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Australian Grape and Wine Authority

THE UNIVERSITY of ADELAIDE

OBJECTIVE MEASURES OF SPARKLING WINE STYLE AND QUALITY



FINAL REPORT to

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Abstract:

Sparkling wine represents a small but significant proportion of the Australian wine industry's total production and a market niche for which there is growing consumer interest. This project employed a range of chemical and sensory analyses to profile the variation in composition, sensory properties and quality amongst (i) Australian sparkling white wines and (ii) Australian Moscatos. Consumer preferences for different styles of sparkling white wine and Moscato were also studied. Research outcomes enable industry to better understand the domestic sparkling wine market and provide insight which might inform production and/or marketing strategies, so as to influence consumer purchasing decisions and consumption behaviour.

Executive Summary:

Sparkling wine represents a small but significant proportion (~10%, 37 ML) of the Australian wine industry's total production, yet surprisingly, little research has been undertaken to determine Australian consumers' preferences for the array of sparkling wine styles produced or to investigate the appeal of different sparkling wine styles to new or emerging markets (e.g. the Millennials or Generation Y). In 2012, Australian sparkling white wines accounted for the majority (54%) of total sparkling wine sales in Australia (by value), but Champagne maintains a sizeable (19%) share (Nielsen, 2012). The Australian wine industry seeks to capture a greater proportion of existing and emerging sparkling wine markets, for financial gain. To achieve this, winemakers and wine marketers need to better understand the relative importance of different styles of Australian sparkling wine, i.e. white and pink Moscato, and sparkling white, rosé and red wines, and the target markets for each of these wine segments. Sparkling wine producers might also benefit from identification of markers by which wine style and quality can be determined, so that wine styles (and their marketing strategies) can be better tailored to specific segments of the domestic market.

The key objectives of this project were therefore to characterise the relative importance of different segments of the Australian sparkling wine sector, to gain insight into consumer preferences for different styles of sparkling wine and their sensory properties, and to develop objective measures by which sparkling wine style and quality can be determined.

To achieve these objectives, market sales data was obtained to determine the relative importance of different sparkling wine styles. This enabled trends in sparkling wine sales to be established, including: a significant increase in the share of sales (by value) for Champagne (from 8% to 19%) between 2005 and 2012; decreased sales (by value) for sparkling white wine (from 64% to 54%), sparkling rosé (from 9% to 7%) and sparkling red wine (from 4% to 3%) between 2005 and 2012; and the rise in popularity of Moscato, which in 2012 held 8% of overall sales value.

Based on this data, together with input from an industry reference group (comprising several prominent Australian sparkling winemakers), a range of chemical and sensory analyses were undertaken to profile the variation in composition, sensory properties and quality of: (i) 50 Australian sparkling white wines – representative of not only the four key methods of sparkling wine production, i.e. Méthode Traditionelle, transfer, Charmat and carbonation – but also a range of price points, Australian wine regions and brands; and (ii) 24 Australian Moscato wines – also representative of a range of price points, Australian wine regions and brands.

Compositional analyses included basic wine parameters such as pH, titratable acidity (TA), residual sugar, alcohol and total phenolics, aroma profiling by gas chromatography-mass spectrometry (GC-MS), and acid, sugar and phenolic profiling by high performance liquid chromatography (HPLC) and fluorescence. In the case of sparkling white wines, protein, polysaccharide, amino acid and fatty acid/ethyl ester determinations were also performed; as well as measurement of foaming properties, such as foam volume (V*f*) and foam lifetime (L*f*). Sensory analyses included determinations of wine quality by expert panels and sensory profiles by descriptive analysis (DA) with trained panels. Statistical analysis of sensory data enabled identification of wine subsets (n=6 for both sparkling white wines and Moscatos) for consumer acceptance testing; with wines selected to be representative of the sensory diversity observed amongst each sparkling wine segment. Consumer acceptance tests enabled the sensory appeal of different styles of Australian sparkling white wine and Moscato to be determined. However, in recognition of the inherent diversity amongst wine consumers, segmentation based on consumers' individual liking scores was also performed, in order to identify consumer clusters with distinct preferences for different wine styles.

The suitability of attenuated total reflection (ATR) mid-infrared (MIR) spectroscopy, combined with multivariate data analysis – principal component analysis (PCA) and partial least squares regression (PLSR) – was also evaluated as a rapid analytical technique for the classification of sparkling wine style and quality. The MIR spectra of a range of Australian sparkling wines, i.e. sparkling white (n=50), rosé (n=25), red (n=25), Prosecco (n=14) and Moscato (n=25) wines were recorded. Qualitative compositional differences between wines were observed by MIR spectroscopy, and following PCA, enabled discrimination of wines according to both sparkling wine style, and in the case of sparkling white wines, production method.

This is the first study to profile the compositional, sensory and quality variation amongst Australian sparkling white wines and Moscatos, and importantly, consumer acceptance of different styles of each sparkling wine segment. Research findings enable industry to better understand the preferences of different segments of the sparkling wine consumer market and might therefore be used to inform wine production and/or marketing decisions, i.e. to tailor/target different styles of sparkling wine to specific consumer segments.

Two complementary projects were established alongside the research outlined above: (i) an Honours project at the University of South Australia (undertaken by Melissa Lane in 2013) titled *Understanding consumer preferences for Australian sparkling vs. French Champagne*; and (ii) a PhD project at the

University of Adelaide (undertaken by Naomi Verdonk and due for completion in early 2018) titled *Understanding Australian wine consumers' preferences for sparkling wine.*

The research team gratefully acknowledges the Australian wine producers who generously donated sparkling wines to the project, and the sparkling winemakers and wine show judges, University of Adelaide staff and students, and wine consumers who participated in quality ratings, descriptive analysis and consumer acceptance trials, respectively. Additionally, the direction, feedback and input provided by the project's industry reference group, comprising Ed Carr (Accolade Wines), Teresa Heuzenroeder (Yalumba), Dan Buckle (Domaine Chandon) and Trina Smith (Treasury Wine Estates), is greatly appreciated. The involvement of collaborators from The Australian Wine Research Institute (Dr Paul Smith and Dr Jacqui McRae), CSIRO (Dr Paul Boss and Emily Nicholson) and The University of Melbourne (Dr Kate Howell and Bruna Condé) is also gratefully acknowledged.

Background:

Sparkling wine has accounted for almost 10% of Australian domestic wine sales since the late 1980s. Between 2004 and 2012, the number of Australian sparkling wine producers increased from 570 to 948, and annual production reached 37 ML. Sparkling wine therefore represents a small but significant proportion of the Australian wine industry's total production, and importantly, a market niche for which there is growing consumer interest.

The Australian sparkling wine market is diverse, comprising white and pink Moscato, and white, rosé and red sparkling wines, as mono-varietals and blends, at commercial, premium and luxury price points. However, the relative importance of each wine style to consumers within the domestic sparkling wine market remains unclear. This project therefore aimed to: (i) characterise the relative importance of different styles of Australian sparkling wine; (ii) provide insight into consumers' preferences for different sparkling wine styles and their sensory attributes; and (iii) develop objective measures by which sparkling wine quality can be determined.

There is very little (scientific) literature concerning Australian wine consumers' preferences for sparkling wine. Oenology-based research has investigated the physical attributes of sparkling wine, such as foam quality (Andrés-Lacueva, 1996, Vanrell et al. 2006) and effervescence (Liger-Belair et al. 2010). The influence of factors such as grape variety, yeast selection and lees contact on sparkling wine composition and/or sensory properties have also been studied (e.g. Brissonet and Maujean 1991, Presa-Owens et al. 1995, Vannier et al. 2003), but almost exclusively in relation to French Champagne or Spanish Cava. In contrast, consumer/marketing-related research typically focuses on table wine; albeit some highly specific studies, involving 'Gen Y' sparkling wine consumers for example, have been reported (Charters et al. 2011).

While there is literature concerning Champagne as a brand, compositional comparisons and comprehensive studies investigating Australian consumer preferences for sparkling wine have not been reported. Perceptions of sparkling wine quality are usually closely associated with consumers' wine involvement, i.e. high involvement consumers recognise brand names as trademarks of quality, for which they are willing to pay a premium (Charters 2005); but there is presently no objective measurement for sparkling wine quality. This project therefore sought to characterise Australian sparkling wine styles, to gain insight into consumer preferences for these styles and their sensory properties, and to develop objective measures by which sparkling wine style and quality can be determined.

Project Aims and Performance Targets:

The project originally aimed to:

- characterise the relative importance of different sparkling wine styles (Year 1)
- employ a range of chemical and sensory analyses to profile the variation in composition, sensory properties and quality of Moscato and sparkling white wines, including mapping trials to determine consumer preferences for different Moscato and sparkling white wine styles (Years 1&2)
- employ a range of chemical and sensory analyses to profile the variation in composition, sensory properties and quality of Moscato and sparkling white wines, including mapping trials to determine consumer preferences for different sparkling rosé and red wine styles (Years 2&3)

The research activities and outputs proposed in the original application are tabulated below:

Year 1 Activities	**Year 1 Outputs**
Market sales data (obtained from AC Neilsen and via in-store observational studies) will be analysed to identify the relative importance of different sparkling wine styles (i.e. Moscato and sparkling white, rosé and red wines) to inform selection of wines representative of each market segment, for chemical and sensory analysis.	A shortlist of sparkling wines (8 to 12 per style, depending on the relative importance of each market segment) to be subjected to chemical and sensory analyses. Preparation of a factsheet or descriptive note describing the current Australian sparkling wine market and the relative importance of individual sparkling wine styles.
Descriptive sensory analysis of Moscato and sparkling white wines to characterise the sensory attributes (i.e. appearance, aroma, flavour, taste and mouthfeel) that define different styles of sparkling white wine; d-optimal selection will be used to inform selection of wines for consumer preference mapping.	A shortlist of Moscato and sparkling white wines (approximately 8) representative of the entire flavour map to be used for consumer preference mapping experiments.
Year 2 Activities	**Year 2 Outputs**
Compositional analyses of Moscato and sparkling white wines using traditional wine chemistry (i.e. pH, TA, alcohol and colour measurements), GC-MS-O (for aroma profiling), IR spectroscopy, and HPLC/UPC and fluorescence (for acid, sugar and phenolic profiling). Consumer preference mapping of subset of Moscato and sparkling white wines (using 150 consumers to determine preference and for segmentation analysis). Statistical analysis (e.g. Principal Component Analysis and Linear Discriminant Analysis) of chemical, sensory and consumer data to identify style and/or quality markers for sparkling white wines.	Preparation of materials for publication/dissemination describing the application of chemical and sensory analyses (including consumer preference mapping) to identify key markers of preference and quality for Australian Moscato and sparkling white wine.
Sparkling white wines representative of different grape varieties, vintages, wine regions, production methods and price points will be chemically analysed (as above) to determine which factors most strongly influence wine composition and to validate the style and quality markers identified above. The quality of commercial sparkling wines will be determined by an expert panel and correlated with compositional data using chemometric analysis.	Preparation of materials for publication/dissemination describing the compositional differences of sparkling white wines representative of different grape varieties, vintages, regions (climates), production methods and price points and evaluating the classification of sparkling wine style and quality using the objective measures identified above.

