assess the wine samples (i.e. RATA by experts vs DA by trained panel), common descriptors were found to be important for each region. Altogether, Coonawarra wines were typified with a significant presence of a 'minty' attribute, Margaret River wines were represented by the presence of 'floral' attribute, and the wines from Yarra Valley and Bordeaux had 'savoury'/'cooked vegetables' as important characters. The outcomes from these sensory cohorts give rise to the possibility of identifying specific sensory characters that are representative of the sensory typicity concept from the region analysed.

The study reported in **Chapter 3** highlights the importance of using multiple sensory methodological approaches to understand compositional traits of a highly complex product such as wine and especially to examie a multilayered concept such as typicity. Although variability was observed between the different assessments, a general tendency was detected for the regional sensory profiles, and more importantly, some of the outcomes noted in **Chapter 2** were confirmed.

### 6.1.4. Consumer liking evaluation with rate-all-that-apply assessments to explore level of regional engagement and purchase behaviour

Understanding wine sensory typicity is important for the wine industry when trying to create or preserve a regional style. However, comprehending how this concept can influence consumer purchase behaviour and opinion is also imperative as part of the overall goal when producing a wine, as shown in **Chapter 4**. Assessing a subset of the same regions as described in **Chapters 2** and **3**, a pre- and post-tasting survey was performed with 112 red wine consumers that were also segmented based on their involvement with the wine industry. According to the computed answers, Australian consumers were fairly familiar with the connotation behind the typicity concept and its association with a product's provenance. However, the expression of typicity appeared to be an external idea instead of being expressed through distinctive sensory profiles.

The consumers involved in this study indicated that origin information stated on a wine bottle can have a positive impact on their purchase decision and on the price they were willing to pay. When actually tasting the wine samples, being informed about the wine provenance beforehand had a positive impact on the liking scores. Although the liking score was influenced by the information condition, it was interesting to observe that having such information did not translate when characterising the sensory traits of the samples. In other words, consumers that had wine provenance information liked the wine more when compared with the uninformed panel but both used the same sensory descriptors for the samples. Sensory familiarity was also assessed, with the scores having a different impact depending on the samples evaluated, whereby provenance information had a negative influence over the familiarity scores except for samples from Coonawarra in which information had a positive impact. The RATA exercise highlighted the distinctive regional profile and the sensory terms associated with each region analysed, reinforcing the findings outlined in Chapters 2 and 3. Sample liking was again associated with wines that were characterised by 'minty', 'herbaceous', 'dark fruits', and 'jammy' descriptors, as well as samples that had a fuller body.

### 6.1.5. Exploring spectrofluorometric data to model and predict sensory traits of Cabernet Sauvignon wine

In order to understand and connect results found in the studies discussed in Chapters 2, 3, and 4 to compositional traits present in the wine, a set of unfinished wines that had a limited influence of winemaking processes (e.g., maturation, oak contact, or blending) from the Coonawarra GI was selected. The wines were assessed through a RATA exercise generating sensory profiles and through spectrophotometric analysis generating excitation-emission matrices (EEMs) for each sample, as described in Chapter 5. Using agglomerative hierarchical clustering (AHC) analysis, the sensory characterisation was used to segregate the sample set into five clusters that were further modelled with EEMs data. The sensory analysis showed 'minty' as an important character for Coonawarra wines, confirming what was shown in Chapters 2, 3, and 4. Using the EEM data, extreme gradient boosting discriminant analysis (XGBDA) (a machine learning technique) was able to classify the wines with 100% accuracy according to the five sensory clusters established by AHC, indicating a possible direct or indirect correlation between those two sets of data.

Taking this further with parallel factor analysis (PARAFAC), four main fluorophores (Components 1, 2, 3, and 4) were tentatively identified and associated with different classes of phenolic compounds. The compound classes that may be responsible for specific sensory traits according to the literature were further analysed with the sensory profile found by the RATA exercise. Through multiple factor analysis (MFA) between EEM signals and RATA results, component 1 was assumed to be related with catechin (including tannin) and was associated with 'dark fruits' and 'savoury' characters, component 2 was deemed to arise from phenolic aldehydes and was related with 'barnyard' attribute, component 3 was tentatively assigned to anthocyanins and was associated with 'cooked vegetables' and 'vanilla/chocolate' terms, and finally, component 4 was assumed to involve stilbenoids and was related with 'barnyard' character and a lack of sensory descriptors associated with component 1. Notably, these associations were more likely to be an indirect correlation instead of a causative correlation and further research is necessary to understand how those fluorophores could serve as drivers for the sensory traits found above.

Partially addressing the existence of direct correlations, the use of spectrophotometric data to predict sensory attributes was explored through partial least squares (PLS) regression modelling. No suitable model was generated for any sensory term apart from perceived astringency. The appropriate model was able to predict with 68.1% confidence the astringent mouthfeel rating and was able to explain 84.8% of the variance in the sample set. Considering the novelty and how ambitious it was to associate compositional traits identified by spectrofluorometric analysis with product characterisation according to sensory analysis, the results presented in this study were quite promising and laid the foundation to better understand the role of fluorescence analysis in predicting sensory traits.

# 6.2 Future Perspectives

Wine typicity is a concept that is important for the wine industry, not only from the production perspective but also from a commercialisation standpoint when considering consumer purchase behaviour, as reviewed in Chapter 1. However, the challenging task for the industry is being able to express their own regional typicity while preserving their unique branding style, assuming it exists, while preserving their wine quality and concurrently being mindful of consumer expectations. The industry also needs to be flexible and able to adjust and/or evolving taking into consideration how dynamic consumer behaviour can be. Therefore, there will always be gaps for more in-depth research to better comprehend what typicity represents for consumers, for individual brands and for delimited wine producing regions. Ultimately, further outputs are necessary to aid the wine sector in connecting the typicity expression with the natural and social dimensions involved in the wine production, eventually providing tools to manipulate and encapsulate that expression.

Different methodologies are available to assess a wine's sensory profile as demonstrated in Chapters 2, 3, and 4. Different variations of these methodologies also open new possibilities to further evaluate regional sensory profiles. In Chapter 2, content analysis was used for Cabernet Sauvignon wines from selected regions and it would be worthwhile exploring whether this methodology can be applied to other GIs and for other varieties produced in Australia and even for other viticultural regions around the world. It will also be interesting to explore the content analysis methodology as a way to link scientific and production information with wine sales and popularity in order to understand drivers for quality perspectives. In Chapter 3, a free sorting task was performed with industry experts that provided valuable results about the large sample set assessed, but more relevant results could perhaps have been achieved using a variation of this methodology. In this case, pre-defined regional groups could be established before the sorting task to decrease the complexity involved. A comparative study between both method variations including a set of pre-defined rules and the impact a sorting task could be useful for selecting the most appropriate methodology.

Dealing with complex constructs such as consumer opinions and expectations is a challenge not only for the research field but also for the industry. In Chapter 4 liking evaluation with different participant contextual conditions (with wine origin information and without wine origin information) was performed, but opportunity still remains to explore consumer segmentation and knowledge about the intrinsic expression of regional typicity as well as their capability to identify and differentiate wines that come from a protected (e.g., Protected Designation of Origin, PDO) region. Additionally, a cross-cultural work would also be interesting considering that there could be differences between New World and Old World consumer behaviour and sensory ability and that this thesis was focussed on Australian (New World) consumers. Further investigation is also needed to assess whether the difference in results between liking scores without an evident difference according to RATA characterisation for the two conditions was caused by an assimilation effect or because the panel was performing two contrasting methodologies, being a holistic test (liking) and an analytical evaluation (RATA). It would be informative to explore whether the results are replicable in different tasting contexts and whether different emotions are evoked. Additionally, there are new possibilities to further understand how the meaning of typicity is formulated in the consumer mind, using content analysis of open-ended questions. It was shown in Chapter 4 that consumers stated region information as a positive influence over their purchase behaviour – more realistic projection assessments involving real purchases could be performed to verify this. In that same study (Chapter 4) a small (n = 8) sample set was used, which could be implied as a limitation for the sample representativeness, and for that reason this sort of study could be replicated with a larger sample set.

In Chapter 5, the possibilities around the association between sensory profile and spectrofluorometric data were demonstrated and future investigations are essential to better understand how those two data sets are correlated. There are new possibilities by using reconstituted samples with important chemical compounds that are associated through spectrofluorometric analysis and whether those are translated to the perceived sensory profile (whether marker compounds exist). Reconstituted samples can also be used to further improve prediction models for sensory traits such as the astringency mouthfeel that was studied in Chapter 5.

As elaborated throughout this thesis, sensory evaluation is an important component when understanding the sensory typicity and that concept is translated into the consumer perception. However, it is not enough to comprehend in depth the sensory expression of the wine typicity and how practices can be implemented to preserve or enhance regional distinctiveness. Analytical instrumentation (e.g., HPLC, GC-MS) is necessary to help identify and quantify important chemical compounds. The identification of the chemical constituents responsible for regional uniqueness is a step forward to directly connecting vineyard and winemaking practices and environmental conditions with the typicity expression. This would lead to the ultimate goal of providing the industry with enough knowledge to be able to modulate their wine style while guaranteeing its uniqueness.

# List of Abbreviations

| | |
|---|---|
| AHC | Agglomerative hierarchical clustering |
| ANOVA | Analysis of variance |
| AOC | Appellation d'origine contrôlée |
| A-TEEM | Absorbance-transmission and fluorescence excitation-emission matrix |
| CA | Correspondence analysis |
| CV | Cross-validation |
| CVA | Canonical variate analyses |
| DA | Descriptive analysis |
| DOC | Denominazione di origine controllata |
| DOCa | Denominación de origen calificada |
| DOCG | Denominazione di rigine controllata e garantita |
| DOP | Denominação de origem protegida |
| EEM | Excitation-emission matrix |
| FWI | Fine wine instrument |
| GI | Geographical indication |
| GLSW | Generalised least squares weighting |
| HCL | Hydrochloric acid |
| HPLC | High performance liquid chromatography |
| IBMP | 3-isobutyl-2-methoxypyrazine |
| JAR | Just-about-right |
| LV | Latent variables |
| MDS | Multidimensional scaling |
| MFA | Multiple factor analysis |
| OIV | Organisation Internationale de la Vigne et du Vin |
| PARAFAC | Parallel factor analysis |
| PCA | Principal components analysis |
| PDO | Protected designation of origin |
| PGI | Protected geographical indication |
| PLS | Partial least squares |
| PTFE | Polytetrafluoroethylene |
| RATA | Rate-all-that-apply |
| RMSEC | Root mean square error of calibration |
| RMSECV | Root mean square error of cross-validation |
| RMSEP | Root mean square error of prediction |
| RV | Regression vector |
| $SO_2$ | Sulfur oxide |
| TA | Titratable acidity |
| UPGMA | Unweighted pair-group average |
| UV-vis | Ultraviolet-visible |
| XGBDA | Extreme gradient boosting discriminant analysis |

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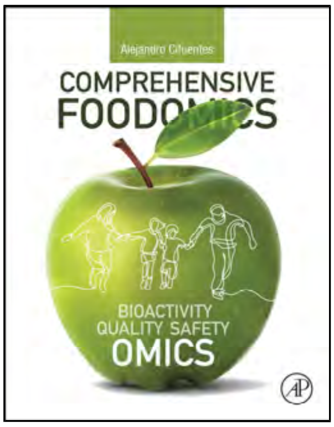
# Appendix A

## Book Chapter

Authenticity and Traceability in the Wine Industry: From Analytical Chemistry to Consumer Perceptions.

Ranaweera, R. K. R., **Souza Gonzaga, L.**, Capone, D. L., Bastian, S. E. P., & Jeffery, D. W. (2021) Comprehensive Foodomics. Elsevier. DOI.






From Ranaweera, R.K.R., Souza Gonzaga, L., Capone, D.L., Bastian, S.E.P., Jeffery, D.W., 2021. Authenticity and Traceability in the Wine Industry: From Analytical Chemistry to Consumer Perceptions. In: Cifuentes, A. (Ed.), Comprehensive Foodomics, vol. 3. Elsevier, pp. 452–480.
ISBN: 9780128163955

# 3.33 Authenticity and Traceability in the Wine Industry: From Analytical Chemistry to Consumer Perceptions

**Ranaweera KR Ranaweera[a], Lira Souza Gonzaga[a,b], Dimitra L Capone[a,b], Susan EP Bastian[a,b], and David W Jeffery[a,b],**
[a] Department of Wine and Food Science, The University of Adelaide, Glen Osmond, SA, Australia; and [b] Australian Research Council Training Centre for Innovative Wine Production, The University of Adelaide, Glen Osmond, SA, Australia





## Glossary

**Ampelographic** Associated with the identification and classification of grapevines by assessing anatomical features and morphological differences, such as the shape and color of leaves, and features of growing tips (hairless, shiny, etc.).
**Chaosmetric** Refers to technology that uses a non-human intervention approach to creating tags with unique features using a random and unreproducible process.
**Fining agents** Permitted wine additives that help protect wine against the development of physical or chemical instabilities.

 https://doi.org/10.1016/B978-0-08-100596-5.22876-X

Comprehensive Foodomics, 2021, 452–480

**Organoleptic** Related to the senses, as in the perception of smell, taste, flavor, tactile sensations and appearance.
**Terroir** Delimited geographic location that links cultural traits and practices with the natural environment where a product is produced. Together these factors lead to originality, typicity and recognition of products from a region.

## 3.33.1 Introduction

### 3.33.1.1 Wine as a Global Beverage

Wine has been part of human history for thousands of years (McGovern et al., 2017) and endures today as a revered beverage in many cultures that combines potential health benefits with pleasure (Higgins and Llanos, 2015). Old World wines, represented by regions in Western and Southern Europe, and New World wines, from North and South America, South Africa, Australia, New Zealand, and more recently, others such as China, India and Japan, define the modern world of wine. Old World producers are recognized by their traditional and consistent geographical locations, viticultural practices, and winemaking techniques (Banks and Overton, 2010). On the other hand, New World producers are not as restricted by local viticultural and enological customs, and have benefited from innovations afforded through research and development coupled with interaction among different industry stakeholders (Aylward, 2003).

In relatively recent times, a noteworthy change has been observed in the international wine industry, with the perception that Old World producers no longer dictate the wine market as they once did (Aylward, 2003; Koutroupi et al., 2015; Campbell and Guibert, 2006; Wongprawmas and Spadoni, 2018). Reflecting this, wine production volume in Old World countries such as France and Italy has decreased between 1980 and 2016, whereas the opposite occurred for New World countries such as USA, Australia, New Zealand, Chile, and China. The same trend is true for domestic wine consumption in Old and New Worlds (Anderson et al., 2017; Koutroupi et al., 2015). The change is not only one of production but also of culture, and can be explained at least partially by consumers' growing appreciation of the traits that New World wines can provide, such as quality, uniqueness, and value for money (Aylward, 2003; Wongprawmas and Spadoni, 2018). Nonetheless, the changes also emphasize the truly global nature of wine production and consumption.

It is accepted that wines represent an association with the geographical location where they are produced, and consumers specifically demand trustworthy information about origin (Vergara et al., 2011), which it is often considered a significant factor in wine quality (Riovanto et al., 2011). Year of vintage, grape variety, and producer reputation are also viewed as major factors that can determine consumer preference and their notions of wine quality (Schamel and Anderson, 2003). When considering what consumers value, and within the context of a global market worth hundreds of billions of dollars, wine ultimately turns out to be no different to other consumer goods that need to be protected against various types of fraud. This requires the means to authenticate wines and verify product origin, variety and quality (Waterhouse et al., 2016a), and traceability systems to monitor the integrity of the grape and wine production processes.

This chapter provides up-to-date knowledge on authenticity and traceability in the wine industry. It covers the need for wine authentication, analytical methods and applications, the implications of wine fraud, and technological approaches to traceability that record information and help protect product integrity. Authenticity and traceability are also considered from the perspective of consumers, who are the ultimate stakeholders when it comes to the value of wine. The complexity of the topic requires some context, so the chapter begins by outlining the notion of wine quality, and explains its underpinnings in *terroir* and the importance of wine composition.

### 3.33.1.2 Wine Quality

Although it is a commonly used word, quality is a challenging concept to objectively describe and measure because of its broad meaning and close connection with hedonics (Hopfer and Heymann, 2014; Niimi et al., 2018). From a subjective standpoint, there are two ways to view the quality of wine. One option relies on the judgment of wine practitioners based on their assessment of a range of sensory characteristics, and especially a lack of faults (Charters and Pettigrew, 2007). A final wine quality score can be derived in this way, but difficulty arises due to the different approaches to such evaluations. Alternatively, wine quality can be judged from the consumer perspective, where there is reliance on the perceived quality, which can result from expected quality based on brand name, price and labeling, and experienced quality based on the actual sensory cues (Charters and Pettigrew, 2007). Perceived quality is a multidimensional concept involving a complex relationship between intrinsic (i.e., appearance, sensory traits, pleasure, origin, variety, typicity) and extrinsic (i.e., grapes, technically correct and consistent winemaking, marketing, packaging) elements (Charters and Pettigrew, 2007). Verdú et al. (2004) had previously suggested that red wine could be evaluated using a two-dimensional scale containing other dimensions (i.e., multidimensional): one dimension involved extrinsic attributes (region of origin, image/renown, and presentation/packaging), and the other related to intrinsic attributes (age, harvest information, sensitivity (balance/body), and acuteness (intensity/complexity of bouquet)).

D'Alessandro and Pecotich (2013) noted that assessment of sensory quality can be a difficult task for inexperienced consumers, who rely mainly on country of origin and brand name (to a lesser extent) as indicators of quality, whereas experts were able to objectively use sensory quality in association with price, brand and country of origin. Hopfer and Heymann (2014) demonstrated that consumers could evaluate quality through tasting experiences just as well as an expert panel, with the only limitation being the difficulty of clearly communicating their opinions. Nonetheless, consistently judging wines can be challenging even for experts due to the highly variable matrix and dimensions involved in wine quality (Hopfer and Heymann, 2014).

The complexity of wine aromas and flavors means that no one chemical compound or sensory descriptor is expected to completely explain all the aspects involved in a wine quality definition (Hopfer et al., 2015). Instead, the resultant sensory attributes are reliant upon synergies and interactions between a broad range of volatile and non-volatile compounds (Hjelmeland et al., 2012). As an example, analysis of Cabernet Sauvignon wines by Hjelmeland et al. (2012) showed a large number of chemical constituents could be positively as well as negatively correlated with aroma and flavors attributes of the wine, which suggested the existence of additive and interactive effects among compounds in the wine matrix. Despite the impact of the matrix, certain sensory attributes can be considered as negative or positive in terms of quality, or even both, depending on the intensity of those characters in the wine (Hopfer et al., 2015).

Even though sensory and chemical attributes can be correlated with hedonic aspects, quality can be a broad concept and can be represented through a number of factors for the consumer. For many, the region of origin is a determinant for a purchase decision, and can be the most important information used to predict quality by raising a quality expectation of the region (Ray and Johan, 2007). For consumers with high involvement in the wine sector, wine that expresses the typicity expected of the region is an indicator of high quality (Tustin and Lockshin, 2001; Charters and Pettigrew, 2003). Just as regionality can be considered an aspect of wine quality, a high average quality can boost a wine region's reputation and shape the regional individuality (Easingwood et al., 2011). Wine typicity and regionality have their origins in the environment where the grapes are grown, which falls within the broad concept of terroir.