Descriptive sensory analysis of sparkling rosé and red wines to characterise the sensory attributes (i.e. appearance, aroma, flavour, taste and mouthfeel) that define different styles of sparkling red wine; d-optimal selection will be used to inform selection of wines for consumer preference mapping.	A shortlist of sparkling rosé and red wines (approximately 8) representative of the entire flavour map to be used for consumer preference mapping experiments.
Year 3 Activities	**Year 3 Outputs**
Compositional analyses of sparkling rosé and red wines using traditional wine chemistry (i.e. pH, TA, alcohol and colour measurements), GC-MS-O (for aroma profiling), IR spectroscopy, and HPLC/UPC and fluorescence (for acid, sugar and phenolic profiling). Consumer preference mapping of a subset of sparkling rosé and red wines (using 150 consumers to determine preference and for segmentation analysis). Statistical analysis (e.g. Principal Component Analysis and Linear Discriminant Analysis) of chemical, sensory and consumer data to identify style and/or quality markers for sparkling rosé and red wines.	Preparation of materials for publication/dissemination describing the application of chemical and sensory analyses (including consumer preference mapping) to identify key markers of preference and quality for Australian sparkling rosé and red wines.
Sparkling rosé and red wines representative of different grape varieties, vintages, wine regions, production methods and price points will be sourced and chemically analysed (as above) to determine which factors most influence wine composition and to validate the style and quality markers identified above. The quality of commercial sparkling wines will be determined by an expert panel and correlated with compositional data using chemometric analysis.	Preparation of materials for publication/dissemination describing the compositional differences of sparkling rosé and red wines representative of different grape varieties, vintages, regions (climates), production methods and price points and evaluating the classification of sparkling wine style and quality using the objective measures identified above.

However, following analysis of market sales data sourced from AC Nielsen and in consultation with an industry reference group (comprising prominent Australian sparkling winemakers), the decision was made to focus on sparkling white wine and then Moscato, as the two most commercially significant segments of the sparkling wine market. As such, the project aims were to:

- characterise the relative importance of different sparkling wine styles (Year 1)
- employ a range of chemical and sensory analyses to profile the variation in composition, sensory properties and quality of sparkling white wines, including mapping trials to determine consumer preferences for different sparkling white wine styles (Years 1&2)
- employ a range of chemical and sensory analyses to profile the variation in composition, sensory properties and quality of Moscato wines, including mapping trials to determine consumer preferences for different styles of Moscato (Years 2&3)

Method:

Part A: Analysis of the Australian sparkling wine market.

Market sales data, comprising sparkling wine sales (by volume and value) for 2005 and 2012, were sourced from AC Neilsen. This enabled comparisons to be made regarding the relative importance of different segments of the sparkling wine market. Results were also compared with findings from an online survey which investigated the sparkling wine consumption behavior of 1,030 regular sparkling wine consumers (undertaken by Naomi Verdonk as part of her PhD research).

Part B: Objective measures of the style and quality of Australian sparkling white wine.

Sparkling white wines: A range of commercial sparkling white wines (n=50), comprising Méthode Traditionelle wines (n=20, priced $25 to $90), transfer wines (n=10, priced $10 to $31), Charmat wines (n=10, priced $8 to $23) and carbonated wines (n=10, priced $5 to $24) were sourced (either commercially or from industry), with input from an industry reference group comprising prominent Australian sparkling winemakers: Ed Carr, Accolade Wines; Teresa Heuzenroeder, Yalumba; Dan Buckle, Domaine Chandon; and Trina Smith, Treasury Wine Estates. The wines chosen were intended to reflect not only the four key methods of sparkling wine production, but also a range of price points, Australian wine regions and brands. With the exception of five carbonated wines, wines were made from the traditional varieties, i.e. Chardonnay, Pinot Noir and Pinot Meunier, or blends thereof. Wines were then subjected to various chemical and sensory analyses, to profile wine composition, sensory properties and quality.

Chemical analysis of sparkling white wines: Samples were degassed (using an ultrasonic bath) and basic chemical measurements, i.e. pH, titratable acidity (TA), residual sugar, alcohol and total phenolics, performed according to published methodology (Iland et al. 2004). pH and TA (as tartaric acid equivalents to an endpoint of pH 8.2) using a Crison CE95 Compact Titrator equipped with a Crison Sampler 15 autosampler (Crison Instruments, SA, Alella, Spain). Glucose and fructose (i.e. residual sugar) were measured enzymatically (Boehringer-Mannheim/R-BioPharm, Darmstadt, Germany) using a liquid handling robot (Corbett 3800) and spectrophotometric plate reader (Tecan M200 Infinite). Alcohol content (as % alcohol by volume) was measured with an alcolyzer (Anton Paar GmbH, Graz, Austria). Total phenolics was measured as the absorbance of wine at 280 nm, using either a GBC Cintra 40 or GBC Cintra 4040 UV-Visible spectrophotometer (GBC Scientific Equipment, Melbourne, Australia).

Protein and polysaccharide analyses were performed in collaboration with the Australian Wine Research Institute (AWRI). The composition and concentration of haze-forming proteins were

determined by high performance liquid chromatography (HPLC) according to a modified version of methodology described by Van Sluyter and colleagues (2009), using an Agielent 1260 UHPLC (Agilent Technologies, Santa Clara, USA). Polysaccharides (mannoproteins, arabinogalactans, and rhamnogalacturonans) were also measured by HPLC, using previously published methods (Bindon et al. 2013). Amino acid analyses were performed in collaboration with CSIRO. Amino acids were determined as fluorescent 6-aminoquinolyl-N-hydroxysuccinimidyl carbamate (AQC) derivatives, using AccQ-Fluor reagent kits (Waters, Tokyo, Japan) and HPLC. Foaming properties were measured in collaboration with the University of Melbourne. Foamability and foam stability were calculated from measurements of foam volume (V*f*) and foam lifetime (L*f*) performed using a robotic pourer and image analysis, according to methods described by Condé and colleagues (Condé et al. 2017). The volatile profiles of sparkling wines were determined by gas chromatography-mass spectrometry (GC-MS) using a 7890A gas chromatograph coupled to a 5975C inert XL mass selective detector (Agilent Technologies). Where appropriate, chemical data were analysed by one-way analysis of variance (ANOVA) using GenStat (15th Edition, VSN International Limited, Herts, UK). Mean comparisons were performed by least significant difference (LSD) multiple comparison test at $P< 0.05$.

Degassed sparkling white wine samples were also analysed by attenuated total reflection (ATR) mid-infrared (MIR) spectroscopy, using a Bruker Alpha instrument (Bruker Optics, GmbH, Ettingen, Germany), together with a selection of commercial sparkling rosé (n=25), sparkling red (n=25), Prosecco (n=14) and Moscato (n=25) wines, which were also sourced either from retail outlets or from industry. Spectral data were subjected to principal component analysis (PCA) and partial least squares (PLS) regression.

Sensory analysis of sparkling white wines: The quality of sparkling white wines was determined by an expert panel of 19 sparkling winemakers or wine show judges, using the 20 point scoring system employed in Australian wine show judging (Gawel and Godden, 2008); while the sensory profiles of sparkling wines were determined by descriptive analysis (DA, Lawless and Heymann, 2010), using a trained panel comprising 10 research staff and students. Sensory data was subjected to statistical analysis, i.e. an I-optimal computer-aided design of experiments algorithm, to identify a subset of sparkling white wines that best reflected the sensory diversity of all sparkling wines, for consumer testing. Initially seven wines were selected: two Méthode Traditionelle wines, three transfer wines, one Charmat wine and one carbonated wine. However, one of the transfer wines was excluded (based on limited production volume) in order to limit the acceptance testing to 6 wines so as to mitigate any risk of consumers losing interest and/or experiencing sensory fatigue (Lawless and Heymann, 1998, Hersleth et al. 2003, Lattey et al. 2007). One hundred and fifty consumers (of legal drinking age) were

recruited to participate in acceptance tests; with a higher proportion of females participating than males (60% vs 40%), which likely reflects the perception that sparkling wine is a female drink (Charters et al 2011). Consumers were first asked to complete a questionnaire designed to capture demographic information, as well as consumers' alcohol consumption, (including sparkling wine consumption) and wine involvement (Bruwer and Huang, 2012). The subset of sparkling white wines were then presented to consumers in random order and consumers were asked to rate their liking of each using 9 cm line scales (anchored from dislike extremely to like extremely). Consumer acceptance data were analysed using a combination of descriptive and multivariate techniques, including ANOVA (with post-hoc Tukey's test), PLSR and PCA. Segmentation (cluster analysis) was also performed on hedonic liking scores, to identify consumer clusters with distinct preferences for different styles of sparkling white wine.

Part C: Objective measures of the style and quality of Australian Moscato.

Moscato wines: A range of commercial Moscatos (n=24), comprising both sparkling (n=16) and semi-sparkling (n=8), and white (n=8) and pink (n=14) styles, were sourced (either commercially or from industry), with input from the industry reference group (as above) The wines chosen were intended to reflect a range of price points ($8 to $30), Australian wine regions and brands. Wines were then subjected to various chemical and sensory analyses, to profile wine composition, sensory properties and quality.

Chemical analysis of Moscato wines: Samples were degassed and basic chemical measurements performed, as for sparkling white wines. The volatile profiles of Moscatos were again determined by GC-MS.

Sensory analysis of Moscato wines: Moscato quality was again determined by an expert panel, this time comprising 9 sparkling winemakers. The sensory profiles of each Moscato were also determined by DA, using a trained panel comprising 10 research staff and students, and sensory data analysed by PCA. Sensory data was then subjected to I-optimal prime analysis, to identify the subset of Moscato wines that best reflected the sensory diversity of all Moscato wines, for consumer acceptance tests. One hundred and forty consumers (of legal drinking age) were recruited to participate in acceptance tests. Again, a considerably higher proportion of females participated than males (68% vs 32%).

Results and Discussion:

Part A: Analysis of the Australian sparkling wine market.

The Australian domestic sparkling wine market is quite diverse and comprises Moscato and white, rosé and red sparkling wine styles, as mono-varietals and blends, at various price points; as well as imported sparkling wines, including Champagne from France. Recent growth in domestic sparkling wine sales has largely been driven by Champagne and Moscato (Table 1). Indeed, Australia remains a significant importer of Champagne; with sales increasing from 8% in 2005 (worth AU$34 million) to 19% in 2012 (worth AU$102 million) (AC Nielsen Australia). Although Australian winemakers now produce sparkling wines which rival those from Champagne houses in France, the tradition, heritage and prestige associated with the Champagne brand infer superior product quality and reliability, and therefore represent less purchase risk to consumers (Charters 2009). This likely explains the continued growth in Champagne sales, which resulted in the decline observed in sparkling white, red and rosé wine sales between 2005 and 2015.

Table 1. Distribution of sparkling wine sales in Australia for different wine styles based on percentage of overall sales values of AU$444 million in 2005 and AU$545 million in 2012 (AC Nielsen Australia).

Wine style	Percentage share of sales (by value)	
	2005	2012
Champagne	8	19
Sparkling white wine	64	54
Sparkling rosé wine	9	7
Sparkling red wine	4	3
Moscato	0	8
Other	15	9

These results are similar to findings from a recent consumer survey, which investigated regular sparkling wine consumers' preferences for different sparkling wine styles. Sparkling white wine accounted for the lion share (i.e. 42%) of the 1030 participants' total sparkling wine consumption, followed by Moscato (18%) and then Champagne (14%). Sparkling red (12%), rosé (9%) and Prosecco (5%) were consumed less frequently.

The following paper was published in the Wine and Viticulture Journal in 2015 and presents the sparkling wine sales data (by value) for 2005 and 2012, demonstrating the relative importance of different segments of the sparkling wine market. The paper also presents preliminary results from: (i) the online survey (undertaken by Naomi Verdonk as part of her PhD research) which investigated the sparkling wine consumption and preferences of 1,030 regular Australian wine consumers; (ii) a consumer trial (undertaken by Melissa Lane as part of her Honours research) which investigated factors influencing consumer preferences for Australian sparkling wine vs. French Champagne; and (iii) an observational study which investigated sparkling wine consumers' purchasing behavior.

Verdonk, N.R., Culbert, J.A. and Wilkinson, K.L. (2015) All that sparkles: Consumer perceptions of sparkling wine. Wine and Viticulture Journal **30**, 71–73.

Part B: Objective measures of the style and quality of Australian sparkling white wine.

Classification of sparkling wine style and quality by MIR spectroscopy.