### 3.33.1.3 Terroir

The definition of terroir is important because it relates to the variables that need to be considered when studying authenticity. Terroir is a French word that cannot be precisely translated into English and can have a broad spectrum of definitions when described in English depending on the perspective of the writer (Gladstones, 2011). It is a concept that is discussed worldwide and can be used for different contexts. During a UNESCO gathering, professionals from two French institutes (INRA/INAO)[1] proposed a definition for terroir as:

> Terroir is a delimited geographic space, defined by a human community that during its history builds a distinct set of cultural traits, knowledge and practices, based on a system of interactions between the natural environment and human factors. This applied knowledge creates an originality, confers a typicity and allows products and services from this space to be recognized.
>
> (translated and adapted) (UNESCO and Association Terroirs & Cultures, 2005; Unwin, 2012)

According to Unwin (2012), the definition of terroir covers a broad range of factors and goes beyond physical dimensions that some notions are restricted to. In order to be scientifically valid, however, terroir has to be given an objective and specific meaning, with studies dedicated to terroir primarily interested in understanding the impacts on grape and wine quality of environmental aspects in vineyards or specific regions (Vaudour, 2002). Terroir also relates to the authenticity of a product by defining the factors, such as climate and soil conditions that directly affect the chemical composition of grapes and ultimately translate into differences in wine composition. Winemaking inputs such as fermentation conditions, yeast strains, and processing steps will further affect wine constituents (Arvanitoyannis et al., 1999), and can also be considered as important aspects of terroir.

### 3.33.1.4 Wine Composition

Investigating wine authenticity first requires knowledge of wine composition (**Fig. 1**), which is a complex fermented beverage that mainly consists of water and ethanol (Waterhouse et al., 2016b). Accounting for about 97% w/w of the constituents in wine, ethanol and water are mainly responsible for the physicochemical properties of wine, including viscosity, polarity and solubility, but also have direct and indirect effects on organoleptic properties (Margalit, 2004; Waterhouse et al., 2016c). The remaining 3% of components represent the main contributors to the perceived color, aroma and flavor of the wine, and other sensory attributes that drive style, quality and consumer liking. These components can be categorized into non-volatile and volatile compounds. The non-volatiles primarily include phenolic compounds, sugars, glycerol, proteins, amino acids, organic acids and inorganic compounds (Alañón et al., 2015). The volatile compounds include higher alcohols, terpenes, esters, aldehydes, ketones, volatile acids, and heteroatomic compounds involving sulfur and nitrogen (Villamor and Ross, 2013). Brief examples provided in the following paragraphs indicate how such components have been studied for authentication purposes (see Section "**Authentication Methods for Wine**" for detailed information about analytical approaches).

[1]INRA – Institut National de Recherche Agronomique en France/INAO – Institut National des Appelletions D'origine.

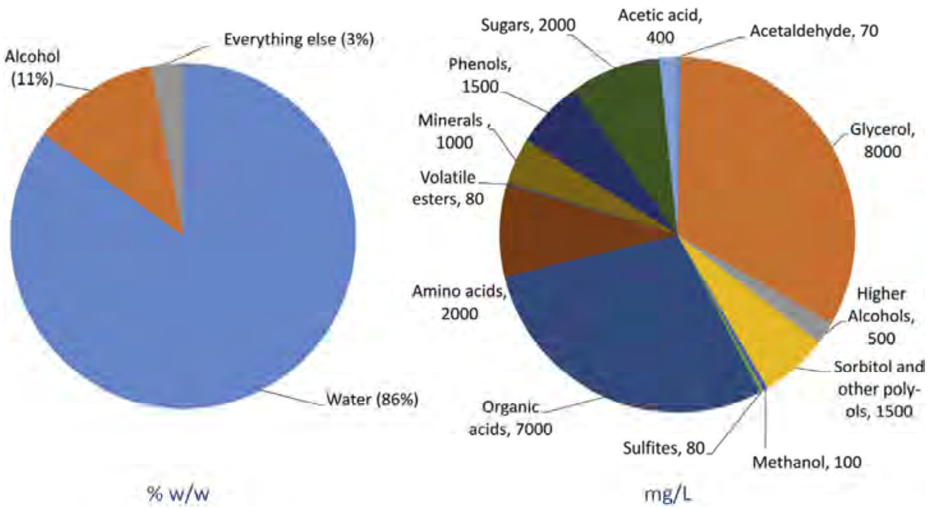



**Figure 1** Chemical composition of dry red table wine with major components given on a weight-for-weight (w/w) % basis, and "Everything else" presented in mgL$^{-1}$. Adapted from Waterhouse et al. (2016b).

Grape carbohydrates, mainly consisting of the monosaccharides glucose and fructose, play a major role as the carbon source for yeast during fermentation. They can also exist in polymerized forms, as pectins and other polysaccharides, and glucose and certain monosaccharides form glycosides with anthocyanidins (grape pigments) and other molecules (Jackson, 2014). Residual sugars, for example arabinose and xylose, are also present but are less than 1.5 gL$^{-1}$ and do not contribute sweetness to wine (Jackson, 2014). Aside from ethanol as the major product of fermentation, glycerol is also derived from glycolysis and is a relatively abundant sugar alcohol in wine, where it may contribute to perceptions of wine body and mouthfeel (Zhao et al., 2015). The $\delta^{13}C$ isotopic ratio of glycerol, ethanol and grape sugars has been applied in wine authentication, providing information on sugar origin (Guyon et al., 2011). Other polyols constitute additional sugar alcohols but are present to a much lesser extent than glycerol.

Organic acids are another important class of constituents in wine, with some being formed in grapes (tartaric, malic, and citric) and others formed by yeast or bacteria during winemaking (succinic, lactic and acetic) (**Fig. 2**). Tartaric acid is the most prominent acid in ripe grapes and is mainly responsible for the pH of wine but others, including an array of volatile acids (e.g., acetic), contribute to total acidity (Waterhouse et al., 2016d). Even though organic acid profile is not commonly used as a characteristic index for wine authentication, it has been applied successfully (Huang et al., 2017).

The mineral content of wine arises in diverse ways, including from irrigation water, vineyard soils, processing aids, winery equipment and external contaminants. The concentrations and oxidation states of these metals not only affect wine sensory properties and stability, but their profiles can also be used for authentication purposes (Waterhouse et al., 2016e).

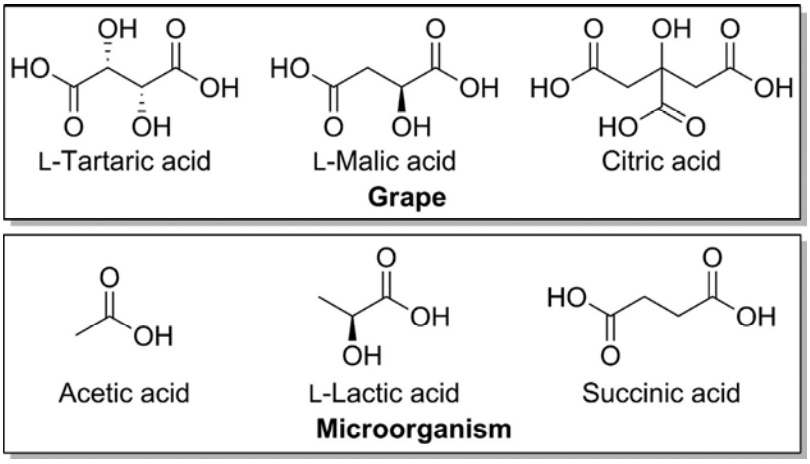



**Figure 2** Major organic acids present in wine from grape and microbiological sources.

Phenolic compounds are one of the most significant components of wine responsible for organoleptic properties such as color, astringency, and bitterness; they are also important from a health perspective as bioactives with antioxidant and anti-inflammatory properties (Waterhouse, 2002). Phenolics are found at various concentrations depending on the type (red or white) and variety of grape (Waterhouse et al., 2016f), and their profiles can be used successfully for varietal authentication. Many of the phenolics are found in grape seed and skin, with some occurring in the flesh. They are extracted during wine production, especially for red winemaking where maceration with grape solids occurs. Wine phenolics can be categorized into two groups according to the carbon structure: as flavonoids ($C_6$–$C_3$–$C_6$) and non-flavonoids (**Fig. 3**).

Flavan-3-ols, flavonols, and anthocyanins are the main flavonoids, with phenolics such as hydroxycinnamates, stilbenes, and benzoic acids classified as non-flavonoids (Waterhouse et al., 2016g). White wine has a lower concentration of phenolic compounds and a higher abundance of hydroxycinnamoyl tartaric acid esters, whereas red wine is characterized by having anthocyanin pigments and tannins (Garrido and Borges, 2013).

Nitrogenous compounds present in grapes and wine are of special interest due to their effects on fermentation performance (as a nutrient) and role in protein haze due to heat instability (Margalit, 2004). The content of amino acids in finished wine tends to be low but they are important as a source of volatile higher alcohols produced during fermentation (Huang and Ough, 1991) and essential in decreasing $H_2S$ formation (Mendes-Ferreira et al., 2011). The concentrations of the major amino acids present in wine, including proline, arginine and glutamine (**Fig. 4**), vary among different varieties and can be used as a marker for varietal authentication of wine (Herbert et al., 2000).

Volatiles that can contribute to the aroma profile of wines include aldehydes and ketones, with acetaldehyde being the most abundant. Esters are another class of volatiles that are formed primarily during fermentation and are significant due to their *organoleptic* contributions, especially of pleasant fruity aromas (Villamor and Ross, 2013). Although a range of trace volatiles are absent from **Fig. 1** due to their low concentrations, some are important as character impact compounds in certain varietal wines. Examples include rotundone (a sesquiterpene that contributes pepper aroma in Shiraz), polyfunctional thiols (citrus and tropical fruit aromas in Sauvignon blanc, such as 3-sulfanylhexan-1-ol, 3-SH) and methoxypyrazines (green capsicum and vegetal aromas in Cabernet Sauvignon, such as 3-isobutyl-2-methoxypyrazine, IBMP) (Jeffery and Wilkinson, 2014; **Fig. 5**). Volatiles are one of the major groups of compounds that can be utilized for wine varietal authentication (Villano et al., 2017).

Overall, given the links between region of origin, vineyard, winery, and the compositions of fruit and wine, characterization of the aforementioned chemical markers is critical when attempting to determine the identity and authenticity of a specific wine. Considering the broader supply and distribution chains and the use of various processing aids, bottling equipment, vineyard blocks, etc., traceability also becomes an important additional element that is worthy of attention. These aspects are introduced in the following sections.

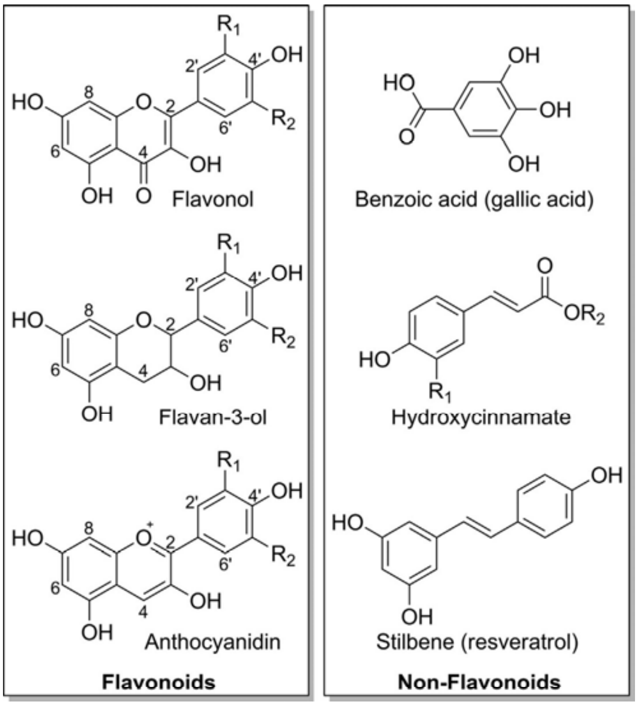



**Figure 3** Examples of phenolic compounds present in wine that are classified as flavonoids and non-flavonoids.

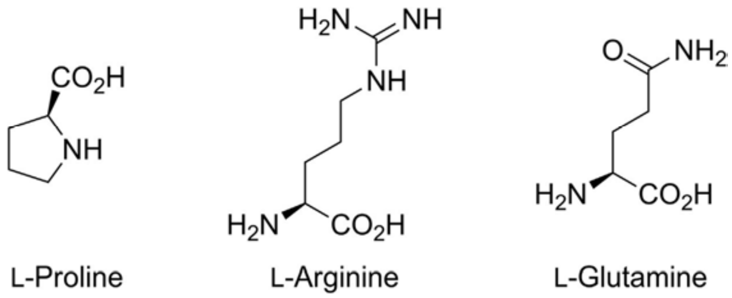



**Figure 4** Major amino acids present in wine.

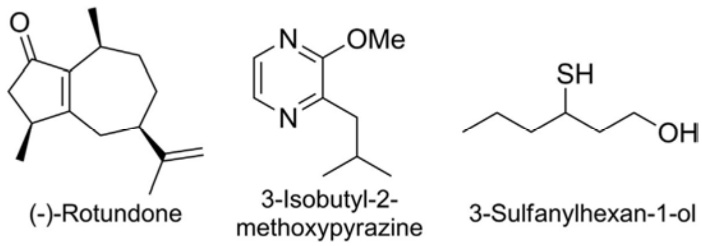



**Figure 5** Trace volatiles found in wine include rotundone (left), methoxypyrazines such as IBMP (center), and polyfunctional thiols such as 3-SH (right).

## 3.33.2 Wine Authenticity

### 3.33.2.1 Overview of Authenticity

Ensuring the identity of a food product has become more of a concern in recent times, especially with the advance of globalization, which invokes a borderless economy that facilitates easier transportation of food commodities across international borders (Carcea et al., 2009). Hence, it has become a challenge for government authorities and industry stakeholders to confirm the identity and provenance of food products throughout the food supply chain (Aung and Chang, 2014). Another reason identified for the increased interest in food authentication is the rise in food fraud, where the product has been altered for economic gain (Pustjens et al., 2016). Most importantly, any failure in quality assurance of food not only has serious economic consequences but also bears a potential risk for human (and animal) health (FAO/IAEA, 2017).

In general, food authenticity can be defined as the process that certifies the product is the same as described on its label (Danezis et al., 2016). However, criteria that define the authenticity of foods are numerous and vary from product to product, and include geographical origin, botanical origin, composition, year of manufacture, and production process (Pascu, 2013). Therefore, the detection and investigation of potentially fraudulent products or processes requires the implementation of various methods and techniques appropriate to the food product in question.

In the particular case of wine, authenticity is a paramount factor when considering quality and consumer confidence in the product. Details present on the wine label, such as brand, variety, origin and vintage, are defining characters associated with wine style and quality that drive consumer expectations (Palade and Popa, 2014). Besides, the complex chemical nature, high prices commanded, and availability around the world, mean that wine is more vulnerable to adulteration than other foods. Hence, guaranteeing the quality and correct information on wine labels, through strict guidelines imposed by authorities, analytical methods, and traceability systems, is important for the wine industry (Makris et al., 2006).

Historically, sensory evaluation has been used to assess wine quality and authenticate wine products, and it still serves that purpose. However, this approach is rather subjective and may lead to misinterpretation, so objective approaches such as those based on analytical methods have been introduced and applied (Kallithraka et al., 2001). Markers of geographical origin, variety, and vintage are considered as the main identity-defining traits that help to determine the value of a wine and therefore have to be considered when developing methods for authentication of wine (Médina et al., 2013). Primarily, these traits can be assessed using chemical markers such as phenolic and volatile compounds, elemental composition, stable isotope ratios, and amino acid profiles (Vergara et al., 2011; Kokkinofta et al., 2017). Given the complexity of the datasets, multivariate data analysis methods (i.e., chemometrics) are often utilized to identify the patterns or classify groups of particular wines (Geana et al., 2016a). Overall, the chosen approach is important in verifying the authenticity of wine and confirming that a wine is in compliance with its label description (Schlesier et al., 2009).

#### 3.33.2.2 Applications of Wine Authentication

More evidently in recent times, popular wines of the world are every so often subject to adulteration, substitution or counterfeiting (Waterhouse et al., 2016a). Therefore, authentication of wine has become inevitable to address such fraudulent activities. Wine authentication gives an assurance to the consumer that they are buying an original product and getting what they paid for, but also encompasses aspects of food safety in the case of adulteration. One of the oldest incidents reported is the addition of lead acetate to increase wine sweetness, which caused severe health effects due to lead poisoning (Lachenmeier, 2016). Another well-known example involved the addition of diethylene glycol to enhance the quality of wine and mask the addition of sugar (Holmberg, 2010), but diethylene glycol is not a legal wine additive due to its toxicity (Sebastian, 2009). Similarly worrying, addition of exogenous methanol to increase alcohol content has caused fatalities in Italy (Suro, 1986). In addition to safety assurance, authentication provides a marketing advantage for producers who can protect their brands among unauthenticated wines.

Because a particular geographical area where a product arises is important to perceived quality and style, a main focus of wine authentication is confirming the origin of wine. EU regulation No 1308/2013 specifies Protected Designation of Origin (PDO) and Geographical Indication (GI), which are terms used to define and protect wines from specific geographical areas. These regulations have significant implications for the reputation, integrity and price of wine, and being able to confirm the origin of wine bestows the advantage of differentiating it according to the region. For example, findings from a study of the wine industry in South Africa suggested that use of GIs increased the value of South Africa's wine exports into the EU (Lubinga et al., 2017).

Other than geographical origin, year of vintage and grape variety (cultivar) are also considered as major factors that determine the value of a wine. Compositional and sensory elements are largely dependent on variety, underlining the importance of varietal authentication (Rapeanu et al., 2009). In the same vein, wine age defines the physical, chemical and biochemical characteristics of wine, and the year of vintage can add great value to the overall sensory characteristics in years with favorable grape growing conditions (Danezis et al., 2016). Therefore, development of particular methods for authentication of wine based on a range of intrinsic factors has been of growing interest to all stakeholders of the wine sector.

Another application of wine authentication is counteracting wine fraud. This aspect includes identifying different means of adulteration, such as dilution, unapproved enhancements like sweeteners or taste/mouthfeel enhancers, and substitution, with less expensive varieties or regions (Waterhouse et al., 2016a). Moreover, authentication techniques enable identification of false statements regarding production processes. For example, in the authentication of rosé wine, identifying the source of raw material is important, whether it is red grapes, a mixture of red and white grapes, or addition of extracts from grape pomace, that yield the color (Rapeanu et al., 2009). Similarly, in sparkling wine production, identifying the origin of $CO_2$ (endogenous or exogenous incorporation) is required because this dictates quality and style. Notably, prestigious wines are often subject to adulteration (Waterhouse et al., 2016a), so identifying and protecting the reputation and integrity of a product/brand against fraud is an important challenge for modern analytical chemistry.