Classification of Sparkling Wine Style by MIR Spectroscopy

The ATR-MIR spectra of commercial sparkling wines showed moderate to strong absorbance peaks at 1045, 1085, 1640 and 3300 cm-1 (Figure 1); with peaks at 3300 and 1640 cm-1 corresponding to the O–H stretching and bending respectively, associated with water (Hashimoto and Kameoka, 2000, Patz et al. 2004). The MIR region between 1100 and 1000 cm-1 has previously been attributed to C–O vibrations of sugars, such as glucose and fructose, and alcohols, phenols, esters and lactones (Williams and Fleming, 1995). In particular, absorbance in the region of 1080 to 1045 cm-1 has been associated with C–OH bonds present in primary alcohols (e.g. ethanol), glycerol and sugars (glucose and fructose) (Cozzolino et al. 2009, 2011a, 2011b, Riovanto et al. 2011); i.e. compounds which are likely to be constituents of sparkling wine.

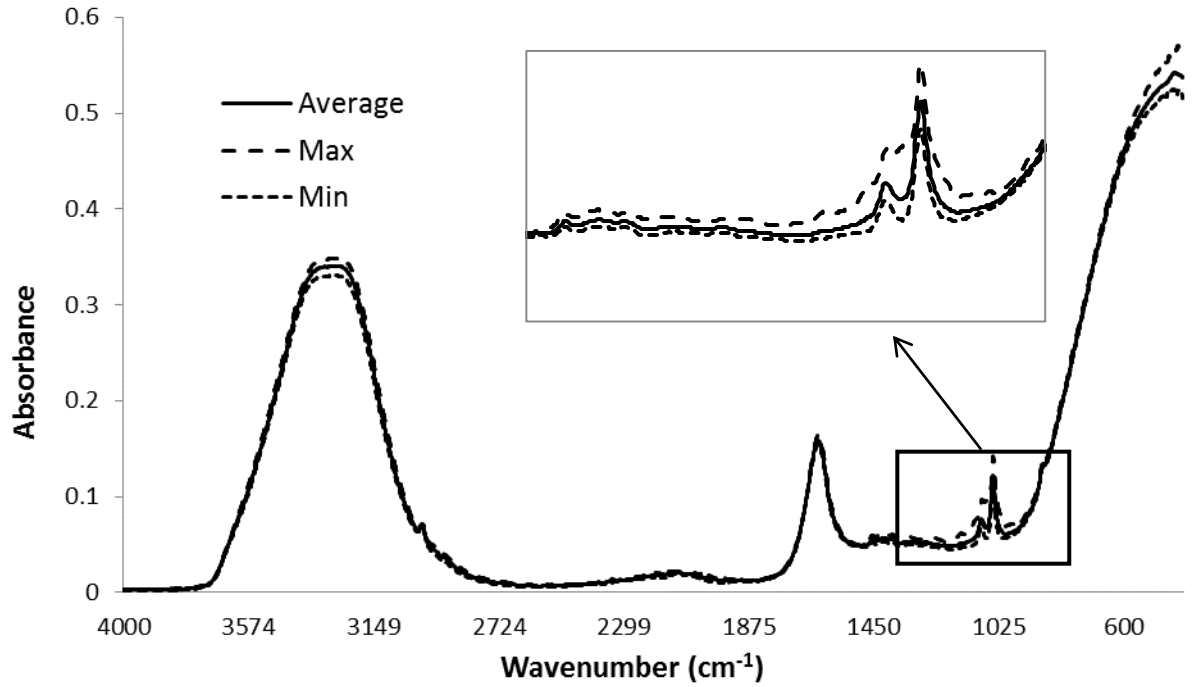


Figure 1. Mean, maximum and minimum ATR-MIR spectra (4000–400 cm-1) obtained from (degassed) sparkling wine samples (n = 139). Reproduced from Culbert et al. 2015.

A comparison of the minimum and maximum ATR-MIR spectra (Figure 1) obtained from the (degassed) sparkling wine samples indicated most of the variation observed amongst the samples occurred within the 'fingerprint' region; i.e. between 1500 and 900 cm-1. For grape and wine samples, this region is known to contain absorbance bands attributable to water, sugars and phenolic compounds (Shah et al. 2010), and results from stretching and/or bending of CH–OH, C–C, C–O and C–H bonds.

Multivariate analysis was therefore performed on the MIR 'fingerprint', given this region accounted for the most variation.

The PCA score plot of the first two principal components (PC) derived from the ATR-MIR 'fingerprint' spectra of all sparkling wine samples is shown in Figure 2. The first principal component (PC) explains 89% of the variation observed and resulted in clear separation of Moscato wines (lower left quadrant) from the other sparkling wine styles. Separation of sparkling red (lower right quadrant) and sparkling white, rosé and Prosecco wines (upper quadrants) was also observed. Several outliers were observed, i.e. individual wines that did not cluster with other wines of the same style, namely: three sparkling rosé wines and a sparkling red wine, that instead clustered amongst the Moscato wines; and two sparkling rosé wines that instead clustered together with the remaining sparkling red wines. A plausible explanation for these outliers is suggested below.

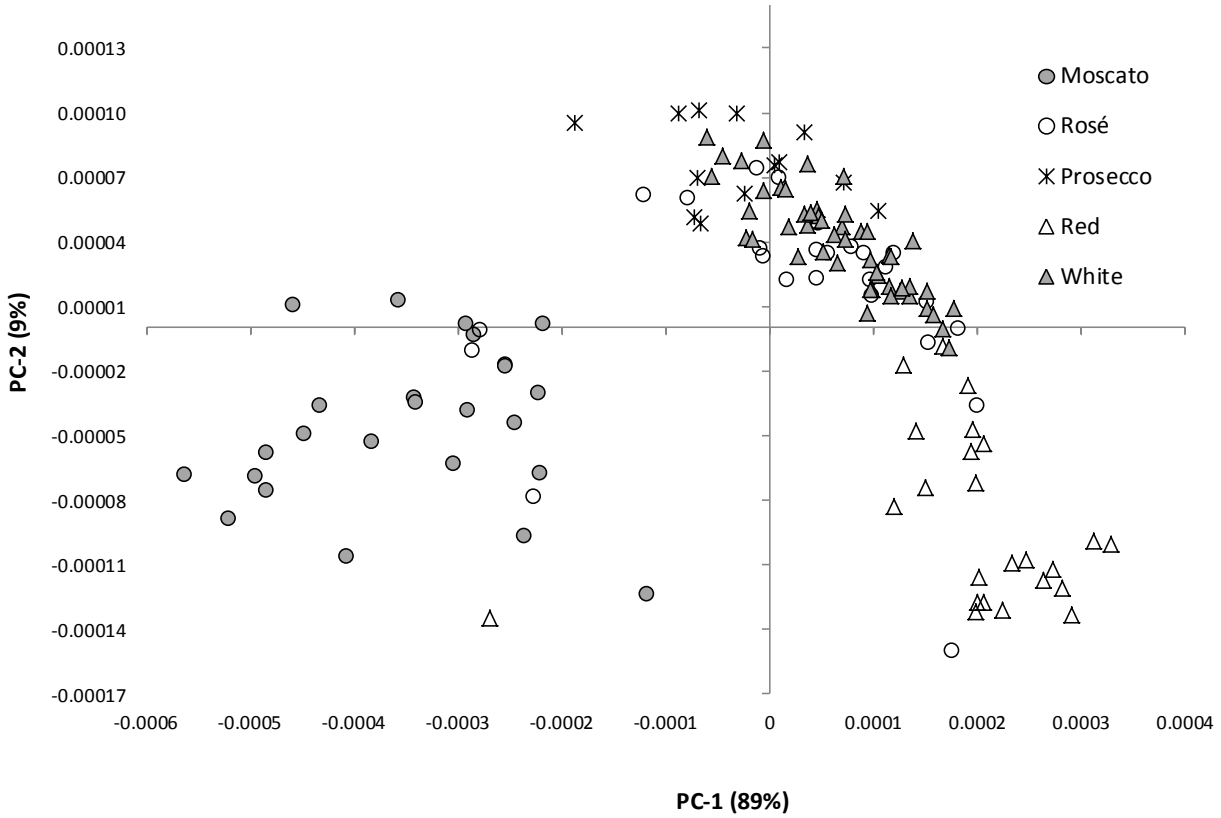


Figure 2. Score plot of the first two PC's derived from the MIR 'fingerprint' (1500–900 cm-1) of white, rosé, red, Prosecco and Moscato wines (n = 50, 25, 25, 14 and 25, respectively). Reproduced from Culbert et al. 2015.

The clustering pattern of sparkling wines likely reflects compositional differences that can be attributed to both varietal expression and wine style. In terms of grape variety: sparkling red wines largely comprised Shiraz (or blends thereof); sparkling white wines comprised the classic varieties, i.e. Chardonnay, Pinot Noir and/or Pinot Meunier; sparkling rosé wines were predominantly Pinot Noir (or

blends thereof); and Moscato comprised Muscat varieties. Analysis of several basic wine chemistry parameters, i.e. pH, titratable acidity (TA), residual sugar (RS), alcohol content and total phenolics (Table 2), demonstrated several large compositional differences between the various sparkling wine styles; primarily related to residual sugar, alcohol and phenolic content. As expected, Moscato wines had the highest residual sugar levels (91 g/L on average, compared with 10 to 30 g/L for the other sparkling wines) and the lowest alcohol levels (i.e. 7%, compared with 11 to 13%). Sparkling red wines typically had higher alcohol levels, and the highest total phenolics (due to the presence of grape skins during primary fermentation). To determine to what extent these constituents influenced wine clustering in the PCA score plot, the loadings for the first three PCs derived from the fingerprint region of sparkling wine MIR spectra were evaluated (Figure 3).

Table 2. Composition of the different styles of sparkling wine studied.

Sparkling Wine Style		**pH**	**TA (g/L)**	**RS (g/L)**	**Alcohol (% abv)**	**Total Phenolics (au)**
White (n=50)	range	3.0 -3.5	5.8 – 9.6	0.5 – 20.1	10.3 – 13.1	0.3 – 5.8
	mean	3.2	7.5	11.2	11.9	2.9
Rosé (n=25)	range	3.1 – 3.5	5.3 – 8.4	5.1 – 86.7	7.9 – 13.7	2.2 – 6.2
	mean	3.3	6.8	22.9	11.6	4.0
Red (n=25)	range	3.4 – 3.9	5.1 – 7.5	7.2 – 117.6	8.4 – 15.0	37.1 – 67.0
	mean	3.5	6.3	32.7	13.4	49.9
Prosecco (n=14)	range	2.9 – 3.5	5.6 – 7.8	0.4 – 22.4	9.2 – 12.2	0.0 – 3.3
	mean	3.2	6.4	10.6	11.0	0.9
Moscato (n=25)	range	3.0 – 3.5	4.9 – 9.0	57.9 – 143.1	5.1 – 9.9	0.8 – 15.5
	mean	3.2	6.7	90.5	7.4	4.6

The highest loadings for PC-1 were observed at 1069, 1040 and 1020 cm-1. As indicated above, absorbance in the region of 1080 to 1045 cm-1 is usually associated with the C–C and C–OH bonds of primary alcohols (e.g. ethanol), glycerol and sugars (Bevin et al. 2005, Cozzolino et al. 2009, 2011a, 2011b, Riovanto et al. 2011, Fudge et al. 2012). This suggests the variation observed between samples in the first principal component is largely explained by differences in residual sugar and alcohol content. For PC-2, which explained 9% of variation, the highest loadings were also in this region (i.e. at 1073 to 1008 cm-1). Less significant, but larger loadings were also observed for PC-2 within the 1500 to 1400 cm-1 region, which may be indicative of aromatic C–C stretching (Fudge et al. 2012) and/or absorbance by CO=O, C=C, C–H2 and C–H3 bonds from organic acids and aldehydes (Cozzolino et al. 2009, 2011a, Riovanto et al. 2011). PC-2 loadings were also observed at 1130 and

1150 cm-1, with the latter possibly being characteristic of pyranose sugars (Hashimoto and Kameoka, 2000). Therefore, in addition to sugar and alcohol, phenolics and organic acids may also have contributed to the clustering patterns of the different sparkling wines.

Consideration of the basic chemical parameters of individual sparkling wines also helped to explain the clustering of wines identified (above) as outliers. The three sparkling rosé wines and the sparkling red wine that clustered amongst the Moscato wines were found to contain high residual sugar levels; between 63 and 87 g/L, and 118 g/L, for the sparkling rosé and sparkling red wines, respectively. Of the two remaining sparkling rosé wines that were clustered amongst the sparkling red wines, one also had high residual sugar (i.e. 60 g/L), and both had unusually high alcohol levels (i.e. 13.4 and 13.7%). The residual sugar and/or alcohol content of these sparkling wines may therefore have more strongly influenced their clustering, than varietal expression. Collectively, these observations highlight the influence of sugar and alcohol on the positioning of individual sparkling wines on the PCA score plot.

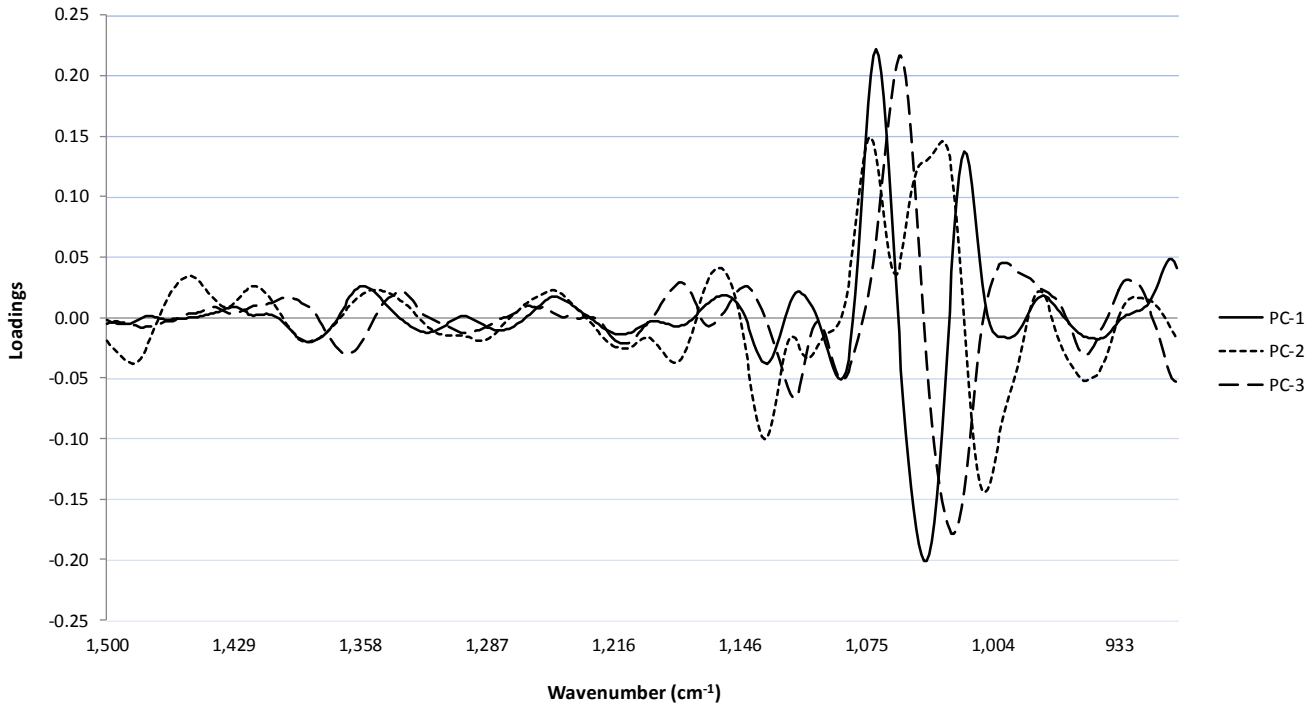


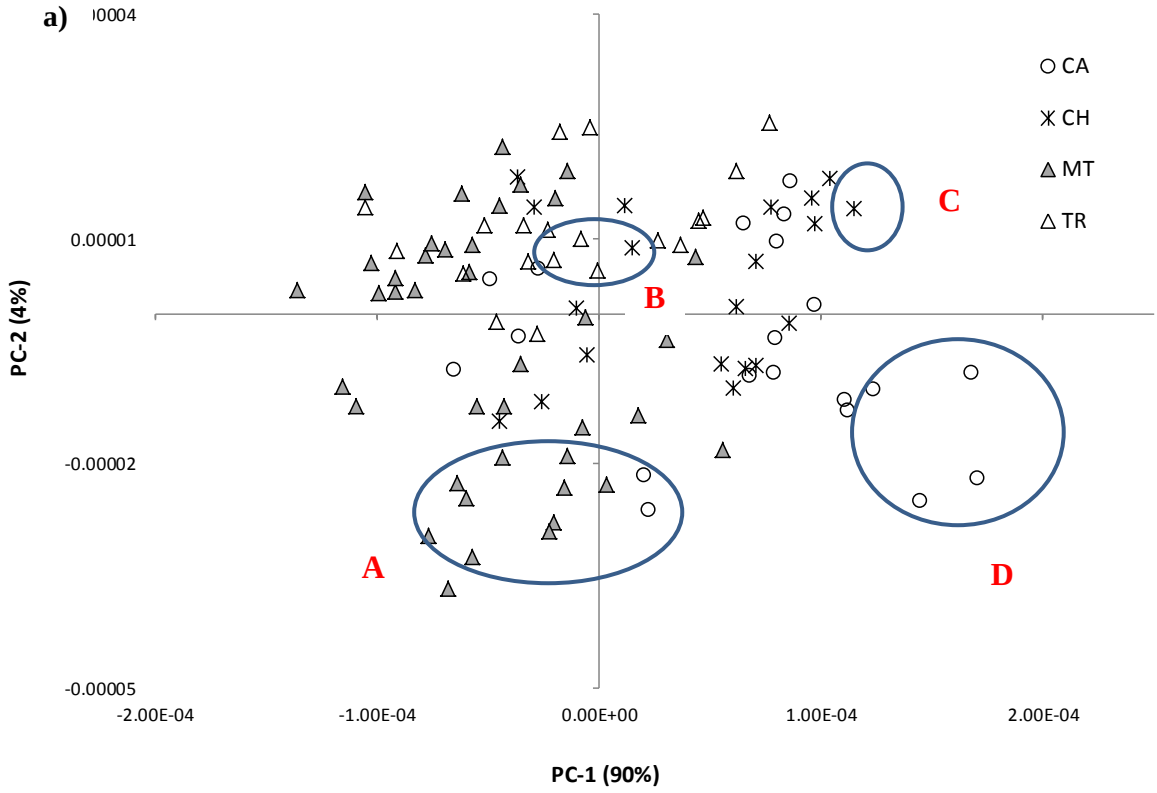
Figure 3. Loadings for the first three principal components for the fingerprint region derived from the MIR spectra of the sparkling wines. Reproduced from Culbert et al. 2015.

Classification of Sparkling White Wine Style and Quality by MIR Spectroscopy

In 2012, the sparkling white wine segment held the lion share of Australian sparkling wine sales, both by value (54%) and by volume (61%) (Neilsen Australia, 2012). Sparkling white wines can also exhibit diverse sensory properties, depending on their method of production, which in turn influences quality and price. As such, the potential for ATR-MIR combined with PCA to classify sparkling white

wines according to production method and/or quality was evaluated. Score plots displaying the first two PCs derived from the 'fingerprint' region of MIR spectra from 50 sparkling white wine samples (analysed in duplicate, from two wine replicates) labelled according to production method and quality scores are shown as Figures 4a and 4b, respectively.

Differences were observed in the PCA score plot of sparkling white wines by method of production (Figure 4a). Carbonated and Charmat sparkling wines mostly clustered in the quadrants on the right; while Transfer and Methodé Traditionelle sparkling wines mostly clustered in the quadrants on the left. However, two carbonated wines and three Charmat wines overlapped with Transfer and Methodé Traditionelle wines. Furthermore, while wine replicates (i.e. samples of the same wine, taken from different bottles) clustered closely together, they rarely overlapped, which indicates some bottle to bottle variation. The influence of production method on the style and sensory properties of sparkling wines is well established; carbonated and Charmat sparkling wines are typically fruit-driven styles, whereas Transfer and Methodé Traditionelle sparkling wines tend to exhibit complexity due to yeast autolysis and lees aging, post-secondary fermentation (Iland and Gago, 1997); albeit sensory analysis indicated some carbonated and Charmat wines exhibited complexity, while some Transfer and Methodé Traditionelle wines displayed overt fruit aroma and flavour (data not shown). This may explain the overlap of some carbonated and Charmat wines, with Transfer and Methodé Traditionelle wines, and vice-versa.



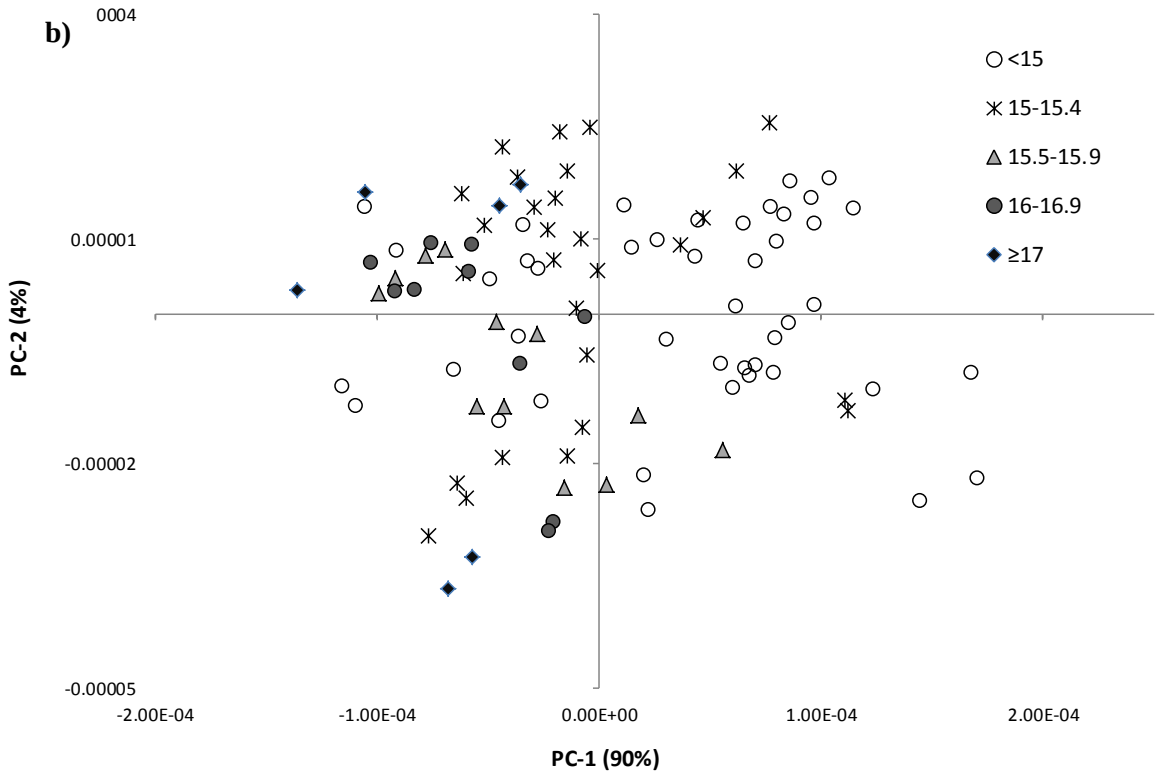


Figure 4. Score plots of the first two PC's derived from the 'fingerprint' region (1500–900 cm-1) of MIR spectra from (degassed) sparkling white wines, labelled by (a) production method, CA=carbonated (n=10), CH=Charmat (n=10), MT=Methodé Traditionelle (n=20) and TR=Transfer (n=10); and by (b) quality scores. Sparkling wines located within the circled regions designated as A, B, C and D have sensory profiles displayed in Figure 6. Reproduced from Culbert et al. 2015.