#### 3.33.2.3 Implications of Wine Fraud

Wine fraud can be viewed in terms of extrinsic and intrinsic factors. Falsification of cultivar and geographic origin, mislabeling, and replacement with low quality wine are considered as extrinsic manipulations whereas modifying original components, such as through addition of water, ethanol, sugar or other substances for coloring and flavoring, are reflective of intrinsic processes (Holmberg, 2010). Wine laws include information on permitted additives and wine production practices and were introduced for various purposes, but mainly for consumer health and safety. Laws are also designed to overcome wine fraud by verifying the origin of wine through regulated protected designations of origin and correct labeling (Fandl, 2018). Along with strict regulations comes the need for authenticity testing and a secure traceability system to guarantee the authenticity of wine.

The economic impact of wine fraud can be substantial for any country, region, or producer engaged in wine trade, and various instances have had potentially serious financial consequences. For example, the so-called Brunello wine crisis in Italy is one where producers were indicted for not adhering to production standards, having used a different grape variety than permitted (Cavicchi and Santini, 2011). Another incident involved the replacement of Pinor Noir wine with cheaper wine that was exported to the USA as Pinor Noir from France (Styles, 2009). Perhaps the most infamous example of wine fraud is that of Rudy Kurniawan, who sold millions of dollars' worth of fake wine before he was caught and who featured in the 2016 documentary "Sour Grapes" (Hellman, 2008).

### 3.33.3 Authentication Methods for Wine

The increase in counterfeit products and the growing consumer interest in verifying product origin and quality have added to the drive for methods that provide information on authenticity. Traditional analytical tools are still valuable assets for authentication, but with the advancement of rapid technologies such as biological/chemical fingerprinting, a range of other product validation methods have been developed. Specifically, high-throughput technologies termed "omics" have gained attention by introducing various measurements from gene to metabolite level that are categorized as genomics, transcriptomics, proteomics, and metabolomics (Sébédio and Malpuech-Brugère, 2016). Application of these techniques in determining the adulteration and authentication of wine has been a powerful approach in recent times (Pinu, 2018).

#### 3.33.3.1 Omic Techniques for Wine

The genotypic and phenotypic traits of grapevine, yeast and bacteria shape the composition of finished wine, giving it specific measurable characteristics. Genomics permits identification of the genetic variations and uniqueness of a particular wine (Borneman et al., 2013). Application of DNA markers for varietal authentication of wine has been advantageous over traditional *ampelographic* methods because morphological characteristics can be affected by diseases, vine growth stage, and different environmental conditions (Işçi et al., 2009). Moreover, the stability of DNA under various wine processing conditions such as high temperature or low pH makes it suitable as a marker for wine authentication (Villano et al., 2017). Identification of a correct DNA sequence is vital in authentication methods and a couple of methods have been applied: simple sequence repeat (SSR) and single nucleotide polymorphism (SNP). Large databases (European Vitis database; Swiss microsatellite database) containing genetic profiles of wines have been developed using these sequencing methods. In particular, the International Organisation of Vine and Wine (OIV) has approved the SSR method for varietal authentication. Similarly, SNPs are being widely applied in the grape and wine industry to identify first-degree genetic relationships of grapevine accessions (Barrias et al., 2019).

Transcriptomics is not directly utilized in wine authentication, but it has been applied to the analysis of variations in different yeast strains from diverse origins (Mendes et al., 2017). A transcriptome reflects the expression of mRNA at any given time and conditions, thus determining the pattern of gene expression and likely changes in organism response and metabolite production. It is important in analyzing the influence of yeast strains on wine flavor and fermentation bouquet, for example. Transcriptomic techniques like next-generation sequencing (RNA-seq) are essential for genomic studies as they facilitate the understanding of the functional elements of the genome (Van Emon, 2016).

Proteomic-based techniques that consider the proteins present in wine are another emerging area for authentication purposes. Proteomics has been used in discrimination of white wines according to the variety (Rešetar et al., 2016) and for detection of adulteration based on proteins from *fining agents* (Cereda et al., 2010). However, these techniques are not widely applied mainly due to the trace levels of proteins remaining in finished wine, and the presence of exogenous proteins from yeast or bacteria that pose further difficulties when attempting to evaluate aspects such as origin, vintage, and variety (Ortea et al., 2016).

Among the “omic” techniques, metabolomic approaches that involve comprehensive analysis of metabolites are the most widely applied in wine authentication. These techniques can be categorized into targeted and non-targeted methods, depending on the objective of the analysis. Specific marker compounds/metabolites are considered in targeted analyses and variations in concentrations are used for differentiation of samples. On the contrary, non-targeted analyses such as by spectroscopic techniques and sensor technologies (e-nose and e-tongue) provide a chemical fingerprint of the sample, with similarities/differences in fingerprint being considered for classification. Other than the main omics techniques described above, isotope profile analysis (of elements, water, carbon) – as in isotopolomics – is also established for wine authentication. It is mainly applied in geographical authentication because of the relationship between the soil profile where grapes are grown with the elemental profile of wine (Coetzee et al., 2014). Recently, various analytical techniques based on metabolomics or isotopolomics have been developed, resulting in the detection of additional identity markers. Along with improvements in data analysis from various instruments or multiple sources, the analytical methods now available have enhanced the possibilities for wine authentication (Versari et al., 2014).

#### 3.33.3.2 Analytical Techniques and Sensors

Different analytical methods applied in metabolomic and isotopolomic studies for wine authentication are useful in various ways, such as to: (a) identify and quantify metabolites; (b) discriminate samples in a population; and (c) to predict categories for building statistical models (Cevallos-Cevallos et al., 2009). Often, using a combination of both qualitative and quantitative data blocks from different methods (targeted or non-targeted) and data fusion are important in determining authenticity by providing more dimensions of information about the sample (Borràs et al., 2015). Furthermore, sample complexity and the different magnitudes of analyte concentrations mean that it is useful to couple different methods, such as separation techniques with detection by spectrometry or spectroscopy, although rapid and simple methods would tend to be the most ideal for implementation by industry. The following section describes the main analytical methods used in wine authentication.

##### *3.33.3.2.1 Mass Spectrometry*

In mass spectrometry (MS), ionized metabolites are resolved based on their mass-to-charge ($m/z$) ratio (Rubert et al., 2015). MS has been used as a standalone tool for varietal, geographical, and vintage authentication (in conjunction with chemometrics) (**Table 1**) as well as being coupled with separation techniques such as gas or liquid chromatography (**Table 2**) and chemical sensor systems such as e-nose (MS e-nose) for detection and quantification of chemical constituents (covered in Sections “**Separation and Detection Techniques**” and “**Sensor Technology**”). However, in terms of practical applicability within an industry setting, some methods may rely too heavily on time and labor, and utilize complex instrumentation that is not readily available. Therefore, application of techniques that use an ambient ion source like direct analysis in real time (DART)-MS have been introduced (Guo et al., 2017). A study by Rubert et al. (2014) compared different authentication strategies involving high resolution MS with quadrupole time-of-flight (Q-TOF-MS) coupled with DART (**Table 1**) or ultra-high performance liquid chromatography (UHPLC), using wine samples that were measured directly as well as a polyphenol fraction isolated from wines. They concluded that DART was suited to a wide range of analytes and offered greater efficiency but lacked the discrimination power afforded by UHPLC-Q-TOF-MS.

**Table 1** Examples of mass spectrometry approaches used for wine authentication

| *Technique* | *Chemical marker* | *Classification method*[a] | *Parameters for authentication* | *References* |
|---|---|---|---|---|
| DART–HRMS | Flavonol glucosides and polyphenols | OPLS-DA | Varietal differentiation | Rubert et al. (2014) |
| MALDI-TOF-MS | Peptide profile | PCA<br>HCA | Varietal and processing method | Rešetar et al. (2016) |
| PTR-MS | Volatile profile | ANOVA<br>PCA | Vineyard discrimination | Schueuermann et al. (2017) |
| ICP-MS | Li, Na, Mg, Si, P, K, Ca, Mn, Fe, Ni, Zn, Rb, Sr, Cs, Ba | LDA (up to 100% classification) | Geographical origin of Australia | Martin et al. (2012) |
| ICP-MS | Tl, U, Li, Rb, Mg | CA (100% classification) | Geographical origin of Argentina, Brazil, Chile, and Uruguay | Bentlin et al. (2011) |
| IRMS | $^{13}C/^{12}C$ and $^{18}O/^{16}O$ | – | Geographical origin and vintage | Magdas et al. (2012) |
| IRMS | $\delta^{13}C$ and $\delta^{18}O$ | ANOVA, LDA | Adulteration by addition of sugar and water | Geana, Popescu, Costinel et al. (2016b) |
| TIMS and IRMS | $^{87}Sr/^{86}Sr$ and $\delta\ ^{13}C$ | GPA | Terroir differentiation | Di Paola-Naranjo, Baroni, Podio et al. (2011) |
| MS e-nose | Volatile profile | LDA, SLDA | Geographical origin of Sauvignon Blanc | Berna et al. (2009) |
| MS e-nose | Volatile profile | PCA, LDA, DPLS | Varietal differentiation of Riesling and Chardonnay | Cozzolino et al. (2005) |

[a]See Section 3.6 of this chapter for details.

**Table 2** Examples of separation and detection techniques used for wine authentication

| *Technique* | *Chemical marker* | *Classification method*[a] | *Parameters for authentication* | *References* |
|---|---|---|---|---|
| HPLC-PDA | Targeted (anthocyanins) | PCA, CDA | Varietal discrimination of Blaufrankisch (Lemberger), Saint Laurent and Blauer Portugieser | Kumšta et al. (2014) |
| HPLC-PDA | Targeted (benzoic acids and stilbenes) | DA | Varietal and regional discrimination | Kallithraka et al. (2007) |
| HPLC-MS/MS | Targeted (phenolics) | CDA | Region, varieties and vintage | Jaitz et al. (2010) |
| UHPLC-Q-TOF-MS | Non-targeted metabolite fingerprinting (polyphenols) | PCA, OPLS-DA, SIMCA | Varietal, geographical and vintage | Rubert et al. (2014) |
| HPLC–Q-TOF-MS | Non-targeted metabolite profiling (anthocyanins) | PCA, PLS-DA | Varietal discrimination | Vaclavik et al. (2011) |
| UPLC-Q-TOF-MS, FTICR-MS | Non-targeted metabolite profiling (caftaric acid, rosmarinic acid, caffeic acid, and aesculetin) | PCA | Geographical origin | Roullier-Gall et al. (2014) |
| HS-SPME-GC-MS | Targeted (esters) | PCA, SLDA | Varietal differentiation of Cabernet Sauvignon, Cabernet Gernischt and Merlot | Zhang et al. (2010) |
| HS-SPME-GC-FID | Non targeted<br>Volatile compounds (ethyl acetate, isoamyl alcohol, ethyl lactate) | PCA, CA, LDA | Varietal differentiation | Márquez et al. (2008) |
| HS-SPME GC × GC-TOF-MS | Non targeted<br>Volatile compounds (2,3-butanediol, 4-carene, 3-penten-2-one, diethyl succinate) | PCA, SLDA | Differentiation of Cabernet Sauvignon, Merlot, Chardonnay, Sauvignon Blanc and Pinot Noir varieties. | Welke et al. (2013) |
| HS-SPME GC × GC-TOF-MS | Non targeted<br>Volatile compounds (3-isobutyl-2-methoxypyrazine, menthone, isomenthone) | CVA and PLS-DA | Differentiation of Cabernet Sauvignon from ten different Australian regions | Robinson et al. (2012) |

[a]See Section 3.6 of this chapter for details.

Matrix-assisted laser desorption ionization mass spectrometry (MALDI-MS) is another atmospheric pressure ionization technique used with MS in the characterization of thermally labile molecules such as proteins (Dreisewerd, 2014). It is considered a simple but sensitive and fast method compared to chromatographic approaches (Danezis et al., 2016). Laser energy is used to vaporize and ionize analytes mixed within a matrix, and ions formed are analyzed by MS. This approach has been applied to the classification of Spanish (Nunes-Miranda et al., 2012) and Croatian (Rešetar et al., 2016) white wines on a varietal basis using wine peptide profiles. According to Rešetar et al. (2016), white wines produced by different production techniques could be differentiated, such as filtered vs non-filtered, which could be useful in production process control. However, further development of the protocol in identifying authenticity markers for regional and vintage classification would be necessary.

Proton transfer reaction mass spectrometry (PTR-MS) is another variation of MS that can be employed (in real-time) for quantitative analysis of volatile organic compounds. This technique uses chemical ionization of water vapor to yield hydronium ions ($H_3O^+$) that react with the analytes to produce protonated ions for MS detection. However, a disadvantage in wine analysis is that ethanol interferes with the proton transfer reaction (Schueuermann et al., 2017; Sémon et al., 2018). Several studies have used different methods to overcome ethanol interference in wine, such as dilution of the headspace ethanol concentration with high purity nitrogen (Spitaler et al., 2007) or separation of ethanol from the wines by using fast GC combined with PTR-TOF-MS (Romano et al., 2014).

Inductively coupled plasma (ICP)-MS is used for elemental analysis and can rapidly quantify multiple elements (especially metals) at ultra-trace to trace levels ($<1\ \mu gL^{-1}$ to $mgL^{-1}$). In ICP-MS analysis, the analytes in the sample are decomposed to elements and ionized by a high-temperature argon plasma prior to detection. It is more advantageous than other methods used to measure elements, such as atomic absorption spectroscopy (AAS), because of the lower detection limits, speed, and multi-element capabilities (Luykx and van Ruth, 2008). ICP-MS has been used for geographical origin determination across countries and regional discrimination within a country (Martin et al., 2012; Bentlin et al., 2011; **Table 1**).

For authentication of wine in isotopolomic studies, the commonly used spectrometric methods are isotope ratio MS (IRMS) and thermal ionization mass spectrometry (TIMS), which are based on combustion or vaporization and ionization of samples to enable precise MS detection of different naturally-occurring isotopes (**Table 1**). Light isotopes are analyzed by IRMS whereas heavier elements utilize TIMS. These methods have been used (with statistical treatment of the data) to determine the ratios of carbon, oxygen, hydrogen or strontium isotopes for geographical origin determination (Di Paola-Naranjo et al., 2011; Magdas et al., 2012) and identification of adulteration (Geana et al., 2016b; **Table 1**). Additionally, IRMS can be hyphenated with separation techniques that enhance the analysis of different isotope ratios (Christoph et al., 2015). The OIV, of which many wine producing nations are members, specifies IRMS as an official method for wine and must analysis, for authentication or analysis of metals (Christoph et al., 2015).

#### 3.33.3.2.2 Separation and Detection Techniques

Chromatographic methods are the most commonly applied separation technique in food analysis. Liquid chromatography (LC) is the technique used for non-volatile liquid samples, as in the analysis of water soluble substances like anthocyanins (Košir et al., 2004). Advanced types of LC methods, such as high performance LC (HPLC) or ultra-high performance LC (UHPLC) have increased the speed, resolution and sensitivity of the application. Various detectors used with LC, such as ultraviolet (UV) and photo diode array (PDA) (**Table 2**), are useful for targeted analysis of phenolic compounds (Jaitz et al., 2010) and fatty acids (Della Corte et al., 2013), for example. However, it is important to select the most appropriate detector to use for authentication as each have their own drawbacks, such as the low resolution of UV detectors (Liu et al., 2017) and lack of discrimination by PDA detectors. Nonetheless, HPLC with PDA has been applied to the analysis of phenolics as a simple and less-expensive technique compared to other detectors. On the other hand, coupling LC separation (which may still include UV or PDA detection) with MS is a very effective solution for characterizing a range of wine constituents (Di Stefano et al., 2012) including the targeting of phenolics (**Table 2**). A number of studies have applied TOF-MS to untargeted metabolite profiling (Vaclavik et al., 2011; Rubert et al., 2014; Jaitz et al., 2010). This extends to the combination of UPLC-Q-TOF-MS with in silico alignment of exact mass data from Fourier transform ion cyclotron resonance mass spectrometry (FTICR-MS), which brings improvements by increasing resolution and mass accuracy for analyte identification. This approach has revealed a diverse range of metabolites and provides greater opportunity to classify samples into groups (e.g., by geographic origin irrespective of vintage) based on a comparison of marker compounds (Roullier-Gall et al., 2015).

As a complementary technique to LC approaches, gas chromatography (GC) is used to separate volatile or semi-volatile compounds and has been applied to the study of authenticity based on the volatiles present in wine. For determination of these compounds, it is often necessary to apply sample extraction and preparation techniques such as liquid-liquid extraction (LLE), solid phase extraction (SPE) or solid phase micro extraction (SPME) prior to instrumental analysis (Vilanova and Oliveira, 2012). As with LC, different detectors are coupled to GC to obtain quantitative measurements. In wine analysis, flame ionization detector (FID) and MS are frequently used for targeted or non-targeted analyses and varietal differentiation (**Table 2**) but other detectors are also common (e.g., selective detectors for sulfur or nitrogen). GC–MS is advantageous because of the ability for simultaneous determination of different metabolite classes, coupled with high chromatographic resolution (Pinu, 2018). Comprehensive two-dimensional gas chromatography (GC × GC), involving two GC columns with orthogonal stationery phase chemistry, provides a more powerful analytical method compared to a single column GC, and offers high peak capacity, selectivity and sensitivity for wine authentication (Welke et al., 2013). Varietal differentiation (Welke et al., 2013) and geographical authentication (Robinson et al., 2012) using volatile markers has been accomplished using GC × GC (**Table 2**).

#### 3.33.3.2.3 Sensor Technology

Chemical sensor systems used for wine analysis, namely electronic nose (e-nose) and electronic tongue (e-tongue), are developed to mimic human olfaction (Śliwińska et al., 2016; **Fig. 6**). The process involves capturing a fingerprint of the flavor or aroma molecules

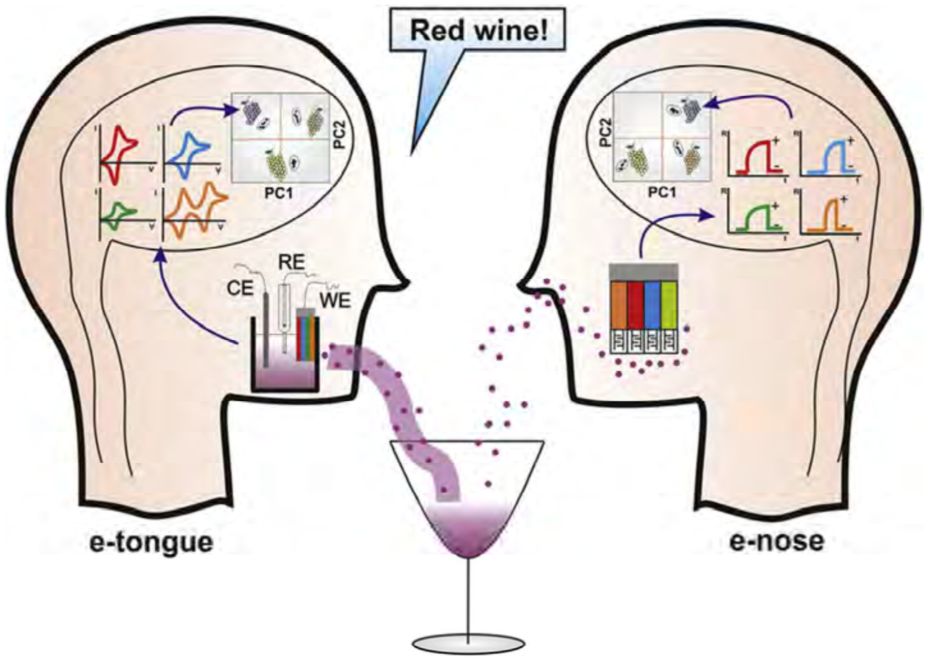



**Figure 6** Scheme of the working principles of e-nose and e-tongue. Reproduced from Rodríguez-Méndez, M.L., De Saja, J.A., González-Antón, R., García-Hernández, C., Medina-Plaza, C., García-Cabezón, C., and Martín-Pedrosa, F., 2016. Electronic noses and tongues in wine industry. Front. Bioeng. Biotechnol. 4:81. Copyright 2016. License at https://creativecommons.org/licenses/by/4.0/.

from a sample with a sensor (often a non-specific array but MS can be used) and using multivariate data analysis to distinguish the specific odor or taste (Mannino et al., 2007).