Classification of sparkling wines according to quality ratings was less evident, albeit a trend was observed (Figure 4b). With the exception of one wine, wines given a quality score of 15.5 or above (n=14) were located in the left-hand quadrants. However, within these quadrants there were also ten wines with ratings between 15 and 15.4 and six wines given ratings below 15. The remaining 20 wines (with quality scores of 15.4 or less), were located in the right-hand quadrants. The difficulty in classifying sparkling wines based on quality scores may reflect the subjective nature of assessing quality. Assessments which rely on individual's perceptions, even assessments by experts, i.e. winemakers or wine show judges, are inevitably less well calibrated than analytical instruments. Furthermore, wines themselves can be deceiving. For instance, one of the carbonated sparkling wines was produced from an aged base wine and it therefore exhibited an unusual level of complexity, which may have contributed to its high quality score. Conversely, one Methodé Traditionelle wine exhibited noticeable volatile acidity (VA) and consequently received an especially low quality score. Whilst VA is ordinarily considered a winemaking fault, in this case, it was an intended to be indicative of a deliberate house style.

Partial least square (PLS) regression models were developed in order to determine any relationship between sparkling wine sensory attributes and MIR spectral data. The sensory profiles of each sparkling white wine were determined by descriptive analysis. A trained panel rated the intensity of 27 attributes, including a range of fruit and yeast-derived aromas and/or flavours, as well as sweetness, acidity and complexity. Nine of these attributes gave coefficients of determination (i.e. R2) $\geq$ 0.50 (Table 3). The perception of sweetness gave the highest correlation, being R2=0.72; i.e. sweetness ratings explained 72% of the variation within the PLS regression model. Ratings of confection and tropical fruit (on the palate) explained more than 60% of variation in the models; while >50% of variation was explained by intensity ratings for tropical fruit, floral and confectionary aromas and meaty/savoury, toasty and floral flavours on the palate. Previous studies have suggested correlations between spectral data and sensory attribute scores might result from co-linearity of compositional variables such as ethanol or residual sugar, or between wavelengths or other sensory properties (Cozzolino et al. 2005, 2006). It was interesting to note that the highest correlations were observed for the sensory attributes rated on the palate, rather than on the nose (i.e. as aroma). Since most wine volatile compounds are present at low concentrations (i.e. ng/L to mg/L levels), they are less likely to influence MIR spectra than more abundant wine constituents. Furthermore, when sensory panellists rate the intensity of aroma attributes, they may be preferentially evaluating the more volatile aroma compounds, i.e. volatiles that are more abundant in the headspace of a wine glass. However, these volatiles may not be representative of a sample's entire composition (Cozzolino et al. 2006).

Table 3. Range, mean, standard deviation (SD) and cross validation statistics for sensory attributes in sparkling white wine samples analysed by ATR-MIR spectroscopy.

Sensory Attribute	Range	Mean	SD	R2	SECV	PLS Terms
Sweetness P	2.3 – 8.3	4.81	1.37	0.72	0.73	4
Confection P	1.6 – 7.2	3.57	1.27	0.63	0.77	4
Tropical Fruit P	4.3 – 9.4	6.27	1.30	0.61	0.82	4
Meaty/Savoury P	1.3 – 6.0	2.86	1.05	0.59	0.68	3
Toasty P	2.4 – 8.0	4.83	1.29	0.57	0.86	4
Tropical Fruit A	3.6 – 8.8	5.20	1.48	0.56	1.00	4
Floral P	3.2 – 7.7	4.72	1.07	0.51	0.76	4
Floral A	2.6 – 8.4	4.83	1.54	0.51	1.08	4
Confection A	1.6 – 7.2	3.43	1.27	0.50	0.91	4

A=aroma, P=palate; SECV=standard error of cross validation.

The loadings for optimal PLS1 calibrations for the five most highly correlated sensory attributes (i.e. sweetness P, confectionary P, tropical fruit P, meaty/savoury P and toasty P) are shown in Figure 5.

The PLS loadings for sweetness, confectionary and tropical fruit followed similar patterns, with the highest positive loadings at 1025 and 1100 cm-1; i.e. regions that had a large influence on the calibration models that were developed. As indicated above, these regions correspond to vibrational frequencies associated with the C–C and C–OH bonds of primary alcohols, glycerol and sugars (Bevin et al. 2006, Cozzolino et al. 2009, 2011a, 2011b, Riovanto et al. 2011, Fudge et al. 2012). Since the perception of sweetness is strongly influenced by both sugar and alcohol content, it is not surprisingly that regions corresponding to these compounds showed the greatest influence in the model. While the loadings for these three sensory attributes followed a similar pattern, there were differences in the size of loadings for some regions. For instance, the model for tropical fruit had less influence at 1025 cm-1 but more influence at 1100 cm-1, compared to the other two attributes. Furthermore, sweetness had higher positive loadings at 912 and 934 cm-1; regions associated with alkene and aromatic C–H vibrational frequencies (Williams and Fleming, 1995). There was also some variation in the region between 1420 and 1380 cm-1, which may be associated with stretching of C–H bonds from polysaccharides. Interestingly, the loadings for the toasty attribute had an inverse relationship to sweetness, confectionary and tropical fruit. Therefore, the wine constituents that contributed positively to the models for sweetness, confectionary and tropical fruit had a negative influence on the model for toasty. This suggests that the toasty model is driven by different wine constituents, particularly those corresponding to bonds with vibrational frequencies at 1060 and 1136 cm-1. Furthermore, the toasty attribute had positive loadings in the region of 1500–1400 cm-1, which could be related to volatile phenols, such as guaiacol and 4-methylguaiacol, which can impart smoky characters to wine (Fudge et al. 2012). However, this region has less influence in the model, as the loadings were relatively small. The meaty/savoury and toasty attributes are indicative of yeast autolysis or lees aging, whereas the 'fresher' characters of sweetness, confectionary and tropical fruit are likely to be grape or fermentation derived. It is therefore not surprising that the fresh characters appear to be driven by similar wine constituents.

To further investigate the relationship between sparkling wine sensory attributes and MIR spectra, comparisons were made between the sensory profiles of selected sparkling wines that were clustered closely together; i.e. those circled in regions designated as A, B, C and D in Figure 4a. The sensory profiles of Methodé Traditionelle (n=6), Transfer (n=3), Charmat (n=2) and carbonated (n=3) sparkling wines are shown in Figures 6a–d, respectively. For simplification, only sensory attributes which gave good correlations in the PLS regression models were included. Furthermore, the carbonated sparkling wine located within circled region B was excluded. In general, wines that clustered together in the PCA score plot (Figure 4a) were found to exhibit similar sensory profiles.

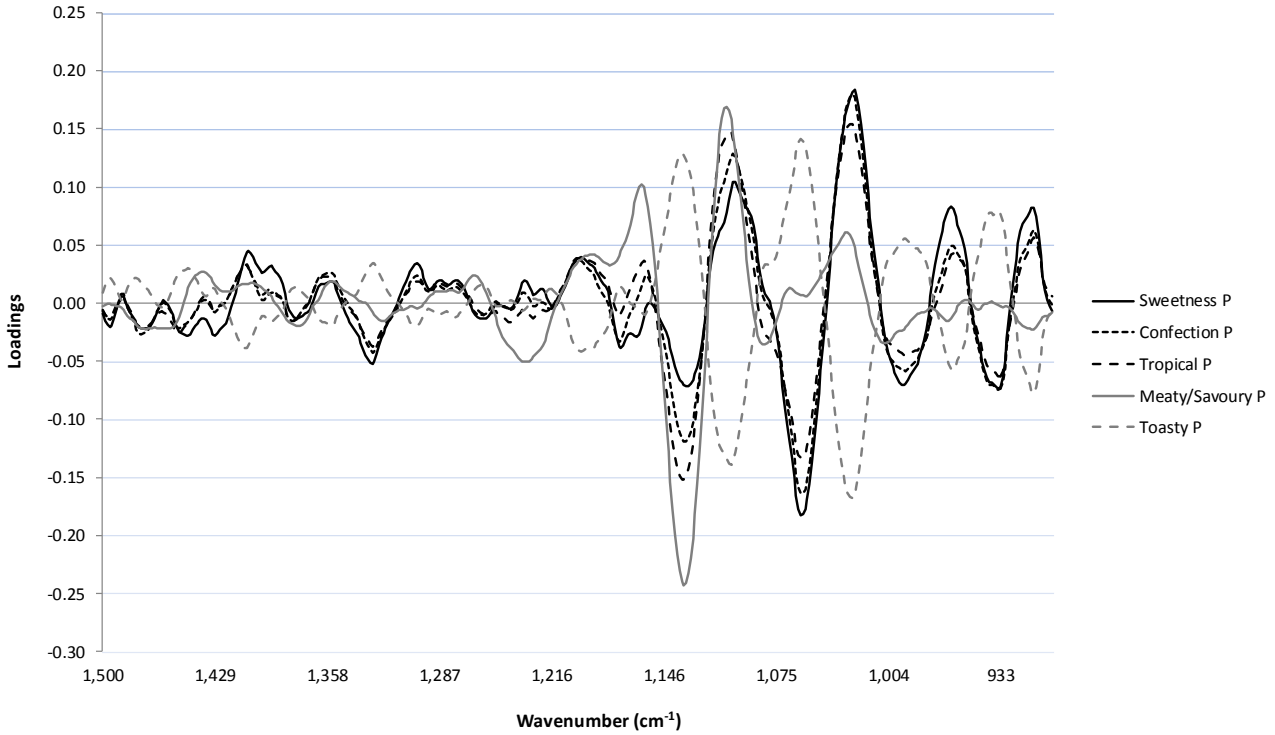


Figure 5. PLSR coefficients derived from analysis of the MIR fingerprint spectra (1500-900 cm-1) against the top five correlated sensory attributes (sweetness P, confection P, tropical P, meaty/savoury P and toasty P) for the sparkling white wines (P denotes palate). Reproduced from Culbert et al. 2015.