Favored for its minimal sample preparation and rapid analysis, a number of studies have utilized e-nose for authentication (Cynkar et al., 2010; Berna et al., 2009). In the application of an e-nose for wine discrimination, the extraction of volatiles is firstly accomplished using techniques such as static headspace (HS), purge and trap (P&T) or SPME (Lozano et al., 2016). This is an important step because the headspace composition needs to represent the wine's original aroma profile. An array of gas sensors then transform the chemical signals obtained from wine volatiles into electronic signals. Different sensors such as metal oxides (MOX) (Berna et al., 2009), conducting polymers (CP), or surface acoustic wave sensors (SAW) (McKellar et al., 2005) have been used (Guadarrama et al., 2001) for authentication of wine by variety and geographically. MS-based e-nose has also been applied (see **Table 1**) and has the advantage of overcoming any interference from ethanol when analyzing headspace constituents of wine (Cozzolino et al., 2005). Finally, a pattern recognizing system classifies the wines according to specific categories by supervised learning or other multivariate types of analysis (Cozzolino et al., 2005).

#### *3.33.3.2.4 Spectroscopy*

Various spectroscopic techniques are available for wine fingerprinting, including near infrared (NIR), mid infrared (MIR), Raman, ultraviolet–visible (UV–vis), and nuclear magnetic resonance (NMR). Based on the electromagnetic (EM) spectrum, the interactions of EM radiation with molecules, compounds, atoms or nuclei, are recorded and represented in the form of spectra, which depend on the properties of the analyzed sample and the wavelength range (**Fig. 7**). Application of appropriate chemometric methods are vital with spectroscopic analyses, and there are several data preprocessing steps to correct for baseline drifts, scattering and path length variation (Oliveri and Downey, 2013).

Being robust and reproducible, NMR spectroscopy is a widely-used technique that requires minimal pre-processing of samples (if doing direct measurements of wine), and has the added advantage that the inherent properties of the sample are maintained (Alañón et al., 2015). $^{1}$H NMR has been applied broadly in wine authentication, due to its ability to provide informative data that could be use in varietal, geographical and vintage authentication (Godelmann et al., 2013; **Table 3**). Gougeon et al. (2018) developed a quantitative NMR (q-NMR) method that can quantify diverse metabolites including alcohols, organic and amino acids, and phenolics, and can be used in combination with chemometrics to differentiate wines based on region and cultivar. However, due to the low sensitivity of NMR, a combination with MS based techniques such as HPLC-MS or GC–MS can be used to provide data on low-level analytes for greater metabolite coverage (Alañón et al., 2015).

Over and above the other techniques, vibrational spectroscopic methods such as IR and Raman are considered as more practicable as they enable in-situ measurements (e.g., with hand held or portable devices) and exhibit sensitivity and robustness

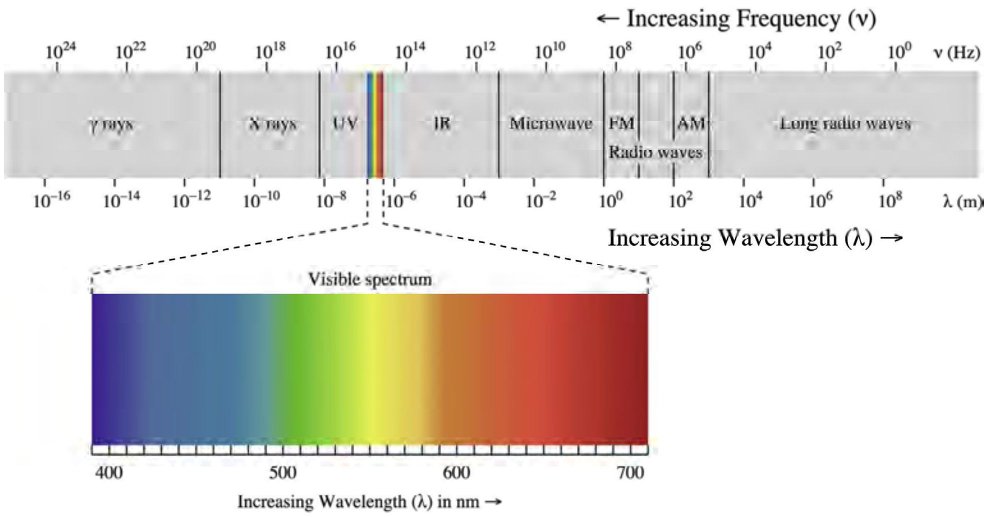



**Figure 7** Representation of the electromagnetic spectrum. Reproduced from Ronan P., 2007. EM spectrum.svg, https://upload.wikimedia.org/wikipedia/commons/f/f1/EM_spectrum.svg. Copyright 2007. License at https://creativecommons.org/licenses/by-sa/3.0/.

**Table 3** Examples of spectroscopic methods used for wine authentication

| *Technique* | *Chemical marker* | *Classification method*[a] | *Parameters for authentication* | *Reference* |
|---|---|---|---|---|
| q-NMR | Phenolics, organic and amino acids | PCA, PLS, OPLS | Varietal discrimination of Riesling and Mueller-Thurgau | Ali et al. (2011) |
| $^{1}$H NMR | Aromatic region of spectra, organic and amino acids | PCA, LDA, MANOVA | Varietal, geographical and vintage discrimination | Godelmann et al. (2013) |
| MIR | Carbonyls, organic acids, sugars, alcohols | PCA, LDA | Varietal discrimination | Bevin et al. (2008) |
| NIR, visible, and UV transmission | Aromatic rings, organic acids, sugars, ethanol | PCA, PLS-DA, SIMCA | Geographical discrimination | Cozzolino et al. (2011) |
| Vis-NIR | Sugars, ethanol, phenolics, pigments | PCA, PLS-DA | Varietal discrimination | Liu et al. (2006) |
| Raman fingerprint | FT Raman Sugars, ethanol, phenolics, organic acids | SLDA | Discrimination of wine variety and geographical origin | Magdas et al. (2018b) |
| | FT Raman Sugars, ethanol, phenolics, organic acids | PCA | Differentiation of grape varieties, production area and aging time | Mandrile et al. (2016) |
| | SERS Hydroxy-cinnamic acids | SLDA | Discrimination of wine variety and geographical origin | Magdas et al. (2018a) |

[a]See Section 3.6 of this chapter for details.

(Teixeira dos Santos et al., 2017a). IR is a versatile technology for routine analysis as it provides the compositional characteristics of a sample by detecting certain functional groups, which can be used for authentication in association with chemometrics (Cozzolino, 2012). The techniques are categorized as near IR (NIR) and mid IR (MIR) according to the range of wavelength. MIR spectroscopy has been employed in distinguishing different varieties (Bevin et al., 2008). Characteristic and specific absorption bands with MIR create more distinct spectra compared to NIR, making MIR more suited to sample identification and quality control (Cozzolino, 2012). Other than wine, MIR has been applied to discriminate Chardonnay juices from different regions (Gambetta et al., 2019). However, calibration and spectral interpretation have been identified as challenges associated with MIR (Cozzolino, 2012). NIR has also been applied in authentication, mostly in combination with visible spectroscopy. A vis-NIR spectroscopic method has been developed to discriminate wines from different geographical regions (Liu et al., 2006; Table 3). Moreover, vis-NIR has been implemented in the development of the "BevScan" (Fig. 8), which can analyze wine directly through the bottle and has in-built calibrations and classification functions. This type of truly non-destructive technique has the potential to be used in quality control as well as in authentication.

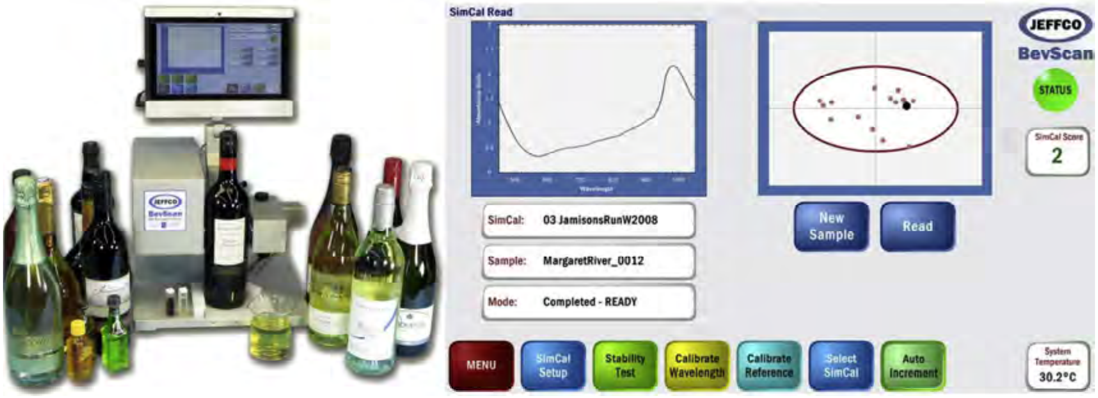



**Figure 8** Bevscan: Through bottle beverage analyzer and classifier. Images courtesy of Jeffress Engineering, www.jeffress.com.au.

Raman spectroscopy is not an overly popular analytical method for wine analysis due to the fluorescence effect, but has been adapted for authentication in the pharmaceutical and materials science fields (Das and Agrawal, 2011). The relative inactivity of water molecules in Raman analysis is considered an advantage for wine analysis (Teixeira Dos Santos et al., 2017b). The Raman technique relies on inelastic scattering of monochromatic light from a laser in the visible, near infrared, or near ultraviolet range (**Fig. 7**). There are two key Raman techniques that are widely applied for food authentication purposes, Fourier transform (FT) Raman spectroscopy and surface-enhanced Raman spectroscopy (SERS) (Craig et al., 2015).

Several studies have evaluated Raman spectroscopy for wine authentication. Mandrile et al. (2016) employed FT Raman to discriminate Italian wine according to variety, vintage and production area (**Table 3**). For white wine discrimination, Magdas et al. (2018a) utilized the SERS technique, determining that it was more successful for the classification of geographical origin rather than vintage. They also explained that according to their previous studies, FT Raman technique provides signals according to the concentration of molecules in a sample whereas SERS gives selective, chemically-specific signals related to particular compounds, which result in different intensities for similar compounds (Magdas et al., 2018a). SERS fingerprinting with minimal sample preparation has been applied to Portuguese white wine, with different incubation times permitting discrimination by variety as well as region (de Almeida et al., 2019).

### 3.33.3.3 Chemometrics

Multivariate statistical analysis of chemical data (chemometrics) is important in understanding the relationship between the chemical properties of substances and parameters such as quality or variety. Chemometrics is an important element in authentication, where the identified variations/similarities can be applied when classifying samples according to their origin or variety, or be used to identify non authentic/adulterated samples. Chemometrics can be divided into three categories according to the purpose of analysis: exploratory, classification/discrimination, and regression/prediction (Trygg et al., 2006). Different statistical tools can be applied to classify wines according to their chemical or spectroscopic attributes obtained from different analytical tools, such as discussed in Section "**Analytical Techniques and Sensors**."

Unsupervized methods including principal component analysis (PCA) and cluster analysis (CA) are exploratory, and help to understand the fundamental structure of a dataset. They are used as a pre-processing step for the interpretation of spectra and quantitative data from targeted analyses to discover natural groupings of analytes (Cubero-Leon et al., 2014; **Tables 1–3**). In PCA, the dominant patterns present within samples and variables are illustrated by plotting the scores and loadings matrices. Multiple factor analysis (MFA) is a variation of PCA used for analyzing multiple sets of data, and is important for understanding the impact of different variables, such as elements and volatile compounds, used in a classification (**Fig. 9**). In the same manner, CA allows grouping of samples based on their similarities or differences using all the variance contained in the original data set. Specifically, hierarchical cluster analysis (HCA) has been applied in wine authentication (**Table 1**), to statistically categorize wine into different groups.

Supervised techniques mostly used in authentication include classification models such as linear discriminant analysis (LDA), soft independent modeling of class analogy (SIMCA) and canonical discriminant analysis (CDA) methods (**Tables 1–3**). Classifications are based on preliminary information such as geographical origin or variety, which will serve as a reference for the target results. Among the types of models, discriminant analysis (DA) methods are applied where there are definitive classes. LDA determines the variables with a major discriminant capacity, for instance in geographical authentication by elemental analysis (e.g., ICP-MS, **Table 1**), where stepwise LDA (SLDA) has shown 100% discrimination of red wines from three Australian regions (Martin et al., 2012). CDA is used as a pattern recognition technique that considers the between class variation. For example, CDA has been applied in classifying Austrian wine according to region, variety and vintage using the phenolic pattern (Jaitz et al., 2010; **Table 2**). Classification with SIMCA focuses on similarities within the classes in assigning groups and is widely applied in spectroscopic data analysis (Oliveri and Simonetti, 2016).

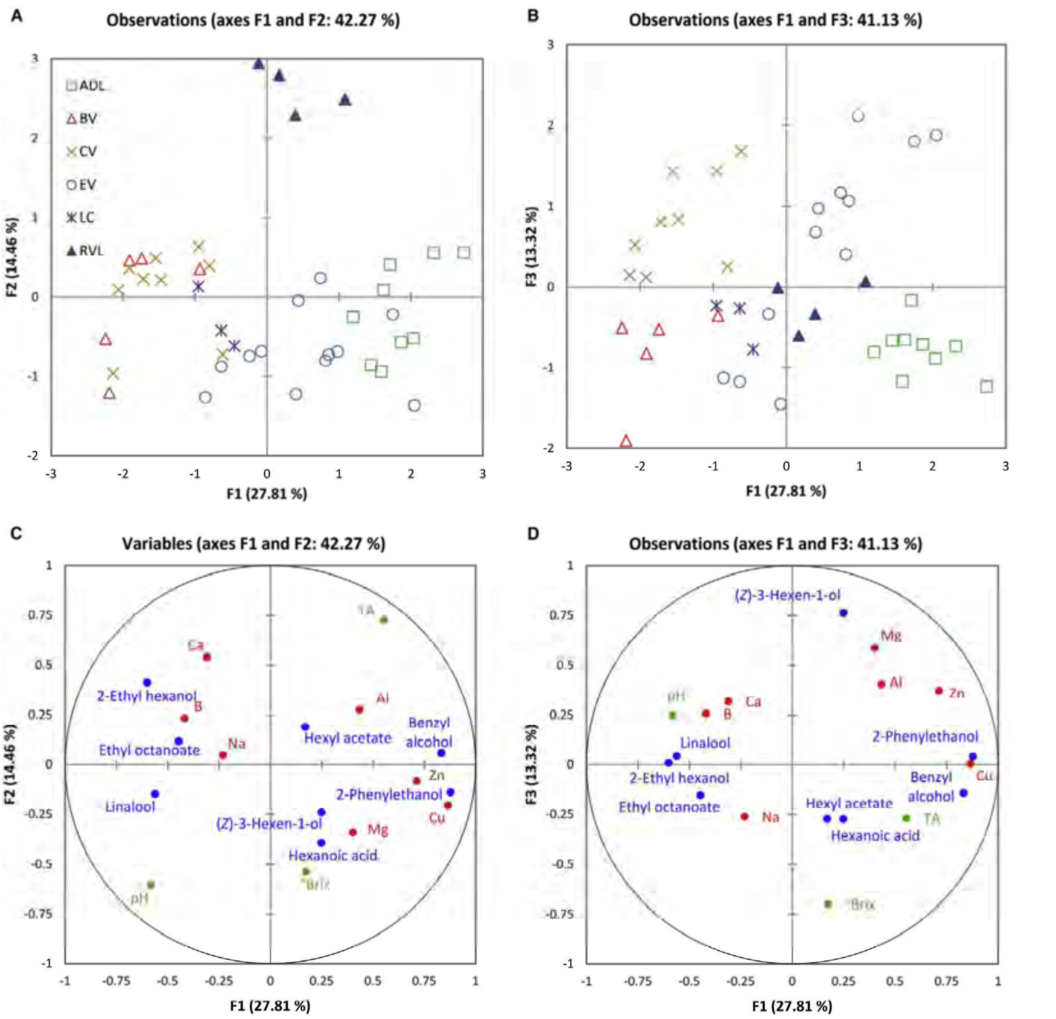



**Figure 9** Geographical classification of Chardonnay grape samples from different regions using MFA on various volatiles, basic juice parameters (titratable acidity, pH, total soluble solids), and elements, showing scores on F1 and F2 (A) and F1 and F3 (B), and corresponding loadings (C and D). Reproduced from Gambetta, J.M., Cozzolino, D., Bastian, S.E.P., and Jeffery, D.W., 2017. Exploring the effects of geographical origin on the chemical composition and quality grading of *Vitis vinifera* L. cv. Chardonnay grapes. Molecules, 22:218. Copyright 2017. License at https://creativecommons.org/licenses/by/4.0/.

As a quantitative regression modeling method, partial least squares (PLS) regression is used in differential sorting of many input variables, such as detecting adulterated samples from spectroscopic data (Oliveri and Simonetti, 2016). PLS can be used in combination with discriminant analysis (PLS-DA). The aim is to optimize separation between different groups characterized by several quantitative variables, which can be evaluated by their ability to predict new and unknown samples (Cozzolino, 2012). Classification of Tempranillo wines according to their geographical origin was undertaken, with PLS-DA models showing 100% correct classification of Australian wines and 85% for Spanish samples (Liu et al., 2006). Orthogonal projections to latent structures discriminant analysis (OPLS-DA) is a variation of PLS-DA that constructs more easily interpretable models that are applied in authentication, such as when differentiating samples according to variety by UHPLC-Q-TOF-MS (Rubert et al., 2014; **Table 2**).

For the developed models, validation is conducted by various methods. Analysis of variance (ANOVA) is a data driven validation method that is commonly used in authentication (Westad and Marini, 2015). Cross validation, single evaluation or repeated evaluation are also applied using a training set and a test set, to support the classification of unknown samples (Oliveri and Simonetti, 2016). In selecting validation methods, it is important to consider the aspects of validation such as the robustness, which dictates the ability to predict future samples, or according to overall conclusions such as finding a significant variable (Westad and Marini, 2015).