This was particularly evident for Methodé Traditionelle, Transfer and Charmat sparkling wines, but less so for carbonated sparkling wines, which exhibited the most style variation. The Methodé Traditionelle and Transfer wines exhibited considerable complexity, characterised by meaty/savoury and toasty characters, which typically result from yeast autolysis and lees-aging post-secondary fermentation. In some cases, sparkling wines are deliberately aged on yeast lees to enhance wine complexity and texture (Iland and Gago, 1997). For example, production of MT17 involved >6 years lees aging; this almost certainly contributed to the high ratings of toasty and complexity on the palate (Figure 6a). In contrast, carbonated and Charmat sparkling wines predominantly exhibited fruit characters (Figures 6c and d). The sensory profile of CA09 was more representative of the carbonated sparkling wines studied; whereas CA06 and CA08 displayed unusually high complexity, due to extended ageing of their base wine. Although these three carbonated wines were clustered together on the PCA score plot (Figure 4a), their sensory profiles were less similar, suggesting different wine constituents influenced the MIR spectra and sensory properties. Since the PLS loadings suggested sugar and alcohol content both impacted the MIR spectra of sparkling wines, the sugar and alcohol concentrations of the wines depicted in Figure 6 were compared (Table 4) and clustering did indeed appear to be based on sugar and alcohol content. The Transfer sparkling wines (upper left quadrant) were high in both sugar and alcohol; Methodé Traditionelle sparkling wines (lower left quadrant) were low in sugar but higher in alcohol; Charmat sparkling wines (upper right quadrant) were high in sugar,

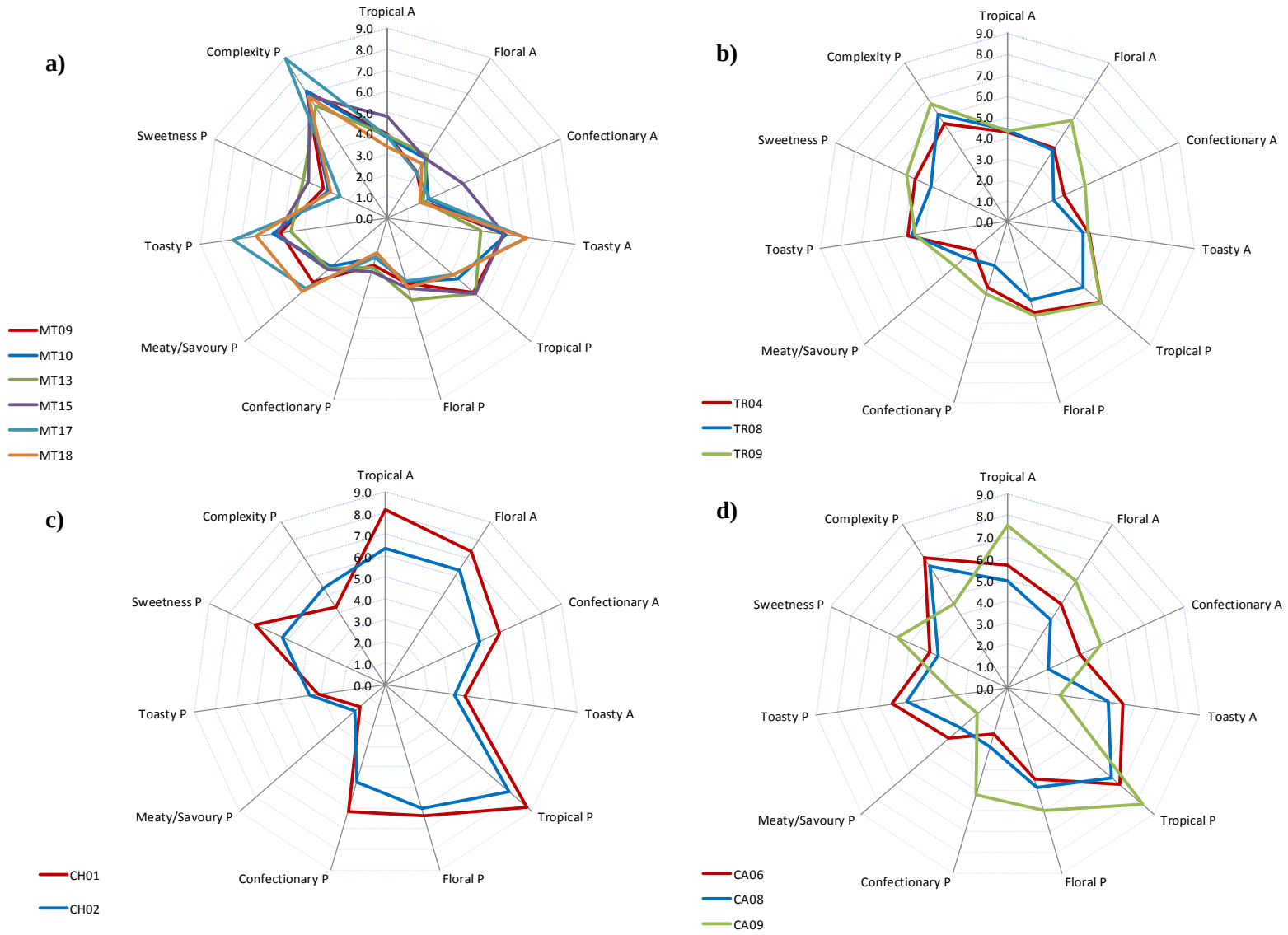


Figure 6. Sensory profiles of (a) Methodé Traditionelle (n=6) (b) Transfer (n=3) (c) Charmat (n=2) and (d) carbonated (n=3) sparkling wines that clustered in the circled regions A, B, C and D respectively, on the PCA score plot displayed as Figure 4a. Reproduced from Culbert et al. 2015.

but lower in alcohol; carbonated sparkling wines (lower right quadrant) were low in sugar and alcohol.

The first PC therefore appears to be differentiating wines according to alcohol content, while the second PC gives separation based on sugar content. A similar trend was observed when the sugar and alcohol content of all sparkling wines was considered; on average: wines located within the upper left quadrant (n=17) had 11.7 g/L of RS and 12.5% abv; wines within the upper right quadrant (n=12) had 13.7 g/L of RS and 11.2% abv; wine from the lower left quadrant (n=13 wines) had 8.2 g/L of RS and 12.1% abv; and wines situated in the lower right quadrant (n=8) had 11.3 g/L of RS and 11.2% abv.

Table 4. Mean sugar and alcohol concentrations for those wines located in the circled regions A, B, C and D located in each of the quadrants in the PCA score plot (Figure 4a).

Upper left quadrant	**Upper right quadrant**
Transfer (n=3)	Charmat (n=2)
RS = 12.2 g/L	RS = 17.3 g/L
Alcohol = 11.8% (abv)	Alcohol = 11.2% (abv)
Lower left quadrant	**Lower right quadrant**
Méthode Traditionelle (n=6)	Carbonated (n=2)
RS = 6.2 g/L	RS = 9.0 g/L
Alcohol = 11.9% (abv)	Alcohol = 10.5% (abv)

RS = residual sugar; abv = alcohol by volume

In conclusion, this study demonstrated the capacity for ATR-MIR spectroscopy (combined with multivariate analysis) to broadly classify sparkling wines according to both style and production method. The results demonstrated qualitative compositional differences between wines that can be observed by MIR spectroscopy and used to distinguish wines, following PCA. Interestingly, discrimination was strongly influenced by the sugar and alcohol content of wines; i.e. two of the more abundant wine constituents. However, some similarities in wine sensory profiles were also observed for wines that were closely clustered based on the 'fingerprint' region of their MIR spectra. ATR-MIR could therefore be used as a rapid method of screening large numbers of sparkling wines, so as to inform selection of a subset of wines for more detailed compositional and/or sensory analysis, by gas chromatography-mass spectrometry or descriptive analysis, for example.

Results from this study were published in Molecules in 2015: Culbert, J.A., Cozzolino, D., Ristic, R. and Wilkinson, K.L. (2015) Classification of sparkling wine style and quality by MIR spectroscopy. Molecules **20**, 8341–8356.

Influence of production method on the sensory profiles and consumer acceptance of different styles of Australian sparkling white wine.

Composition, bottle price and quality of sparkling white wines

Fifty Australian sparkling white wines produced via the four key production methods (carbonation, Charmat, transfer and Méthode Traditionelle) were sourced (either commercially or from industry) and a range of chemical and sensory analyses performed to: (i) characterise the sensory diversity amongst different styles of Australian sparkling white wine; and (ii) to facilitate selection of a subset of wines representative of that diversity, for consumer acceptance trials. The fifty sparkling white wines studied were chosen to reflect a range of price points, i.e. $7 to $90, Australian wine regions, and brands prominent in the domestic sparkling white wine market.

Table 5. Composition, price and quality of Australian sparkling white wines, by method of production.

		pH	**TA (g/L)**	**Residual sugar (g/L)**	**Alcohol (% abv)**	**Total phenolics (au)**	**Price (AUD)**	**Quality ratings (/20)**
Méthode Traditionelle (n=20)	range	2.9 – 3.4	6.4 – 9.6	0.5 – 13.1	11.2 – 13.0	0.3 – 4.9	$25 – $90	13.9 – 17.4
	mean	3.2	8.0	8.8	12.3	2.2	$43	15.8
Transfer (n=10)	range	3.1 – 3.5	5.8 – 7.6	3.9 – 15.8	11.0 – 13.1	0.9 – 4.3	$10 – $31	14.1 – 15.6
	mean	3.2	6.9	12.0	12.0	2.4	$23	15.0
Charmat (n=10)	range	3.2 – 3.5	6.1 – 7.4	8.5 – 19.0	11.0 – 12.2	0.5 – 4.5	$8 – $23	14.4 – 15.2
	mean	3.3	6.8	14.0	11.6	2.9	$15	14.7
Carbonation (n=10)	range	3.1 – 3.4	6.4 – 9.2	7.9 – 13.5	10.3 – 12.5	2.5 – 5.8	$5 – $24	14.1 – 15.2
	mean	3.3	7.6	12.4	11.1	4.7	$10	14.6

TA measured as g/L of tartaric acid.
Quality ratings determined by an expert panel (n=19) using a 20 point scoring system.

The pH, TA, residual sugar, alcohol and total phenolics of sparkling wines are reported in Table 5 (by production method). Variation was observed in the composition of sparkling wines produced via the same production method, but trends were also observed between wines made via different methods of production. Méthode Traditionelle wines generally had higher TA and alcohol levels, but lower residual sugar and total phenolics content. Charmat and carbonated wines tended to have higher residual sugar levels and were lowest in alcohol content and highest in total phenolics. Carbonated wines had substantially higher phenolic content than other sparkling wines, which may reflect inclusion of higher press fractions of juice during base wine production. As expected, Méthode Traditionelle wines were also the most expensive, ranging in price from $29 to $90 per bottle (and $43

per bottle, on average); average bottle prices for transfer, Charmat and carbonated wines followed market hierarchy, being $23, $15 and $10, respectively (Table 5). Wine quality was determined by an expert panel of sparkling winemakers and wine show judges, using the 20 point scoring system employed in Australian wine show judging. Average quality ratings again reflected market hierarchy, being 15.8, 15.0, 14.7 and 14.6 for Méthode Traditionelle, transfer, Charmat and carbonated wines respectively (Table 5). The majority of Méthode Traditionelle wines (i.e. 18 of 20) were rated > 15.0, the exceptions being two wines, MT01 and MT08 (rated 13.9 and 14.6 respectively), which exhibited aldehydic notes that some winemakers considered a fault (data not shown). Expert panellists indicated they rated wines according to: the size and persistence of the bead (bubble); the elegance of palate structure and prominence of complexity (i.e. presence of developed characters derived from yeast autolysis and ageing); the balance of sweetness, acidity and phenolics; and the absence of faults or imbalance (data not shown). PLSR analysis of quality ratings and DA data confirmed sensory attributes associated with yeast autolysis and aging, i.e. complexity, were positively correlated with quality ratings (Figure 7).