## 3.33.4 Wine Traceability

### 3.33.4.1 Overview of Traceability

The importance of traceability in the food industry has increased in recent years due to rising consumer awareness of food safety and quality. It is considered as a risk management tool that can be used in the food supply chain as evidence for consumers and producers to verify the origin and overall production process (Vukatana et al., 2016). Traceability of a food, as defined by the European Commission (EC) within Regulation EC No. 178/2002, implies "the ability to trace and follow a food, feed, food-producing animal or substance intended to be, or expected to be, incorporated into a food or feed, through all stages of production, processing and distribution" (European Parliament, 2002). A proper traceability system gives the opportunity to control products as individuals or a batch, and isolate them if issues with food safety or quality arise. It enables the identification of the source of a contamination, for example, which ensures an effective recall procedure. Additionally, a traceability system provides transparency in the supply chain, enabling detection of where items are located (Kok et al., 2012). Therefore, traceability benefits consumers by protecting against fraud and helps optimize and control the production process for producers, such as in a recall situation (Pascu, 2013).

Traceability in a food manufacturing environment can be applied through the production chain from harvest to sale (chain traceability) or within a single step of the chain (internal traceability) (Moe, 1998). Also, according to the objective of the data collection, traceability can be categorized in different ways, mainly as conventional traceability, genetic traceability, or geographic traceability (Dalvit et al., 2007). Application of these methods varies depending on the industry:

- Conventional traceability is primarily applied in processed food systems, using labeling methods;
- Genetic traceability is important in animal production, for verification of breeds through DNA analysis;
- Geographical traceability is aimed at verification of product origin claims, through chemical analysis that yields a profile of elements, volatiles or stable isotopes (Kok et al., 2012).

The latter kind of verification is largely relevant for specialty products with a PDO or Protected Geographical Indication (PGI), such as wines that are linked to regions of origin (Villano et al., 2017).

### 3.33.4.2 Application of Wine Traceability

The implementation of a traceability system in the wine industry is critical, given the rapid increase in counterfeiting. Traceability prevents fraud in the supply chain by bringing transparency to the overall process, from raw materials to finished products, and thereafter in distribution and sales (Biswas et al., 2017). Global Standards One (GS1) is a world recognized organization responsible for the development of a global traceability model, and for introducing the Wine Traceability Working Group in 2003 (Cimino and Marcelloni, 2012). The collaboratively developed traceability model emphasizes the responsibilities of each key group in the supply chain (**Table 4**) to enhance the traceability of the system (Wine Traceability, 2018). To ensure tracking through the supply chain, it is important that each key group records all the required information so that the next person in the chain can link those data with the related details of their segment (Palade and Popa, 2014).

### 3.33.4.3 Addressing the Issues of a Traceability System

In a food supply chain, it is important to identify any issues that disrupt the effectiveness of traceability. In their review, Dabbene et al. (2014) identified four issues that need to be addressed in order to manage a proficient traceability system:

i Food crisis management is a major concern of a traceability system. In a food recall incident, it is essential to have enough data to track backwards to identify the problem as well as to have required data to track forward to promptly withdraw the affected products. Wynn et al. (2011) introduced a model with a process of collecting and exchanging the required data within the system.
ii Traceability of bulk products is another important concern, including in the wine industry where bulk wine may be stored and shipped. The issue with these products is the inherent possibility of contamination in a batch process, where tanks might contain residues of the preceding batch. Introduction of a threshold limit for batch to batch contamination has been applied in such cases (Comba et al., 2013).
iii Quality and identity preservation (attributes such as geographical origin, varietal origin, or specific production method) are major elements in the traceability system. This is more applicable to specialty products associated with PDO and PGI where product quality is linked to those regions, and luxury products where a minimum level of quality is expected.
iv Fraud prevention is also an important component in a traceability system (Dabbene et al., 2014). Having an effective traceability system allows a company to have more control over what is being produced, and especially who is responsible for each production step, which can tighten the gaps in the supply against fraudulent activities.

It is important to appreciate the significance of a traceability system in the wine industry, as the issues discussed above can have a substantial economic impact if problems arise. A proper traceability system such as the Label Integrity Program introduced by Wine Australia (Wine Australia, 2018) is usually based on different technologies (such as those discussed in Section "**Traceability and Authentication Assurance Systems**") but also needs to be supported with objective analytical evaluations for wine authentication (as discussed in Section "**Authentication Methods for Wine**").

**Table 4** The key areas in the wine supply chain determined by the GS1 traceability system

| *Group* | *Responsibilities* | *Information* |
|---|---|---|
| Grape grower | Production, harvest, delivery of grapes, sampling analysis | Name and address of the vineyard, plot map reference, size of plot/number of vines, vine variety, chemical content of water, annual treatments and any supplier details with products received and batch numbers |
| Wine producer | Production, manufacture/blending of wine, sampling analysis | Identification of the wine producer, product identification, records of operations, supplier details of additives with batch numbers, quantities of wine dispatched, shipping container identifications |
| Bulk distributor | Receipt of wine, sampling analysis, blending, storage, dispatch | Identification of the bulk distributor, quantities of wine received, bulk container identifications, global trade item number, batch and quantity numbers |
| Transit cellar | Receipt of wine, analysis of bulk wine, storage, dispatch | Identification of the transit cellar, container codes, product identification, the quantity of wine dispatched, batch number of each product dispatched |
| Filler/Packer | Receipt of wine, analysis of samples, filling, packing, storage, dispatch of finished goods | Shipping container identification, identification of filler/packer and batch number of the dry goods (bottles, caps, corks), lot number of shipped items |
| Finished goods distributor | Receipt of wine, storage, inventory management, dispatch of finished goods | Lot numbers of inbound pallets and cartons from filler/packer and lot numbers of outbound pallets and cartons to retailer |
| Retailer | Receipt of finished goods, record of received items, sell to the final consumer | Container number, lot number of the components of the cartons, count of the items contained, packaging date and batch/lot number |

## 3.33.5 Traceability and Authentication Assurance Systems

Different methods of traceability management and authentication assurance are available, which can be divided into five groups (Przyswa, 2014a):

i Tamper-proofing features: aspects that guarantee the product integrity from the moment it was bottled;
ii Overt (visible) features: visual components that are accessible for the consumer;
iii Tracking and tracing technologies: systems used in wine industry logistics to ensure that products are traceable;
iv Covert (coded or hidden) features: visual features that can only be accessible through specialized readers;
v Forensic analysis: investigation of physical, chemical and biological markers to confirm the authenticity of the product (i.e., methods presented in Section "**Authentication Methods for Wine**").

Some of the technologies can be classified in more than one category, as elaborated below.

### 3.33.5.1 Tamper-Proofing Technologies

Tamper-proofing devices are the first security check-point for the consumer that do not require any specific prior knowledge about their use nor a particular device to interact with them (Przyswa, 2014b). Tamper-proofing technology aims to provide the consumer with an assurance that the wine has not been altered or replaced after it left the production area (Przyswa, 2014a) and it is a simple visual decision for the consumer: the device needs to be intact and not refurbished, otherwise the product is rejected (Przyswa, 2014b). In its simplest form, tamper-proofing usually encompasses seals and closures that are easily recognized by the consumer when the wine has been tampered with (Przyswa, 2014a), such as the wine in **Fig. 10**, which shows a seal and closure that were damaged when the bottle was opened. Other examples include covers used to conceal the top and sides of a wine bottle to prevent the wine from being opened without removing the plastic, which is damaged irreparably in the process (Bullock III, 1985), or a plastic sleeve can be used around a closure that changes color if any damage has occurred (Model, 2005). A commercial example of a seal that, among other features, uses visual changes to demonstrate tampering is the Bubbletag® from Prooftag (**Fig. 11**). Bubbletag® uses *chaosmetric* technology to generate bubbles in a foil tag to reveal evidence of tampering, with the positioning and the size of the bubbles being created randomly and irreproducibly.

A cover can also be transparent so the consumer can inspect the cork for any damage and view any expected trademark (Taylor, 1989). In addition, holograms can be put to use as a clever tamper-proofing method, whereby the seal does not show any sign of reflective color, but once an attempt has been made to remove the adhesive tag, the holographic layer will become apparent, thus revealing attempts of tampering (Palmasi et al., 2001). A commercial example of this technology is the Variogram® from Prooftag (**Fig. 12**), which includes other information like the Bubbletag®, such as brand logo, quick response (QR) code (see Section "**Quick Response (QR) Codes**") and other information.


**Figure 10** Example of simple wine bottle seal and closure (A) that shows evidence of damage when the bottle is opened (B). Image courtesy of David Jeffery.


**Figure 11** Example of commercially available Bubbletag® tamper evident seal showing various features including (A) brand logo, (B) chaosmetric tag, (C) tag substrate, (D) quick response (QR) code, and (E) batch identification code. Image courtesy of Prooftag, www.prooftag.net.

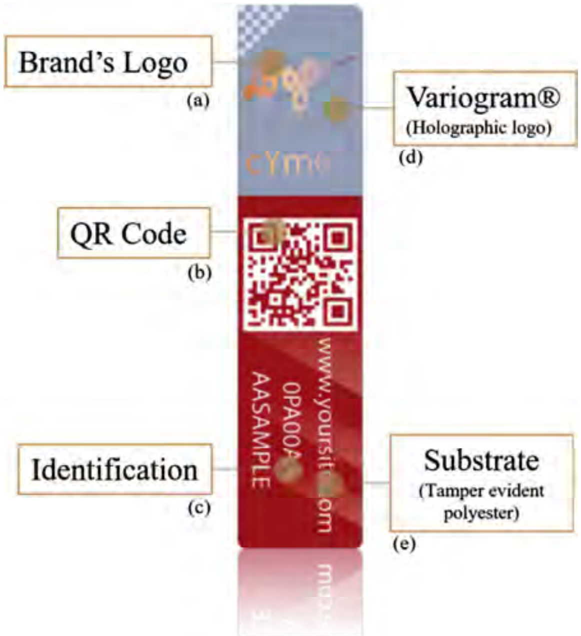



**Figure 12** Example of commercially available holographic Variogram® tamper evident seal showing various features including (A) brand logo, (B) quick response (QR) code, (C) batch identification code, (D) holographic tag, and (E) tag substrate. Image courtesy of Prooftag, www.prooftag.net.

### 3.33.5.2 Covert Packaging Features

A covert packaging feature is the next step for consumers who are seeking a number of ways to authenticate and trace what they are purchasing (Lecat et al., 2017; Przyswa, 2014a). Covert technology includes visual cues on the label that are difficult to replicate, like holograms, variable inks, films, and watermarks that help the consumer judge the authenticity of the product. Figs. 13 and 14 show some examples of those features on a spirit bottle that could equally be applied to wine.

A taggant is an example of covert technology that can be used to ensure product authenticity. One variant uses nanoparticles that can be made from a variety of materials designed to be individually encoded and irreproducible (Li, 2013). Microtaggant® (www.microtracesolutions.com) is a commercial example of this technology, which uses articles that can be detected by visual cues with the presence of a specific reader.

Covert technology is a great resource for the consumer to be able to authenticate wine, but as packaging technology for wines constantly evolves, so too does the sophistication of counterfeiting (Lecat et al., 2017). Because of this, it is crucial for the wine industry to keep innovating and relying on a combination of technologies for traceability and authentication (Lecat et al., 2017; Li, 2013). It is therefore important to consider technologies created for other purposes and apply them to the wine industry where appropriate.

### 3.33.5.3 Blockchain Systems

Created initially for transactions involving cryptocurrency, blockchain systems utilize a network that functions without requiring trust between the parties involved and without requiring an intermediary body, making traceable transactions safer and faster (Christidis and Devetsikiotis, 2016). Due to these advantages, research into the applicability of blockchain methods for food traceability has been increasing over time, including within the wine industry (Rose, 2019; Biswas et al., 2017) for track and trace technologies used in the supply chain.

A blockchain system was effectively developed for the wine production chain in a study by Biswas et al. (2017). The approach integrated the transactions of all main entities (i.e., grape grower, wine producer, bulk distributor, transit cellar, filler/packer, finished goods distributor, wholesaler and retailer) with each one being represented by a block (Biswas et al., 2017). Every block created two keys, one public and one private, whereby the public key was used to share with all the blocks involved (Biswas et al., 2017). Every bottle of wine was assigned with a unique identification (ID) number, making it impossible to sell the same item more than once and eliminating the possibility of counterfeiting (Biswas et al., 2017). Blockchain also provides traceable information for the consumer who enters the ID number of the purchased bottle into the system, enabling verifiable provenance and evidence of


**Figure 13** Examples of commercially available covert and overt technologies (front of bottle) showing (A) tamper-proofing seal, (B) near field communication (NFC) tag, and (C) variable data printing. Images courtesy of All4Labels, www.all4labels.com.

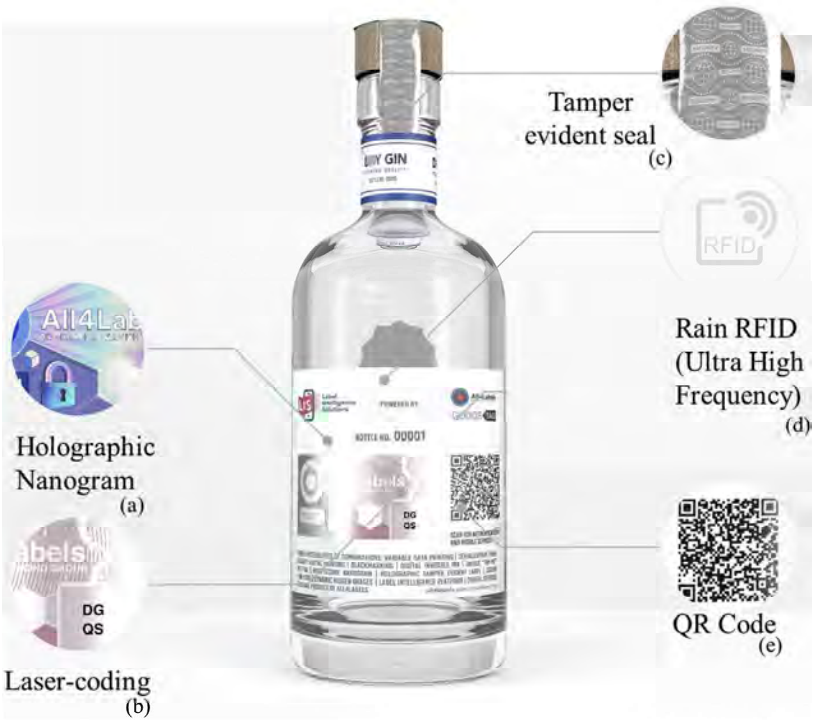



**Figure 14** Examples of commercially available covert and overt technologies (rear of bottle) showing (A) holographic label, (B) laser-coding printing, and (C) tamper evident seal, (D) RFID feature, (E) QR code. Images courtesy of All4Labels, www.all4labels.com.

authenticity (Biswas et al., 2017). This provides transparency, safety and security not only for the entities involved in the supply chain but also for the consumer.

Despite the fact that it is a fairly new concept, the advantages of blockchain have garnered interest from companies that are either applying it or are on the path to applying it in their wine business, e.g., Wine Chain (www.winechain.org), Tao Chain (www.dataokeji.cn) and Ezlab (http://www.ezlab.it/case-studies/wine-blockchain).

### 3.33.5.4 Radio-Frequency Identification (RFID) Technology

RFID is another technology that has become increasingly popular over the years for facilitating fast handling and management over industrialized products (Want, 2006). RFID is used for in-situ tags that operate on a radio frequency system (mainly ultra-high frequencies), enabling discriminative identification from a distance without human assistance (Want, 2006). Each tag is not only capable of storing the product's ID but can also carry extra information about the product (manufacturer, product type, etc.) and even external conditions (temperature, humidity, etc.) during storage (Want, 2006).

This technology has been studied and integrated into different stages of production and distribution of wine. RFID tags can be placed in the neck of the filled bottle and recognized from every side from a range of around 3–7 m (Xi and Ye, 2012). Tags can also be incorporated into the bottle closure (Hu and Cole, 2010; Gonçalves et al., 2014) and act not only as a covert feature but also as a tamper-proofing mechanism. This technology can be used for winemaking process management (Taylor et al., 2006) and through the entire supply chain, working as a tracking and tracing technology as well (Wang et al., 2012; Fu et al., 2009; Cuiñas et al., 2011; Cimino and Marcelloni, 2012).

#### *3.33.5.4.1 Near Field Communication (NFC)*

Derived from RFID, NFC is a covert feature that can transmit encoded data based on short range radio communication between two compatible devices in order to conduct a transaction (see **Fig. 13**B; Du, 2013). Yiu (2014) proposed implementing NFC technology as a ready-to-use tool for the consumer to authenticate wine before purchase at a retailer. Using NFC tags on the bottles (**Fig. 13**) and an NFC-enabled smartphone, the consumer can promptly be connected with data collected by the winemaker and be assured that the wine is authentic (Yiu, 2014). The tags can be designed to be breakable and become corrupted once the wine is opened (Yiu, 2014). As with RFID, NFC systems can also be developed to authenticate and record data throughout the wine supply chain (Yiu, 2014). The NFC-enabled anti-counterfeiting system proposed by Yiu (2014) incorporates:

i NFC tags to attach to bottles;
ii NFC compatible smartphones or tablets;
iii mobile application for the end-user to read the NFC tag before purchasing the wine;
iv internal system for the winemaker to manage and store data about the wine;
v mobile application for the winemaker to encode the NFC tag at wine bottling.

Technology that uses radio frequency communication is still evolving but faces technical difficulties when dealing with complex processes, especially involving metals and water (Hu and Cole, 2010). There is also the increased cost of implementing that technology, which could explain why the industry is still relying on simple and low costs systems (Badia-Melis et al., 2015), like barcodes.

### 3.33.5.5 Barcodes Systems

Most people would be familiar barcodes that are used on many goods, including on a wine back label, which enable efficient, accurate and automated collection of data (Youssef and Salem, 2007). Barcodes are a covert feature that provide a visual representation of information on a surface that can be interpreted by scanning with a laser bar code reader (at a close distance) (Youssef and Salem, 2007). The first barcodes contained information within parallel printed lines and were called linear barcodes because they could only be read horizontally (e.g., EAN-13, interleaved 2 of 5, and Code 39, **Fig. 15**A–C) (Youssef and Salem, 2007; Noraziah et al., 2011). This has evolved into different formats and patterns that can be read in two dimensions, hence these are known as 2D barcodes (e.g., Maxicode and PDF-417, **Fig. 15**D and E) (Youssef and Salem, 2007; Noraziah et al., 2011). Barcoding can be used as simple and inexpensive tracking and tracing technology (Tzoulis and Andreopoulou, 2013) but it loses its efficiency because of the necessity of having a continuous path between the barcode and the reader (Badia-Melis et al., 2015).

#### *3.33.5.5.1 Quick Response (QR) Codes*

As another example of a 2D barcode, QR codes provide a larger set of data in less space, mainly because they are interpreted vertically and horizontally as explained above (**Fig. 15**D and E; Brabazon et al., 2014). Created as a solution for supply chain management as a tracking and tracing technology, it has developed into a powerful marketing mechanism (and covert feature) that provides the consumer with instant and detailed information about the wine before purchase (e.g., **Figs. 11**D, **12**B, and **14**E; Higgins et al., 2014). Vukatana et al. (2016) have proposed implementing a QR code system to manage the wine supply chain, and winemakers were deemed to be interested in such an approach because of the low cost of integration. It comes with the added advantage of building trust with consumers as a result of transparency with respect to product traceability.

**Figure 15** Different types of barcodes: (A) EAN-13, (B) interleaved 2 of 5 (Code 25, I2of5, ITF, I25), (C) Code 39, (D) MaxiCode and (E) PDF-417. Reprinted from Youssef, S.M. and Salem, R.M., 2007. Automated barcode recognition for smart identification and inspection automation. Expert Syst. Appl. 33, 968–977, Copyright (2019), with permission from Elsevier.

Like barcodes, QR codes can be an accessible solution to improve the control in the supply chain and serve as an authentication method for the consumer, but there are limitations. QR codes by themselves do not provide an automatic data feed and require back-end infrastructure to provide the necessary information for their effectiveness. To overcome such limitations, there is research on sensors that can collect and transmit data, and act as a traceability checkpoint.

#### 3.33.5.6 Wireless Sensor Network (WSN)

Some decisions made within the supply chain might be time sensitive and dependent on real-time local condition measurements, making the development and implementation of wireless sensors an attractive option for controlling the supply chain (Anastasi et al., 2009). WSN is usually composed of a number of interconnected sensor nodes that monitor and report data wirelessly without the need for extensive infrastructure (Yick et al., 2008). The sensors have restricted processing and computing capabilities, and are small and low cost (Yick et al., 2008). They are capable of measuring, sensing, and collecting data about the surroundings, and transferring that data to an operator (Yick et al., 2008).

This technology has been used for vineyard tracking and management (McCulloch et al., 2008; Díaz et al., 2011; Beckwith et al., 2004) as well as managing some stages of wine production, like barrel maturation (Anastasi et al., 2009). In combination with other mature and inexpensive technology technologies like RFID, WSN can be successfully implemented to ensure traceability throughout the wine production supply chain (Expósito et al., 2013). The combination provides continuous monitoring and offers a fast and efficient traceability management system (Expósito et al., 2013). However, one of the challenges faced by Expósito et al. (2013) during implementation was the unfamiliarity of the industry partners with the new system. Training was required, but it was also necessary to adapt the system to better cater to the needs of industry and user support.

In summary, there are a number of technologies available or under development for the industry to be able not only to trace their products but also to offer the consumer transparency and better guarantees of authenticity. However, for the latter to be effective, consumer perspectives of the concepts and technologies need to be taken in account.

### 3.33.6 Consumer Perspective of Wine Authenticity

#### 3.33.6.1 Authenticity Concepts and Dimensions

Authenticity can represent different notions when considered from a consumer perspective. There are three authenticity concepts commonly used when studying consumer behavior that can be applied when interpreting wine purchase intentions and attitude:

- Iconic authenticity: covers the idea that a product provides a good image of something else (Grayson and Martinec, 2004) and includes the notion that an object needs to well-represent a pre-existing knowledge of what that object should be (Grayson and Martinec, 2004; Moulard et al., 2015). A product that matches up with a prototype or an exemplar of the category of which it is part, is considered iconic authenticity (Moulard et al., 2015).
- Indexical authenticity: consists of the perception that a product is the original; it is the real one rather than a copy (Grayson and Martinec, 2004). Encompasses the concept that the product is linked to its index, which can be, for instance, a person or a location. It is a concept connected to a physical connotation (Moulard et al., 2015). The uniqueness and rareness of a thing is explained by its association with a specific index (Moulard et al., 2015).
- Moral authenticity: involves the consumer that is less interested in traditions and is looking for a product in which the brand has a genuine intention. These consumers seek companies that do or create something because they deeply believe in it, not because of financial demand (Heine et al., 2016). It transfers the values and meanings embedded in the product (Downing and Parrish, 2019).

Moral authenticity in particular can be a gateway for wineries to engage in an already crowded wine market (Downing and Parrish, 2019). Many of the moral principles already embedded in the winemaking business can be enveloped by moral authenticity, for instance when wineries create stories about environmental sustainable practices around terroir or craftsmanship techniques that convey a sense of moral beliefs with them (Downing and Parrish, 2019).

Authenticity is still an open concept and can be defined differently depending on the product and the target market. Considering authenticity for food products, Lunardo and Guerinet (2007) suggested that authenticity is compiled from three dimensions: projection (self-expression), or in other words, the image that wineries want to project to the consumer and how that image can be associated with their own motives; uniqueness; and originality (respect for tradition and provenance). Wine authenticity can have a strong relationship with quality, provenance, and how far the product is from mass production (Beverland, 2005). For wine authenticity branding, Beverland (2006) suggests six dimensions important to be conveyed to the consumer:

- Heritage and pedigree: heritage is established by connecting the wine brand with its past and by celebrating that history. To demonstrate pedigree, the wineries need to show an ability to consistently track and record their performance by running periodic tastings of past inventories, and by building a reliable stock collection.
- Stylistic consistency: wineries need to deliver a consistent taste in order to give the consumer the ability to form a judgment about the brand independently of the vintage.
- Quality commitments: investing in areas that concern the quality of the wine and conveying that commitment to quality is a critical factor for the consumer.
- Relationship to place: relying on the place of origin is a core strategy for the wine industry and it is no less important when portraying an authentic brand. For the consumer, the place of origin conveys a commitment to terroir, traceable origin and unique product.
- Method of production: the consumer has a need to know what goes into the production of the wine and wineries serve that need by providing the bond between the production process and the final product.
- Downplaying commercial motives: consumers value wines that are less mass-marketed. To have a high valued brand, wineries need to express their ability to always prioritize production of a better quality product over commercial motives.

Even though it is still an open concept, authentic products have increasingly become an important factor when discussing wine (Rössel et al., 2016). For example, analyzing wine journalism in Germany from 1947 to 2008, Rössel et al. (2016) observed that a shift occurred with the language when writing about wine, giving more emphasis to the authentic aesthetics of the wine instead of the technical and commercial angles. Authentic aesthetics of wine can be emphasized through geographical linkages, techniques that encompass craft production, and enhancement of an identity coupled with the winemaker as an individual, along with contextualization of the production as a historical and traditional marker (Rössel et al., 2016).

### 3.33.6.2 Looking for Authentic Products: The Consumer Profile

The search for authentic experiences can be considered as a refuge for consumers that invokes an emotional sense of nostalgia (Lunardo and Guerinet, 2007). Production methods that are more traditional and nostalgic are linked to authentic foods, in contrast to foods that are produced through industrialized methods and enhanced agriculture (Sidali and Hemmerling, 2014).

Consumers today display a great awareness of what they consume and the risks associated with food products (Lunardo and Guerinet, 2007). This behavior is led by two principles:

- Classification, in which food is classified so that norms and rules can be created, meaning some foods can be authentic and others not;
- Incorporation, whereby regulating what is eaten provides a level of control that influences self-esteem, and where authenticity may afford a guarantee about what is being consumed (Lunardo and Guerinet, 2007).

In essence, consumers are looking for brands that have the same ideals that they live by (Larson, 2012).

Generally, when considering the endorsement of authentic products, consumers seeking authenticity have a tendency to trust other consumers' judgments more than professional recommendations or commercial marketing strategies (Liao and Ma, 2009). On the other hand, advertisement claims can be used to emphasize an authentic image for the consumer (Beverland et al., 2008). Advertising can transmit three forms of authenticity: pure authenticity (defined in Section "**Authenticity Concepts and Dimensions**" as indexical authenticity), approximate authenticity (defined in Section "**Authenticity Concepts and Dimensions**" as iconic authenticity), and moral authenticity (Section "**Authenticity Concepts and Dimensions**"), and one of those forms will be used primarily to judge a brand's authenticity (Beverland et al., 2008).

### 3.33.6.3 Branding Authenticity: What Do Consumers Want From an Authentic Brand?

A fundamental factor for creating a successful brand is authenticity, as it builds a distinctive trademark identity (Beverland, 2005; Kapferer, 2008). In general, when a brand is perceived to be managed by individuals that are truly interested, passionate, and motivated by what they are producing, that brand can be perceived as more authentic (Moulard et al., 2016). The opposite is also true, whereby a brand can be perceived as non-authentic when it is directed by professionals that are driven by profit and commercial values (Moulard et al., 2016). In conjunction with the wine professional's ideals, their nationality and heritage may also influence the consumer authenticity perception (Spielmann and Babin, 2011). For example, authenticity perceptions of American consumers were highest when the winemaker and the wine had the same heritage, but that statement was only true for wines coming from France in comparison to wines coming from USA (Spielmann and Babin, 2011). Because American consumers have the image that French wines are an exemplary representation of the category, when the appearance of "Frenchness" is reinforced by having a French winemaker producing American wines, the value of those wines was also enhanced (Spielmann and Babin, 2011).

Presenting an image of an authentic brand to the consumer is crucial for wineries to strengthen their position as a quality brand, to mandate premium prices, and to differentiate themselves from the competition (Beverland, 2005; Sjostrom et al., 2014). In order to offer an authentic image, wineries need to establish and promote a truthful and sincere brand story. This is accomplished by considering the six dimensions defined in Section "**Authenticity Concepts and Dimensions**"; in order words, by linking the wine to its provenance, reinforcing traditional methods, demonstrating a passion and commitment for the craft, having quality production rather than mass industrialized production, paying attention to detail, and always appearing to put ideals above commercial motives (Beverland, 2005, 2006). Increasing the authenticity perception of a wine and the associated brand not only provides differentiation between brands, especially for craft industries (Downing and Parrish, 2019), but also provides producers with the opportunity to increase the perceived value of their wine (Moulard et al., 2015).

### 3.33.6.4 Influence of a Wine Label on Authenticity Perception

As outlined in Section "**Wine Quality**", wine quality is a complex concept that can be perceived through intrinsic and extrinsic cues. Extrinsic cues are of great significance for consumers because purchase decisions are usually made without the opportunity of prior tasting (Sáenz-Navajas et al., 2013). Important extrinsic cues in relation to perceived quality include place of origin, regulatory denominations around origin (appellations), label aesthetic, and bottling process (on- or off-site bottling) (Sáenz-Navajas et al., 2013). These cues afford a wine label a very prominent role in consumer purchase decision making (Thomas and Pickering, 2003) and have a close relationship with the authenticity perceived by consumers (Lunardo and Guerinet, 2007). Indeed, for younger consumers (between 18 and 25 years) in particular, a label can be the decisive signal for authentic versus non-authentic wines, due mainly to the connection of the wine with where it comes from and where it was produced (i.e., indexical authenticity) (Lunardo and Guerinet, 2007).

The description of terroir on a label can also have an impact on authenticity perceptions, depending on the country of origin (Moulard et al., 2015). New World wines were perceived as more authentic when the labels displayed a highly specific description about the terroir, whereas for Old World wines, a vague terroir description was linked with increased perceptions of authenticity (Moulard et al., 2015). The vague description was perceived as authentic because consumers evaluating Old World wines are easily connected to those countries that are highly emotionalized and a common tourist destination with deep cultural linkages. It is likely that a pragmatic description about terroir for Old World wine weakens the transcendent experience (Moulard et al., 2015). Interestingly though, label innovation for Old World wines can be challenging, as in the case of consumers comparing two French wine labels (one modern and one traditional), where the modern label was perceived as a risk and not authentic (Lunardo and Guerinet, 2007).

For Old World wine countries, the geographical origin of the wine is a major factor for authenticity and the connection between the wine and its production origin is regulated through a legislative scheme called PDO (Section "**Applications of Wine Authentication**"; Kamiloglu, 2019). Indeed, the use of the logos indicating the PDO on the label of a wine was positively correlated to the concepts of a protected/delimited region, terroir, and authenticity (Ginon et al., 2014). Terroir can also add an intangible concept of nature giving a "perception of space" (Capitello et al., 2016). It conveys to the consumer cues to assist in building an image of uniqueness, identity, and authenticity (Charters, 2010; Beverland, 2006). When terroir is used as a marketing tool targeting the consumer, it intends to offer a symbolic connotation of authenticity, and is used to segregate the sense of industrial wine from "genuine" wine (Charters, 2010) and as a guarantee of an authentic offering (Gade, 2004).

### 3.33.6.5 Wine Authenticity and Innovation

For a product to stay current in a competitive market and attend to a consumer's desires and expectations, product innovation is crucial for any business (Armstrong and Kotler, 2012). However, because the wine industry is usually tightly connected to traditional production methods and a strong concept of terroir, innovation can have an impact on the consumer's perceptions of authenticity (Spielmann and Charters, 2013; Qesja et al., 2016). Indeed, even though there is a shift in wine trade in terms of the dominance of Old World versus New World wines as discussed in Section "**Wine as a Global Beverage**", consumers are willing to pay more for Old World wines because of the perception that they are more authentic (Moulard et al., 2015). Old World wines apparently match the expectations that consumers have of what the "true" wine represents, according to Moulard et al. (2015). This might be a consequence of New World wine producing countries being more open to adopting innovative strategies, whether in the vineyard or with winemaking practices (Aylward, 2003).

When it comes to implementing new technology in the wine industry, for example, nanotechnology, consumers were observed to be cautious with the application of such technology (Chiodo et al., 2015). When comparing a wine labeled as "nano wine" with another with no designation, the "nano wine" had an overall consumption rejection (Chiodo et al., 2015). However, with a deeper comprehension about the application of nanotechnology, consumers were more open to the concept when it was used to enhance the authenticity of the wine, such as using nanotechnology devices (like taggants, Section "**Covert Packaging Features**") to improve surveillance systems and tracking movements through the supply chain (Weiss et al., 2006). QR codes and NFC tags are another example of technologies that are increasingly presented to the consumer on wine packaging (Sections "**Quick Response (QR) Codes**" and "**Near Field Communication (NFC)**"). For consumers interested in information about regionality and environmental-friendly processes involved in the production of the wine, having a QR code present on the label gives a positive impression (Higgins et al., 2014) and also increases the expected price of the wine (Sillani et al., 2017). In the case of NFC tags, whether consumers intend to use it to authenticate wine will mainly depend on two determinants: the technology is safe from privacy problems, and it fits their lifestyle and fulfills their requirement for information (Bandinelli et al., 2017).

Another factor that needs consideration is the level of involvement of the consumer, either within a country or as an individual. Qesja, Crouch and Quester (2016) observed that for lower alcohol wines, which can be produced using various winemaking technologies, in a country such as Indonesia where wine is not considered a traditional product by the majority of the participants, an innovative wine (with no alcohol content in this case) was positively reacted to and was still considered authentic. When the same study was conducted in Australia, where wine is considered as a traditional product by the majority of the participants, the innovation was perceived negatively and was not considered to be authentic (Qesja et al., 2016).

## 3.33.7 Consumer Perspective on Traceability

As discussed in Section "**Wine Traceability**", traceability processes and devices provide consumers with a means to connect the final product with the raw material and with the producer, helping to both guarantee and satisfy the need for an authentic product (Dimara and Skuras, 2003). The concept of traceability in food products can still be confusing, although generally, when consumers know what traceability is, they connect it to identifying the origin of the product and the production process. Nonetheless, this can be different across countries and across different products (Kehagia et al., 2007).

When traceability is used as an extrinsic quality cue to influence consumer wine purchase decisions, it is usually to target consumers seeking information on a wine label about tradition and authenticity (Dimara and Skuras, 2003). Indeed, according to Kehagia et al. (2007), the best way to communicate traceability to the consumer is through the product's labels and quality seals. However, these need to be simple and clear to facilitate understanding, whereas more complex communication methods that require specific knowledge and reading devices for barcodes or electronic tags might only be confusing and decrease consumer confidence in the product.

## 3.33.8 Conclusion and Future Perspectives

Wine has long been a part of human history and today it represents a culture marker in society. It is compositionally complex and highly connected with its place of origin and with different quality parameters, which all play an important role in its perceived value. Wine is also a luxury product in a global marketplace, and is perhaps more subject to fraud and adulteration than other foods. This is a concern for the consumer and has great financial implications for the wine producers, making wine authentication and traceability important tools.

It is a part of any quality management system to ensure the safety and authenticity of the products being produced. To achieve that, wine authentication needs to be addressed with a multi-dimensional perspective, using different evaluation methods. The development of different analytical approaches that provide a measure of authenticity, when paired with traceability systems and devices, can be used to investigate and guarantee a safe and unadulterated wine for the consumers.

Analytical approaches are based on identification and quantification of specific chemical markers. Using omic approaches, targeted and non-targeted methods can be applied in the process of authentication from the level of a gene to that of molecules, but mostly falling within metabolomics and isotopolomics, and utilizing mass spectrometry in conjunction with chromatographic instruments. Fingerprinting methods based on mass spectrometry and spectroscopic techniques are promising in terms of the speed of analysis, and for detecting certain chemical markers for authentication and identifying adulteration.

For further methodological development, a systematic approach is required that considers chemical compositional aspects and takes into account the applicability of these techniques throughout the supply chain. In that sense, the most appropriate option would be inexpensive methods such as sensor techniques, which give non-destructive, rapid results, and user-friendly hand held instruments that could be easily used in the field. This would help in overcoming limitations in the audit process in the wine industry, as currently only a fraction of commercial wines are chemically audited. Development of more sensitive methods with a higher selectivity would be valuable; for example, in geographical origin authentication, the effect of close proximity of regions has limited the efficiency of the current techniques such as stable isotope analysis by IRMS and elemental analyses by ICP–MS.

With all of these techniques, the application of chemometrics plays a crucial role, since it allows the extraction of hidden information from the acquired multidimensional data, as well as the creation of prediction models in order to classify unknown samples. Commonly applied unsupervized methods (PCA, CA) and supervised methods (LDA, PLS-DA, SIMCA) are currently used for discrimination, classification, modeling and correlation. Validation to ensure robustness of models is an important aspect as well.

Having an appropriate traceability system in place is another way to assure wine authenticity. This system essentially involves record keeping throughout the supply chain, which can be effected by using technological devices. Tags, seals and specific markers on bottle labels can be used not only to ensure effective supply chain tracking but also to guarantee the consumer confidence when the purchase decision is being made. For consumers that are eager for more information about the product or want to verify its provenance, features like NFC and QR codes embedded on the label are an efficient solution. Additionally, those features can be used within the wine supply chain to track the product and to keep records throughout production.

As consumers are the ultimate stakeholders, it is important for producers to consider that authenticity can have different meanings for the consumer and can be used as a marketing strategy by the wine industry. Wine can convey authenticity by creating and transmitting a sincere story that connects the wine with its provenance, with traditional production practices, and with the moral beliefs of the producer. That can be accomplished through information offered to the consumer on the label or through brand construction. Additionally, for effectively transmitting an image of authenticity, the wine industry has to always keep in mind their target consumer, their reputation as a wine producing country, and innovations they are willing to implement.