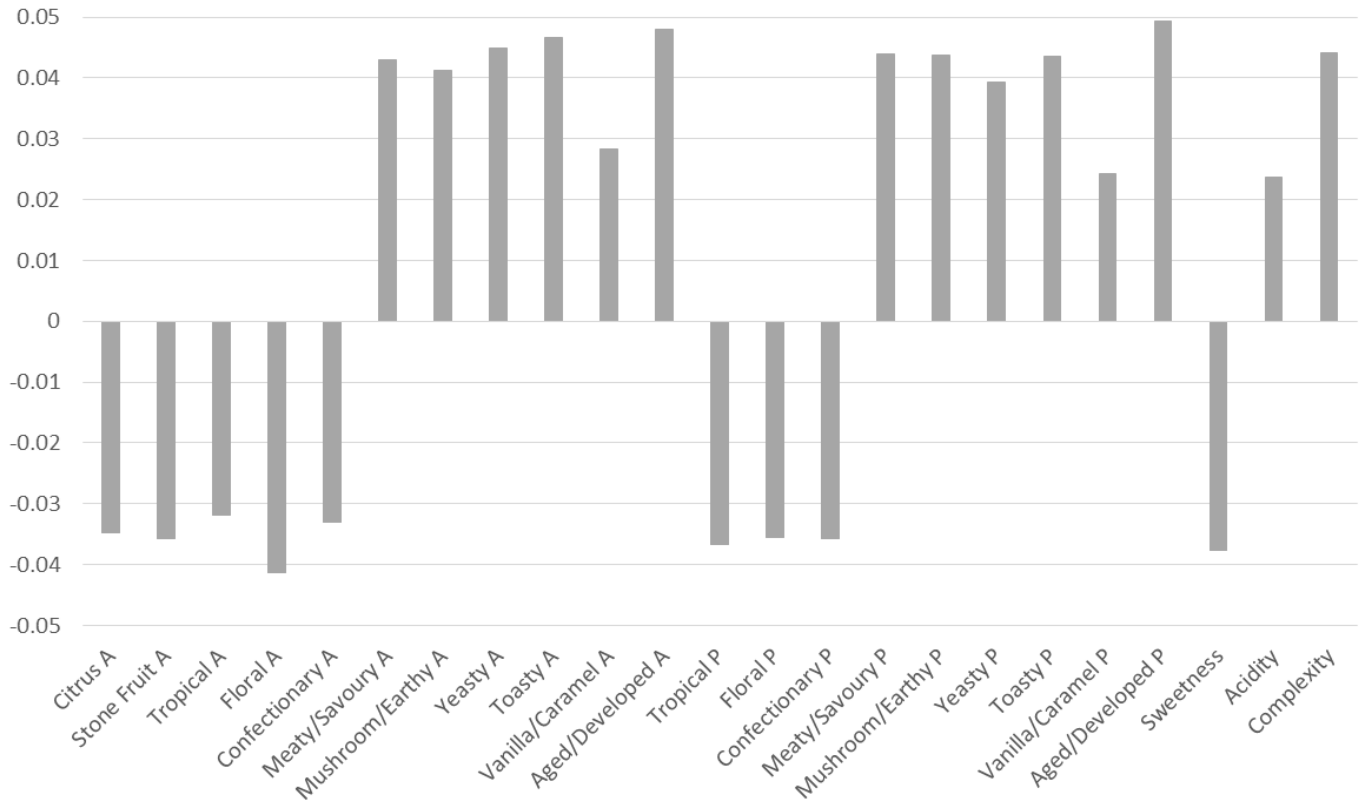


Figure 7. PLSR of quality ratings vs. selected sensory attributes of Australian sparkling white wines. Reproduced from Culbert et al. 2017a. Copyright 2017 Australian Society of Viticulture and Oenology Inc.

Sensory profiles of Australian sparkling white wines

The sensory profiles of sparkling wines were determined by descriptive analysis (DA), with the intensity of 24 aroma and/or flavour attributes being formally evaluated, as well as sweetness, acidity and complexity (Table 6). The DA panel attempted, but was unable to reproducibly assess effervescence, which was attributed to changes in effervescence due to carbon dioxide loss over time, similar to that reported previously (Hood White and Heymann 2015).

Table 6. Attributes used in descriptive analysis of Australian sparkling white wines.

Attribute	Definitions
Citrus	lemon, grapefruit, lime, orange, mandarin
Stone Fruit	apricot, nectarine, peach, white peach
Tropical	pineapple, melon, lychee, banana, passionfruit
Pome Fruit	apple, pear
Floral	rose, perfume, blossom, honeysuckle
Confectionary	turkish delight, bubble gum, musk, sherbet, strawberries and cream
Yeasty	Dough
Toasty	biscuit, bread, brioche, buttery, popcorn
Meaty/Savoury	savoury, meaty, vegemite, soy
Mushroom/Earthy	mushroom, earthy
Honey	Honey
Vanilla/Caramel	vanilla, caramel, coconut, spice/clove
Aged/Developed	nutty, kerosene, developed, Muscat/port, acetaldehyde
Sweetness	intensity of sweetness perceived
Acidity	intensity of acidity perceived
Complexity	intensity of complex yeast-derived attributes
Effervescence	overall perception of bubble size and flow

Sensory data obtained for each sparkling white wine was subjected to principal component analysis (PCA), which gave the biplot shown in Figure 8. The first principal component explained 60% of variation and separated wines based on the prominence of fruit vs. yeast-derived sensory attributes. Méthode Traditionelle and transfer wines exhibited varying degrees of complexity, i.e. toasty, meaty/savoury, yeasty, aged/developed characters. As such, the majority of these wines were located in the quadrants on the right hand side of the biplot; the exceptions, being MT01, Tr02, Tr03, Tr04 and Tr09, were located just left of the y axis, indicative of sensory profiles that comprised a combination of both fruit and yeast-derived sensory attributes. Sparkling wines that were aged on lees for extended periods of time (≥ 6 years), i.e. MT06, MT17 and MT19, clustered together and exhibited more intense aged/developed and vanilla/caramel character, but less acidity. In contrast, carbonated and Charmat wines predominantly exhibited fruit (tropical, stone fruit and pome fruit), floral and confectionery

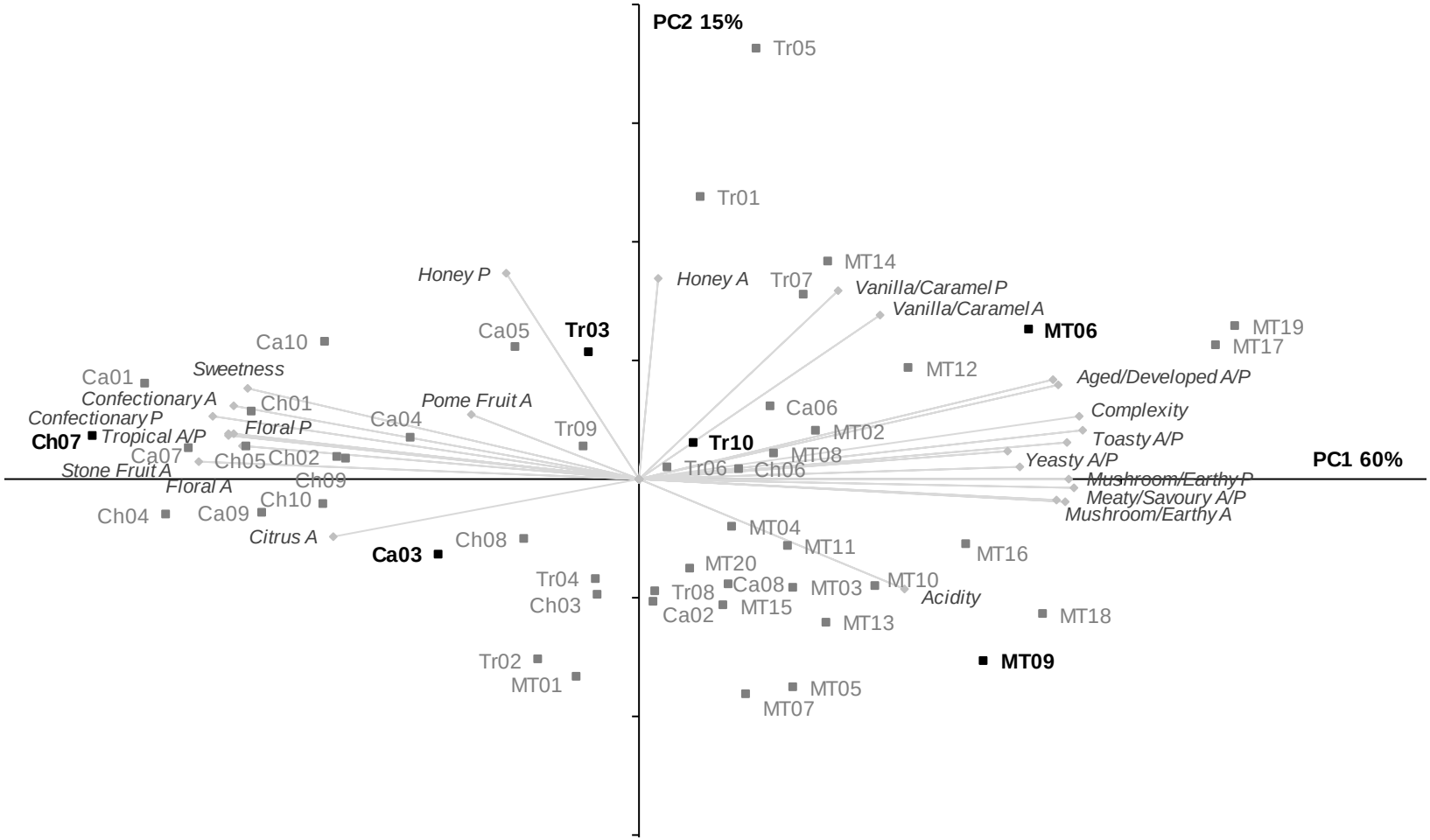


Figure 8. PCA biplot of sensory attribute ratings of Australian sparkling white wines. Ca = carbonated wines, Ch = Charmat wines, Tr = transfer wines, MT = Méthode Traditionelle wines; A = aroma attribute and P = palate attribute. Reproduced from Culbert et al. 2017a. Copyright 2017 Australian Society of Viticulture and Oenology Inc.

characters and perceptible sweetness, and these wines tended to cluster on the left hand side of the biplot (Figure 8). However, there were a few notable exceptions; several carbonated and Charmat wines (Ca02, Ca06, Ca08 and Ch06) were found amongst the Méthode Traditionelle and transfer wines, i.e. on the right hand side of the biplot. In the case of Ca06, which displayed unusually high complexity, this likely reflects extended ageing of base wine prior to carbonation. The distribution of quality scores generally followed a similar pattern, with wines positioned in quadrants on the right typically given higher quality ratings than wines positioned in quadrants on the left. Indeed, the seven wines considered to be of highest quality, i.e. MT06, MT12, MT14, MT16, MT17, MT18 and MT19 (for which quality ratings were $\geq$ 16.2), were those most closely associated with the developed characters and complexity that the expert panel deemed indicative of sparkling wine quality. The quality ratings of the carbonated and Charmat wines that clustered amongst the Méthode Traditionelle and transfer wines ranged from 14.6 to 15.2, i.e. scores greater than or equal to the mean quality scores attributed to carbonated and Charmat wines (Table 5). The second principal component explained a further 15% of variation and separated wines based on the intensity of honey and vanilla/caramel aromas and flavours vs. acidity.

Consumer acceptance of different styles of Australian sparkling white wine

Statistical analysis (I-optimal prime) was performed on sensory data in order to identify a subset of sparkling wines, representative of the sensory diversity of all wines, to be evaluated in subsequent consumer acceptance trials. Initially, seven wines were selected: two Méthode Traditionelle wines (MT06 and MT09), three transfer wines (Tr03, Tr05 and Tr10), a Charmat wine (Ch07) and a carbonated wine (Ca03); but the decision was made to preclude Tr05, to mitigate the risk of sensory fatigue (Hersleth et al. 2003, Lattey et al. 2007, Lawless and Heymann, 1998). The final subset of six wines (shown in bold in Figure 8 and Supp. Table 1) ranged in price from $7 to $70 according to production method, but also varied in composition, sensory profiles and quality (Table 7, Figure 8, Supp. Table 2). MT06 and MT09 were highest in TA and lowest in residual sugar, compared to the other samples, but their alcohol and total phenolics levels differed. These wines were also considered to be of highest quality; the increased bottle price and quality rating commanded by MT06 is attributable to its extended period of lees ageing (i.e. 8 years). Of the subset of sparkling wines, Tr03 had the lowest TA and highest alcohol content. Tr10 had similar TA and residual sugar compared to Tr03, but much higher total phenolics (2.4 vs. 0.9 au). The Charmat wine (Ch07) was highest in residual sugar and lowest in TA; DA confirmed Ch07 to be a perceptibly sweet and fruit-dominant style. The carbonated wine (Ca03) contained the highest total phenolics and lowest alcohol content. Of the subset of wines, Ca03 was deemed to be of lowest quality (i.e. 14.4/20). Collectively these results demonstrate the subset of sparkling white wines selected for consumer acceptance trials comprised different compositions and sensory profiles, and therefore levels of quality, as intended.