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# Appendix B

## Conference Proceedings

Sensory characterisation and consumer perspectives of Australian Cabernet Sauvignon wine typicity

**Souza Gonzaga, L.**, & Capone, D. L., Bastian, S. E. P., & Jeffery, D. W. (2020) XIIIth International Terroir Congress, Adelaide, Australia.

XIIIth International Terroir Congress
17–18 November 2020
Virtual Congress | Adelaide, Australia

# SENSORY CHARACTERISATION AND CONSUMER PERSPECTIVES OF AUSTRALIAN CABERNET SAUVIGNON WINE TYPICITY

Lira Souza Gonzaga, Dimitra L. Capone, Susan E.P. Bastian and David W. Jeffery*

Australian Research Council Training Centre for Innovative Wine Production, and School of Agriculture, Food and Wine, The University of Adelaide, Waite Campus, PMB 1, Glen Osmond, South Australia 5064, Australia

*Corresponding author: david.jeffery@adelaide.edu.au

## Abstract

**Aim:** To identify the sensory attributes responsible for the typicity of Cabernet Sauvignon wines from three Australian Geographical Indications (GIs) and to explore consumer purchase behaviour and preference with regard to regional wines.

**Methods and Results:** Descriptive analysis (DA) was applied to identify the sensory profiles of vintage 2015 Cabernet Sauvignon wines from Coonawarra (n = 24), Margaret River (n = 10), Yarra Valley (n = 13), and Bordeaux (n = 5). A trained panel (3 males and 7 females) rated 45 aroma, flavour, and mouthfeel attributes, of which 19 were found to be significantly different among the wine samples. Results from canonical variate analysis demonstrated that Bordeaux wines had a more distinct sensory profile compared to the Australian regions; within the Australian regions, wines from Margaret River had a closer profile to those from Yarra Valley than Coonawarra. Of the wines that underwent DA, two from each region were chosen for a study involving consumers (n = 112) that were divided into two groups. One group was informed of the regions prior to tasting each sample and the other group had no information about region. Consumers were surveyed about their wine purchase behaviour, knowledge of wine typicity, preference for the wines, and sensory profile of each wine using rate-all-that-apply methodology.

**Conclusions:** Bordeaux wines had a more distinct sensory profile compared to the Australian regions, and were associated with developed characters including ‘savoury’, ‘tobacco’, and ‘earthy’. Wines from Margaret River were deemed to possess a fruit-forward profile along with ‘floral’ characters. With a similar profile to Margaret River, Yarra Valley wines were also found to have a greater incidence of ‘red fruits’ and ‘cooked vegetables’ attributes. Coonawarra wines were characterised by ‘chocolate/vanilla’, ‘mint’, and ‘mallee leaf’ attributes and were rated low in ‘cooked vegetables’. When consumers were informed of the wine region of origin there was an apparent increase in their liking scores, with the effect seeming to be positively related to familiarity with the region.

**Significance and Impact of the Study:** Well-established for “Old World” wine producers, typicity is a concept that incorporates aspects of cultivar and terroir of a wine, and acts as a wine quality indicator. Australia also has a range of terroirs contributing to the characters of regional wines, and knowing more about the drivers of distinctiveness can help harness terroir in the promotion of fine Australian wines at an international level. This extends to understanding wine consumers’ behaviours, and being able to attend to their expectations in an objective manner.

**Keywords:** Descriptive analysis, hedonics, typicality, regionality, consumer preference

**Introduction**

Wine is a product that endures extensive effects during its entire production, from the environmental conditions during grape cultivation and origin of the raw materials through to different practices used in the vineyard and winery. The combination of these influences can drive the typicity of wine through their impacts on aromas and flavours. Put simply, typicity can be defined as the expression of a specific sensory profile that can be attributed to a delimited geographical area with influences from the grape variety and its terroir (Cadot *et al.,* 2012).

Provenance and typicity are prized characteristics that help a high quality wine to be recognisable in the market (Maitre *et al.,* 2010). These traits are also responsible for the consumers' quality expectation construct, and will eventually impact their purchase decision (Boncinelli *et al.,* 2016; Schamel, 2006). Studies indicate Australian consumers depend upon the origin indication presented on wine labels to make a choice and to define their concept of a fine wine (Kustos *et al.,* 2020). Furthermore, the Australian wine industry seeks to emphasise regional branding to promote Australian wines of provenance, with the aim of making provincial styles more recognisable domestically and internationally (Wine Australia, 2015).

Considering the needs of both consumers and the industry, this study aimed to characterise unique sensory profiles of Australian Cabernet Sauvignon wines and understand consumer perspectives and behaviours towards the concept of wine typicity with an emphasis on regional profiles.

**Materials and Methods**

The first sensory study involved descriptive analysis (DA) of 52 commercial Cabernet Sauvignon wines that followed the criteria established previously by Souza Gonzaga *et al.* (2019) and Souza Gonzaga *et al.* (2020). The samples were from Coonawarra (n = 24), Margaret River (n = 10), Yarra Valley (n = 13), and Bordeaux, France (n = 5). They were evaluated by a group of 10 panellists (3 males and 7 females) that were trained for 9 × 2 h sessions, following the methodology established by Lawless and Heymann (2010). After the significance of panellist by sample interaction was minimised, formal evaluation sessions were conducted in individual sensory booths. In total, 21 aroma, 23 flavour, and 3 mouthfeel attributes were assessed using a 100 mm line scale.

The second sensory study was conducted with a subset of the samples mentioned above (2 samples from each region) using a panel of 112 red wine consumers. The panel was divided into two groups: one group received prior information about the region of origin of each wine and the other group evaluated each sample in the same way but without the region information. The consumers were asked about their wine liking (using a 9-point hedonic scale) and purchase behaviour, and then assessed the sensory profile of the wines using rate-all-that-apply (RATA) methodology (Danner *et al.,* 2018). Statistical analyses were performed using XLSTAT (Addinsoft, New York, USA, version 2019.4.1) and sensory data was collected using Red Jade software (2016, Redwood City, USA).

**Results and Discussion**

Of the 47 attributes evaluated by the DA panel, 21 were found to be significantly different (two-way ANOVA, $\alpha = 0.1$) between the 52 wines. Canonical variate analysis (CVA) of the significant data showed that there was good separation between the Australian wines and the wines from Bordeaux (Figure 1a). For the wines from Australia, Margaret River had aspects that were similar to Coonawarra and Yarra Valley, whereas Coonawarra and Yarra Valley were less similar in sensory profile. Figure 1b displays how each region could be characterised based on the sensory attributes determined by the DA panel. This revealed that Bordeaux wines were more closely related with developed characters like 'savoury', 'earthy', and 'yeasty', whereas Coonawarra presented 'minty', 'green', 'chocolate and vanilla' characters. Margaret River was characterised by fruit-forward and floral attributes as well as higher sweetness, and Yarra Valley was related with 'red fruits' and 'cooked vegetables' traits. Along with the developed characteristics, Bordeaux wines presented a lower perception of 'floral' and fruity characters, potentially due to the 'savoury' traits supressing the fruit-related ones (Botha, 2010).

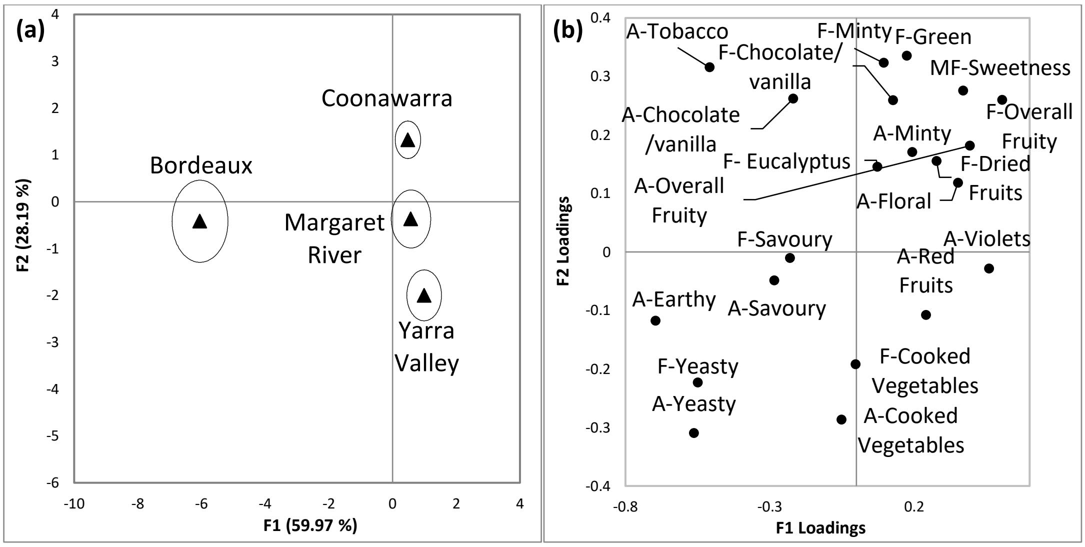


**Figure 1:** Canonical variate analysis plots from the DA study showing (**a**) region centroids as triangles and sample range as circles, and (**b**) factor loadings of significantly different sensory attributes (α = 0.1); aroma (A); flavour (F); taste (T); mouthfeel (MF).

Similar regional profiling using a different approach was presented previously by Souza Gonzaga *et al.* (2019). In that work, Bordeaux wines were found to be related to 'savoury' attributes, Margaret River was related with 'floral', Yarra Valley with 'herbal', and Coonawarra with 'minty' attributes.

Consumer preference trials on two wines from each of the four regions demonstrated that information on provenance had a significant impact (repeated measures ANOVA, α = 0.05) on preference scores (Table 1). When the consumer panellists were informed about the region of origin of the wine, they tended to ascribe a higher liking score, with a larger impact when familiarity with the region was significantly higher (Tukey's HSD, α = 0.05, data not shown). This was especially evident in the case of the Coonawarra region (Table 1). Importantly, as shown by Kustos *et al.* (2019), regionality is a concept that Australian consumers understand, and it can be an important purchase driver by indicating wine quality. In addition, the region familiarity impact in the present work appeared to reinforce the notion that perceived value can increase when wine is connected to its region of origin (Boncinelli *et al.,* 2016).

**Table 1:** Consumer liking mean scores and p-values for Cabernet Sauvignon wines from different regions evaluated with or without region of origin information. Bolded values are significantly different between the two conditions (Tukey's HSD, α = 0.05).

| Sample | Liking (Informed, n = 56) | Liking (Uninformed, n = 56) | p-value |
|---|---|---|---|
| Bordeaux 1 | **6.1** | **5.4** | **0.024** |
| Bordeaux 2 | 6.2 | 6.0 | 0.393 |
| Coonawarra 1 | **7.0** | **6.3** | **0.012** |
| Coonawarra 2 | **6.8** | **6.1** | **0.028** |
| Margaret River 1 | 6.0 | 5.9 | 0.589 |
| Margaret River 2 | **6.5** | **5.5** | **0.004** |
| Yarra Valley 1 | 5.3 | 5.1 | 0.619 |
| Yarra Valley 2 | 6.8 | 6.6 | 0.579 |

The RATA results demonstrated that the preference scores between the two consumer groups (Informed and Uninformed) did not have an impact on the sensory attributes (repeated measures ANOVA, α = 0.05), meaning that both groups profiled the wines similarly (data not shown). Overall preference showed a correlation with 'dark fruits' and 'jammy' attributes, and fuller body wines. Furthermore, the panel appeared to be more familiar with samples that exhibited 'herbal' and 'minty' characters, which may be relevant to other studies that recruit panellists from within the general region of at least some of the wines under evaluation.

**Conclusions**

The DA study was able to distinguish Cabernet Sauvignon wines from the four regions based on sensory composition, with the largest difference obtained between wines from Bordeaux and from the Australian regions. In addition, the consumer study provided insights into the importance of being informed of the region of origin, whereby preference was significantly increased when wine provenance was known. Furthermore, this aspect of the study provided some understanding of the preferred sensory attributes for this cohort of consumers. Overall, the outcomes generated from these two sensory studies will be built upon to assist the wine industry to better understand their regional styles, to gain insights into consumers' preferred wine sensory traits, and to increase understanding of their target audience.

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# Appendix C

## Conference Proceedings

Characterising the chemical typicity of regional Cabernet Sauvignon wines

Capone, D. L., Boss, P., **Souza Gonzaga, L.**, Bastian, S. E. P., & Jeffery, D. W. (2020) XIIIth International Terroir Congress, Adelaide, Australia.

XIIIth International Terroir Congress
17–18 November 2020
Virtual Congress | Adelaide, Australia

# CHARACTERISING THE CHEMICAL TYPICITY OF REGIONAL CABERNET SAUVIGNON WINES

Dimitra L. Capone[1,2]*, Paul Boss[3], Lira Souza Gonzaga[1,2], Susan E.P. Bastian[1,2], David W. Jeffery[1,2]

[1]Australian Research Council Training Centre for Innovative Wine Production, and
[2]Department of Wine Science, The University of Adelaide, PMB 1, Glen Osmond, South Australia 5064, Australia
[3]CSIRO, Locked Bag 2, Glen Osmond, South Australia 5064, Australia

*Corresponding author: dimitra.capone@adelaide.edu.au

## Abstract

**Aim:** To define the uniqueness of Australian Cabernet Sauvignon wines by evaluation of the chemical composition (volatile aroma and non-volatile constituents) that may drive regional typicity, and to correlate this with comprehensive sensory analysis data to identify the most important compounds driving relevant sensory attributes.

**Methods and Results:** A range of specialised analytical methods have been optimised to quantify more than 70 volatile aroma compounds in Cabernet Sauvignon wine. These methods examine a diverse array of metabolites that originate from the grape, fermentation, maturation and oak maturation. Examination of a variety of non-volatile compounds such as tannins, basic chemistry and non-volatile secondary metabolites were also undertaken. These analytes were quantified in 2015 commercial Cabernet Sauvignon wines (n = 52) originating from Coonawarra, Margaret River, Yarra Valley and Bordeaux. Multivariate statistical analysis of chemical datasets and sensory ratings obtained by a trained descriptive analysis panel identified compounds driving aroma attributes that distinguished wines from the different regions. Some compounds, such as dimethyl sulfide, which arises from a grape amino acid and is described as 'black currant or olive' at low concentration and 'canned vegetables' at high concentration, were not statistically different amongst regions. In contrast, compounds such as 1,4-cineole ('mint' and 'bay leaf' aroma), 3-isobutyl-2-methoxypyrazine ('green capsicum' aroma) and 4-ethylphenol ('earthy' and 'band-aid' aroma) were able to differentiate the wines.

**Conclusions:** For the first time, this work has revealed various wine chemical constituents, both volatile and non-volatile, that have been linked with results from comprehensive sensory analysis to determine the important drivers of regional typicity of Australian Cabernet Sauvignon wines. Identifying these candidates will lead us to the next step of identifying which viticultural and/or winemaking practices can influence these compounds to meet target styles for wines of provenance.

**Significance and Impact of the Study:** Identifying the chemical markers that characterise Cabernet Sauvignon regional typicity will lead Australian producers one step closer to having the tools to preserve the 'uniqueness' of their regional wines. A greater understanding of chemical drivers of wine sensory traits will keep the industry at the forefront of the field internationally and will provide producers with knowledge that can be used for promoting their wines and enhancing sales.

**Keywords:** Regional typicity, chemical markers, wine sensory traits, Cabernet Sauvignon

**Introduction**

Cabernet Sauvignon is a popular grape variety grown in almost all wine producing regions around the world. Originating in Bordeaux in the 1700s (Anderson *et al*., 2013), it is an important variety to Australia where it represents approximately 18% of Australia's vineyard area (Wine Australia, 2020). Learning more about the influences of terroir to understand what drives the regional distinctiveness of this important varietal is imperative for helping maintain Australia's reputation as a fine wine producing and exporting nation.

It is well known that aroma and flavour are responsible for a consumer's enjoyment of wine (Ristic *et al*., 2019), and with over a thousand volatile compounds having been identified in wine to date, the complexity of this matrix becomes evident. Not all of these compounds are present in any one wine, and a much smaller number of them play a vital role in wine flavour (Ferreira *et al*., 2009). These compounds originate from various sources including: the grape berry itself either directly or via precursors (including varietal-specific compounds); alcoholic or malolactic fermentation; oak wood contact; and oxidation and ageing, plus exogenous sources. In previous studies, sixty-nine (Tao *et al*., 2008) and seventy-four (Gürbüz *et al*., 2006) volatile compounds were identified in Cabernet Sauvignon wines. These mainly consisted of higher alcohols, acetates, fatty acids and ethyl esters and to a lesser extent terpenes, a norisoprenoid, carbonyls and phenols.

Varietal-specific compounds originate in the grape berry: a classic example is the methoxypyrazines (MPs), which can impart characteristic aromas of 'green capsicum', 'asparagus' and 'green beans'. These characters are well known for their sensory contribution to wines produced from Cabernet Sauvignon and Sauvignon Blanc (Robinson *et al*., 2014). If present at low ng/L concentrations, MPs are considered desirable and characteristic of the grape cultivar, but at higher concentrations they become unpleasant. 3-Isobutyl-2-methoxypyrazine (IBMP) is the most important of the MPs and is thought to originate from enzymatic methylation of hydroxypyrazines, (Dunlevy *et al*., 2013; Guillaumie *et al*., 2013). A range of factors, including climate, grape maturity, light exposure, various viticultural management practices, and crop yield can affect IBMP concentration. In addition, MPs are easily extracted into must and increase during fermentation on skins (Sidhu *et al*., 2015). They are among the very few wine aroma compounds where the concentration can be predicted from berry homogenates (Ryona *et al*., 2010).

Varietal thiols, another group of varietal character impact compounds, contribute characteristic wine aromas of 'tropical fruit', 'passionfruit', 'citrus', 'grapefruit' and 'box hedge'. Having extremely low odour detection thresholds (low ng/L range), the three most common varietal thiols are 3-sulfanylhexan-1-ol (3-SH), 3-sulfanylhexyl acetate (3-SHA) and 4-methyl-4-sulfanylpentan-2-one (4-MSP) (Roland *et al*., 2011). Their importance in Sauvignon Blanc is well known (Roland *et al*., 2011) and recently their significance in Chardonnay wine has been reported (Capone *et al*., 2018). These compounds were identified in Bordeaux red wines over two decades ago (Bouchilloux *et al*., 1998), but minimal data has become available since then. This is most likely attributable to the challenges associated with developing adequate methods to measure these reactive compounds at ultratrace concentrations (Capone *et al*., 2015). Varietal thiols originate from grape berry-derived odourless cysteinylated and glutathionylated precursors and are released enzymatically during fermentation. As such, there can be significant yeast strain effects, and ripening and post-harvest conditions during winemaking can affect the concentration of thiol precursors (Capone *et al*., 2012c; Chen *et al*., 2019).

1,8-Cineole, commonly known as eucalyptol, is another relevant compound that has an aroma described as 'fresh', 'cool', 'minty' and 'camphoraceous'. Elevated levels of 1,8-cineole in wine may be attributable to matter other than grapes (MOG), in particular material from surrounding *Eucalyptus* trees grown in close proximity to grapevines (Capone *et al*. 2012b). From a large survey of commercial Australian red wines (n = 150) including 45 Cabernet Sauvignon wines, it was shown that 40% of the red wines contained concentrations of 1,8-cineole above its aroma detection threshold and that the concentration increased during fermentation with skin contact (Capone *et al*., 2011). Furthermore, studies showed that once present in wine, 1,8-cineole is extremely stable (Capone *et al*., 2012b). Sensory evaluations of the isomeric compound 1,4-cineole revealed descriptors of 'hay' and 'dried herbs', both independently and in the presence of 1,8-cineole. Quantitative analysis revealed higher concentration of 1,4-cineole in Margaret River Cabernet Sauvignons compared with Barossa Valley, McLaren Vale, and to a smaller degree, Coonawarra Cabernet Sauvignon wines, suggesting this aroma compound could assist with characterising terroir (Antalick *et al*., 2015). Interestingly 1,4-cineole was not present in any of the samples above its aroma detection threshold of 0.6 µg/L (Antalick *et al*., 2015).

Oak volatiles, of which several hundred have been identified in wine (Pollnitz *et al*., 2004), are related to terroir through human intervention, particularly in the winery. These compounds may originate by extraction directly from oak wood, interactions between wood constituents and wine constituents, or through chemical or biological reactions of wood constituents. Only a few of these oak volatiles are thought to be important for wine aroma, with the most noteworthy including *cis*- and *trans*-oak lactone, guaiacol, 4-ethylphenol, 4-methylguaiacol, 4-ethylguaiacol, eugenol and vanillin (Pollnitz *et al*., 2004). The isomers of oak lactone, arguably the most significant of the oak volatiles, exhibit aromas of 'coconut', 'vanilla', 'woody', 'citrus' and 'red berry' for the *cis*-isomer and 'coconut' and 'celery' for the *trans*-counterpart (Gunther *et al*., 1986; Wilkinson *et al*., 2004). Oak used in commercial winemaking can originate from different sources, the most popular being from France and America, adding another layer of terroir impacting on the oak volatile concentrations. For example, it has been demonstrated that 10:1 and 1:1 ratios of *cis*:*trans* oak lactone are indicative of American and French oak, respectively (Waterhouse *et al*., 1994). 4-Ethylphenol (4-EP) and 4-ethylguaiacol (4-EG) are not so desirable and result from microbial spoilage (*Brettanomyces bruxellensis*). This slow growing yeast can cover a barrel and reside in between staves and reproduce when the barrels are refilled with wine. In addition, Brettanomyces can be present on the grapes, in soil and water, and in the winery environment, and could therefore also be considered as being related to terroir (Rayne *et al*., 2007). 4-EP and 4-EG have aromas that can be described as 'leather', 'horse stable', 'band aid' and 'spice, clove', with a ratio of 8:1 of 4EP:4-EG being indicative of *Brettanomyces* spoilage (Chatonnet *et al*., 1995).

Non-volatile compounds are another class of components present in wine that are important to taste and mouthfeel properties. These include things like tannin, polysaccharides, polyols, and organic acids. Only a few of the compound groups are considered here. With a multitude of compounds being present in any one wine, determining the most important ones responsible for characteristic sensory attributes is undoubtedly a challenge. Chemometric methods for analysis of the different datasets are crucial, and partial least squares regression (PLSR) has been adopted as a technique of choice for linking the chemical and the sensory data (Lee *et al*., 2006). This statistical approach enables the determination of which compound(s) are related to particular sensory attribute(s), and helps to identify the basis for any differentiation of wines from various regions of origin. PLSR was thus applied to a suite of chemical data originating from various sources in 52 Commercial Cabernet Sauvignon wines from four different wine producing regions, along with the data obtained from the sensory descriptive analysis (DA) of the same wines. Preliminary results are presented and discussed in relation to differentiating the regions under investigation.

**Material and Methods**

Fifty-two commercial 2015 vintage Cabernet Sauvignon wines from Coonawarra (n = 24), Margaret River (n = 10), Yarra Valley (n = 13) and Bordeaux (n = 5) were analysed for a range of compound groups. SIDA-SPME-GCMS methods were optimised for the quantification of $C_6$ compounds (Capone *et al*., 2012a), 1,4- and 1,8-cineole (Antalick *et al*., 2015; Capone *et al*., 2011), DMS (Segurel *et al*., 2005) and a range of fermentation derived volatiles (Wang *et al*., 2016). Oak volatiles were measured utilising liquid injection based on the published method (Pollnitz *et al*., 2000). IBMP was quantified utilising a SIDA-SPME-GC-MS/MS method adapted from Dunlevy *et al*. (2013). Varietal thiols were quantified by HPLC-MS/MS (Capone *et al*., 2015). Tannin and total phenolics were determined by AWRI Commercial Services and non-volatile profiling of secondary metabolites was undertaken through Metabolomics Australia. Basic chemical parameters were analysed as described in Ranaweera *et al*. (2020). All wines underwent sensory profiling using descriptive analysis (DA) as described in Souza Gonzaga *et al*. (2020).

**Results and Discussion**

Concentrations of a selection of volatile compounds that originate from different sources for the 52 Cabernet Sauvignon wines from four regions are presented in Figure 1. Varietal thiol 3-MH was found at similar concentrations in the Bordeaux and Coonawarra wines, with approximately 250-350 ng/L (Figure 1a). Significantly higher concentrations were measured for Margaret River and Yarra Valley wines, at approximately 280-400 ng/L (Figure 1a). The concentration of 3-MH in all wines was well above the aroma detection of 60 ng/L (determined in a hydroalcoholic solution) (Roland *et al*., 2011), meaning that 3-MH could contribute to the 'berry jam', 'earthy', 'plum' and 'soy' aroma of the wines, as recently reported by Garrido-Bañuelos *et al*. (2020).

The results for 1,4-cineole (Figure 1b) were in reasonable agreement with the previous findings that highlighted 1,4-cineole as being characteristic of Margaret River Cabernet Sauvignon wines. Furthermore, a broader distinction between Bordeaux and the Australian regions existed on the basis of 1,4-cineole concentration (significant differences among the means, $\alpha = 0.05$), but there was no statistical difference between Yarra Valley and Coonawarra wines. The concentrations of 1,4-cineole shown in Figure 1bwere below the aroma detection of this compound, which again was in agreement with the previous study (Antalick *et al*., 2015). In contrast to 1,4-cineole, whose origins are not yet defined, 1,8-cineole has been previously found to be increased by aerial transfer of volatiles from *Eucalyptus* trees to the grapes when vines are planted in the vicinity of the trees, and especially by the presence of MOG (particularly Eucalypt material) ending up in a ferment. Although the concentrations of 1,8-cineole were quite variable, mean values were < 5 µg/L, and there were no significant differences amongst the Australian regions (Figure 1b). Bordeaux wines were found to have < 1 µg/L, but the mean value was only significantly different to that for Coonawarra.

The data for IBMP, an important varietal compound for Cabernet Sauvignon, is shown in Figure 1c. The concentration of IBMP was mostly below the aroma detection threshold of this compound in red wine (10 ng/L (Kosteridis *et al*., 1998)). At these low concentrations, it would be expected that IBMP would not impart any undesirable green characters to the wines. There were no statistically significant differences between the means of IBMP for the Australian regions, whereas Bordeaux was significantly lower than the amounts determined for Coonawarra and Margaret River. This may be attributable to the Bordeaux wines having a lower relative amount of Cabernet Sauvignon in the blend (minimum of 60% vs minimum of 85% for the Australian wines).

The data obtained for *cis*- and *trans*-oak lactone, 4-ethyl phenol and 4-methylguaucol can be seen in Figure 1d. There was no significant difference amongst the regions for *trans*-oak lactone but the *cis*-oak lactone concentration did vary. Interestingly, the ratio of *cis*-oak lactone:*trans*-oak lactone was around 1:1, which is indicative of the predominant use of French oak. Only a few samples had slightly higher ratios, which could infer there was some percentage of American oak being used. Perhaps unsurprisingly, both 4-ethylphenol and 4-ethylguaiacol were significantly higher in Bordeaux wines compared with the Australian wines. These compounds are usually present in higher concentrations as a result of microbiological activity of *Brettanomyces spp* during oak maturation (if the impact of smoke taint can be ruled out). The characteristic ratio of 4-EP:4-EG that is symptomatic of *Brettanomyces* spoilage (Chatonnet *et al*., 1995) appeared to be the reason for the presence of these volatile phenols in the Bordeaux wines (i.e., approximately 8:1 in most of these cases). Notably, one of the Bordeaux samples had 4-EP at up to 378 µg/L, which would undoubtedly have imparted an evident 'band-aid' or 'barnyard' aroma in that wine.

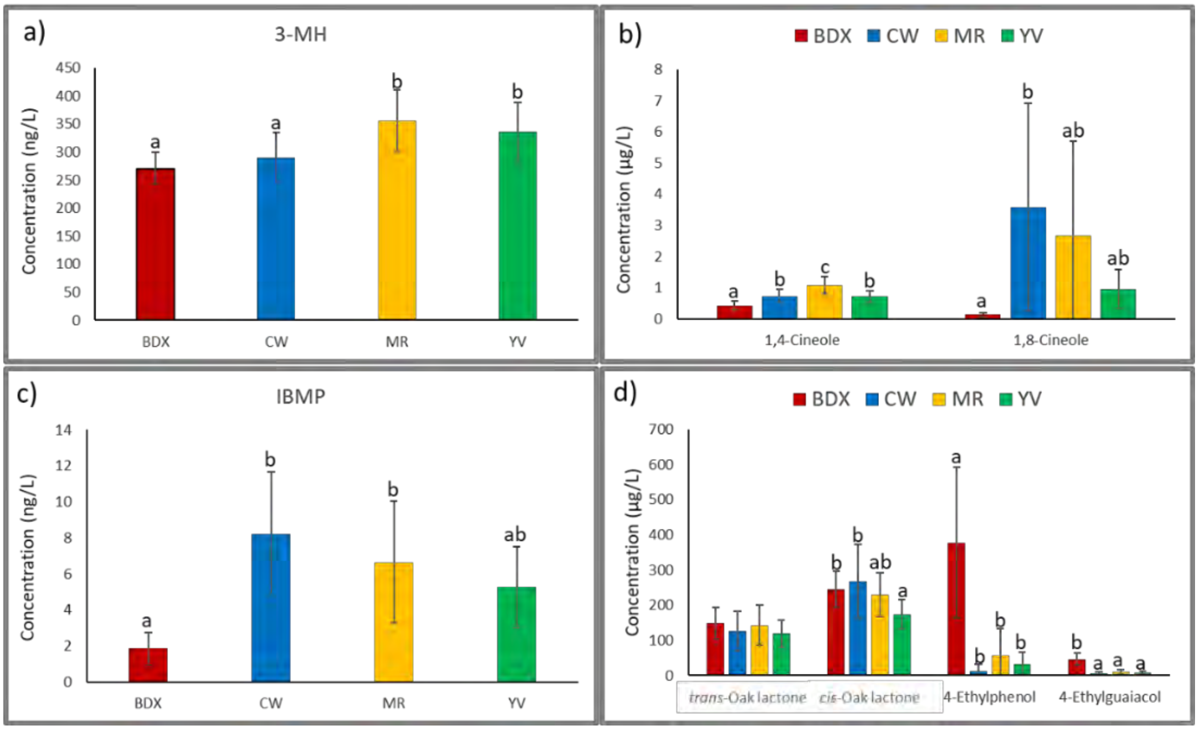


**Figure 1:** Concentration of a) 3-mercaptohexan-1-ol (3-MH), b) 1,4- & 1,8-cineole, c) 3-isobutyl-2-methoxypyrazine (IBMP), and d) *cis*- and *trans*-oak lactone, 4-ethylphenol and 4-ethylguaiacol in Cabernet Sauvignon from Bordeaux (BDX) (n = 5), Coonawarra (CW) (n = 24), Margaret River (MR) (n = 10) and Yarra Valley (YV) (n = 13). Error bars indicate the standard deviation and different letters above the error bars denote significant differences among the means according to Tukey's post-hoc test (α = 0.05).

To examine any relationships between the regions studied and to determine whether chemical components are able to explain particular sensory attributes, the chemical data generated so far (including non-volatiles, data not shown) was analysed against the sensory DA data using PLSR (Figure 2). With an optimum number of two factors for the preliminary model, the variation of the sensory data was not explained to a high degree (16%) but it gave the first insight into potential regional differences. This will likely be significantly improved once all chemical data is available. From the scores plot, partial separation of the regions was achieved although there is some overlap with certain wines (Figure 2a), which may be expected on the basis of winemaking and style. The Bordeaux wines were clearly separated from the other Australian regions, a large cluster from Coonawarra was separated from Yarra Valley wines, whereas Margaret River seemed more closely related to wines from both Coonawarra and Yarra Valley. Figure 2b indicates that the chemical constituents 4-ethylphenol and 4-ethylguaiacol were driving the separation of the Bordeaux wines, and these compounds were closely related to 'earthy' and 'yeasty' aromas. This relationship could be expected based on the chemical data presented earlier (Figure 1d). A cluster of some of the Coonawarra wines was related to 'minty', 'liquorice', 'dark fruit' and 'spice', with these sensory traits being associated with hexanol, 1,8-cineole, ethyl propanoate and ethyl butyrate, and a range of other compounds to a lesser extent. A cluster of Yarra Valley wines was related to 'red fruit' and 'jammy' characters, and associated with 1-octanol, 2-octanone and DMS. A cluster of wines from Margaret River were characterised by 'grassy', 'eucalypt', 'savoury' and 'chocolate' aromas and were associated with ethyl decanoate, butan-1-ol, (*Z*)-3-hexen-1-ol and ethyl-3-methyl butanol.

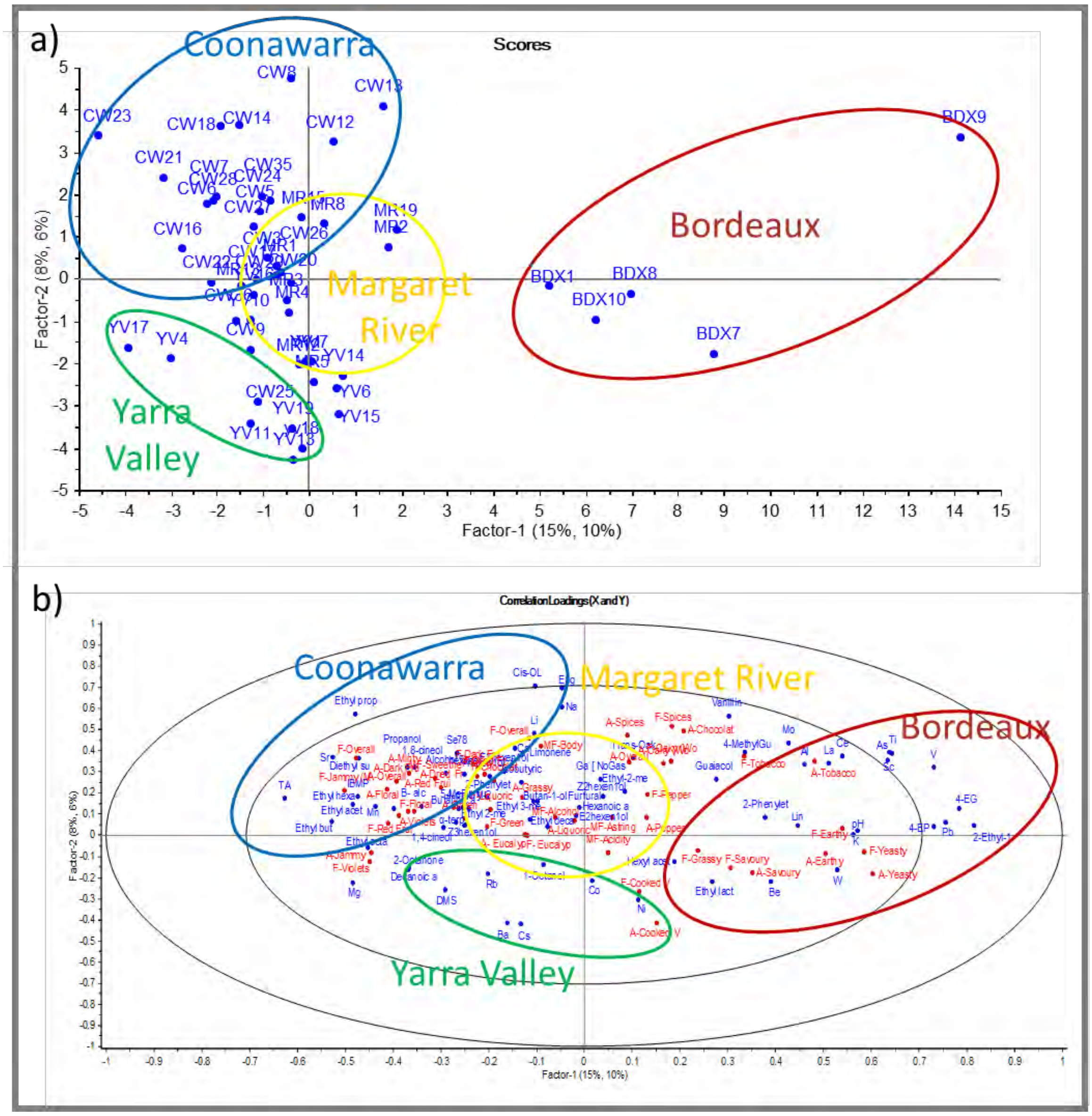


**Figure 2:** Plot of scores and loadings from PLSR (two factor model) using significant (P < 0.1) chemical data (X-variables) and sensory attributes (Y-variables) for the commercial Cabernet Sauvignon wines (n = 52). For the sensory attributes, A = aroma, F = Flavour and MF = Mouthfeel.

In addition to the quantitation of volatiles, elemental analysis data obtained by ICP-MS showed similar trends to those previously reported by (Ranaweera *et al*., 2020). It appeared that separation of Bordeaux wines was driven by the elements K, Sc, Ti, V, As, La, W and Pb, whereas Coonawarra seemed to be higher in Se, Li, Ca and Sr, Margaret River in Co, and Yarra Valley in Mg, Ba, Cs and Rb. Previous research by others has also revealed Sr to be a good marker for authenticating wine (Ranaweera *et al*., 2020).

**Conclusions**

This work has explored various volatile and non-volatile wine chemical constituents that have been related with sensory descriptive analysis to determine the significant drivers of typicity of regional Cabernet Sauvignon wines. Preliminary data provided examples such as 4-ethylphenol and 4-ethylguaiacol being linked with ‘earthy’ and ‘yeasty’ aromas and driving the separation of the Bordeaux wines from the others. Additionally, 1,4-cineole was successful at distinguishing the Australian regions, particularly Margaret River. The varietal compound 3-MH was found to be significantly different in the Bordeaux and Coonawarra wines compared with Margaret River and Yarra Valley, with the amounts being above the aroma detection threshold of this compound. Interestingly, the other varietal compound IBMP, which is an impact compound in Cabernet Sauvignon wines, was lowest in Bordeaux wines. Finalising the remaining chemical data and identifying candidate compounds that differentiate the regions will lead to the next stage, being the of identification of viticultural and/or winemaking practices that can influence wine chemical profiles so that target styles can be met while preserving or enhancing the terroir of the regions.

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Even the longest wine tasting has its end.