Table 7. Composition, price and quality ratings of the subset of Australian sparkling white wines.

	pH	TA (g/L)	Residual sugar (g/L)	Alcohol (% abv)	Total phenolics (au)	Price (AUD)	Quality ratings (/20)
MT06	3.2b	8.6	9.5c	12.7b	2.5b	$70	16.6a
MT09	3.3ab	8.5	4.6c	12.0c	0.3c	$41	15.6b
Tr03	3.2ab	7.6	10.5abc	13.1a	0.9c	$23	14.8bc
Tr10	3.2ab	7.9	13.3ab	12.7b	2.4b	$26	15.3bc
Ch07	3.3ab	7.8	17.3a	11.9c	2.0b	$10	14.6c
Ca03	3.4a	8.4	11.6ab	11.1d	4.1a	$7	14.4c

TA measured as g/L of tartaric acid. With the exception of price and quality rating, values are means of 3 replicates.Quality ratings determined by an expert panel (n=19) using a 20 point scoring system. Means within a column followed by different letters are significantly different (P = 0.05).

Table 8. Demographics, sparkling wine consumption and involvement of consumers.

	Total sample (n=150)	Cluster 1 (n=37)	Cluster 2 (n=34)	Cluster 3 (n=47)	Cluster 4 (n=32)
Gender					
Male	39.3	35.1	35.3	42.6	43.8
Female	60.7	64.9	64.7	57.4	56.2
Age (years)					
18-34	39.5	35.1	50.0	38.6	34.4
35-54	36.0	43.3	23.5	40.9	34.4
55+	24.5	21.6	26.5	20.5	31.2
Education					
High school/certificate/diploma	40.7	37.8	35.3	40.4	50.0
Bachelor's degree	35.3	43.3	41.2	31.9	25.0
Postgraduate	24.0	18.9	23.5	27.7	25.0
Household income (AUD)					
<$30,000	12.8	18.9	15.1	10.9	6.2
$30,001-$50,000	17.6	27.1	15.1	6.5	25.0
$50,001-$75,000	15.5	16.2	18.2	15.2	12.5
$75,001-$100,000	17.6	16.2	9.1	30.4	9.4
$100,001-$200,000	28.4	18.9	36.4	26.1	34.4
>$200,000+	8.1	2.7	6.1	10.9	12.5
Sparkling wine consumption					
Low (< once every 2 months)	43.3	46.0	35.3	49.0	40.6
Medium (once every 1-2 months)	38.0	35.1	44.1	34.0	40.6
High (once a fortnight or more)	18.7	18.9	20.6	17.0	18.8
Wine involvement[a]					
Low (<4.0)	30.0	40.5	14.7	38.3	21.9
High (≥4.0)	70.0	59.5	85.3	61.7	78.1

Values represent percentage of consumers.

[a] Involvement determined using the wine involvement scale (Bruwer and Huang, 2012), with low < 4.0/7 and high ≥ 4.0/7.

One hundred and fifty consumers were recruited to participate in acceptance tests (Table 8). A higher proportion of females participated than males (60% vs. 40%) which may reflect a gender-based interest (and/or preference) in sparkling wine, as has previously been suggested (Bruwer et al. 2011, Verdonk et al. 2017). Consumers were distributed relatively evenly across the different age groups, almost 60% held tertiary qualifications and approximately a third had household incomes >$100,000 per annum. Most participants consumed sparkling wine at least once every 1-2 months (57%), and were highly involved with wine (70%).

Table 9. Consumer liking scores for subset of Australian sparkling white wines.

	Hedonic ratings[a]				
	Total sample (n=150)	**Cluster 1 (n=37)**	**Cluster 2 (n=34)**	**Cluster 3 (n=47)**	**Cluster 4 (n=32)**
MT06	4.4bc	5.2a	2.0c	5.4a	4.8bc
MT09	4.1c	2.9c	3.3b	3.9d	6.5a
Tr03	4.4bc	2.9c	5.2a	4.8bc	4.5bcd
Tr10	4.5b	5.9a	4.8a	2.8e	5.2b
Ch07	5.1a	5.5a	5.0a	5.6a	4.2cd
Ca03	4.5b	4.3b	5.2a	4.4cd	3.9d

Means within a column followed by different letters are significantly different ($P = 0.05$).
[a] Hedonic ratings determined using a 9 cm line scale, with anchors from left (dislike extremely) to right (like extremely).

Significant differences were observed between the liking scores given to the subset of sparkling wines, which ranged from 4.1 to 5.1 (Table 9). On average, the Charmat wine (Ch07) was liked the most, while MT09 was liked least; although there was no significant difference between liking scores for Tr03, MT06 and MT09. The influence of factors such as gender, age, frequency of sparkling wine consumption and wine involvement were all considered, but very few significant differences were observed (Supp. Table 3). The Charmat wine remained the most liked sparkling wine, irrespective of consumer age, consumption frequency or wine involvement; while older consumers tended to like sparkling wines, Méthode Traditionelle and transfer wines in particular, more than younger consumers (although liking scores were not statistically significant). Similarly, consumers who indicated they consumed sparkling wine regularly (i.e. at least once a fortnight) tended to like sparkling wines more than other consumers. Previous research has shown that consumer preferences for wine, including sparkling wine and Champagne, can vary considerably (Lange et al. 2002, Combris et al. 2006, Vignes and Gergaud 2007, Culbert et al. 2016), so cluster analysis was employed to differentiate consumers based on their individual liking scores. Four distinct clusters comprising consumers with different preferences for the subset of sparkling wines were identified (Tables 8 and 9). Cluster 1 comprised 37 consumers who liked MT06, Tr10 and Ch07, but disliked MT09 and Tr03. Cluster 2 (n=34) comprised

the highest proportion (85%) of highly involved consumers, yet surprisingly, these consumers disliked Méthode Traditionelle wines, in favour of less complex sparkling wines. Cluster 3 (n=47) comprised consumers who most liked MT06 and Ch07, but disliked Tr10; while Cluster 4 consumers (n=32) liked MT09 the most and Ca03 the least. It could be hypothesised that younger consumers, particularly those with lower disposable incomes, might be more familiar with the lower priced, fruit-driven carbonated and Charmat wines, than with the more expensive, and complex, transfer and Méthode Traditionelle wines. Conversely, older consumers, particularly those with higher disposable incomes could reasonably be expected to afford, and therefore, more frequently consume, higher priced sparkling wines. Thus, familiarity with different wine styles (i.e. fruit-driven vs. complex) might influence sparkling wine preferences. To some extent, Cluster 2 represents younger consumers who tend to prefer the more fruit-driven styles, while Cluster 4 represents older consumers who tend to like sparkling wines which exhibit more complexity; albeit these trends were less obvious than in a recent study concerning consumer preferences for Australian sparkling wine vs French Champagne (Culbert et al. 2016).

PCA was performed on sensory data, liking scores (by consumer cluster) and quality ratings for the subset of sparkling wines, to determine the extent to which different sensory attributes influenced consumer wine preferences; with the first and second principal components explaining 66% and 18% of variation, respectively (Figure 9). The stylistic preferences of Clusters 2 and 4 were more obvious than for clusters 1 and 3. Cluster 2 was positioned between the carbonated and Charmat wines, i.e. the wines that exhibited apparent fruit characters; whereas Cluster 4 was positioned in close proximity to the more complex yeasty, mushroom/earthy MT09. In contrast, Clusters 1 and 3 were both located in the top left quadrant, which perhaps reflects these clusters' liking of a broader range of sparkling wine styles.

Previous studies have shown that in blind tastings, consumers generally struggle to differentiate sparkling wines, including Champagne, on the basis of quality (Lange et al. 2002, Combris et al. 2006, Vignes and Gergaud 2007, Culbert et al. 2016), i.e. using intrinsic cues, such as wine aroma, flavour and taste properties, alone. In retail and on premise situations, consumers can usually only assess a wine's sensory properties after it has been selected/purchased. As such, perceived quality, and therefore purchase decisions, are based on extrinsic cues, such as price, packaging, labelling, and/or brand (Lockshin and Corsi 2012); albeit prior consumption, wine style, grape variety and occasion have also been shown to be important to consumers when selecting (table) wine (Johnson and Bastian 2007, Crump et al. 2014). In the case of sparkling wine, Champagne in particular, country of origin also influences perceptions of quality and price (Lange et al. 2002, Combris et al. 2006, Culbert et al. 2016), together with consumption occasion (Verdonk et al. 2017). Indeed, previous research suggests

the symbolic aspects associated with sparkling wine consumption (i.e. occasion, celebration and prestige) motivates consumers, especially younger consumers, much more than wine sensory properties (Charters et al. 2011). Ultimately, consumer preferences for different styles of sparkling white wine (i.e. based on the blind tastings) may not reflect their purchasing decisions, due to an array of competing factors; but insight into the sensory attributes driving consumers' sparkling wine preferences will enable industry to better their tailor marketing strategies to target the different segments of the sparkling wine consumer market.



Figure 9. PCA biplot of sensory attribute ratings, liking scores (for consumer clusters) and quality ratings for subset of Australian sparkling white wines. Ca = carbonated wines, Ch = Charmat wines, Tr = transfer wines, MT = Méthode Traditionelle wines; A = aroma attribute and P = palate attribute. Reproduced from Culbert et al. 2017a. Copyright 2017 Australian Society of Viticulture and Oenology Inc.

Results from this study have demonstrated the diverse sensory profiles exhibited by different styles of Australian sparkling white wines. Evaluation of sparkling wines by an expert panel confirmed

complexity was closely associated with wine quality, with those wines exhibiting the most intense toasty, yeasty, aged/developed notes typically awarded the highest quality scores. Carbonated and Charmat wines tended to be fruit-driven sparkling wines, that were generally considered to be of lower quality. In contrast, varying degrees of complexity were observed in transfer and Méthode Traditionelle wines. Consumer acceptance was seemingly unrelated to wine quality or production method, with a $10 Charmat wine liked more than Méthode Traditionelle wines (on average). Segmentation enabled identification of four consumer clusters, each with distinct sparkling wine preferences. These research findings will enable industry to better understand the domestic sparkling wine consumer market and may provide insights that can be used to tailor production and/or marketing strategies to particular consumer segments.

Results from this study were published in the Australian Journal of Grape and Wine Research in 2017:
Culbert, J.A., Ristic, R., Ovington, L.A. Saliba, A.J. and Wilkinson, K.L. Influence of production method on the sensory profiles and consumer acceptance of different styles of Australian sparkling white wine. Australian Journal of Grape and Wine Research **23**, 170–178.

Supplementary Table 1. Vintage, varietal composition, geographical origin, price and closure of the Australian sparkling white wines studied.

Wine code	Vintage	Varieties	Region	Price (AUD)	Closure type
MT01	2011	PN, CH	SA	34	cork
MT02	NV	PN, CH, PM	Vic	25	cork
MT03	2010	Ch, PN, PM	Vic, SA, Tas	26	cork
MT04	NV	Ch, PN, PM	Tas	28	cork
MT05	2010	PN, CH	Vic	35	cork
MT06*	2004	Ch, PN	Tas	70	cork
MT07	2009	Ch, PN	Tas	50	cork
MT08	2010	PN, CH	SA	35	cork
MT09	2010	PN, Ch, PM	Australia	41	cork
MT10	2009	Ch	Vic	29	cork
MT11	2008	Ch, PN	Tas	35	cork
MT12	NV	Ch, PN	Tas	32	cork
MT13	NV	Ch, PN	SE Australia	32	cork
MT14	2008	PN, CH	Vic	47	cork
MT15	2008	Ch, PN, PM	Tas	50	cork
MT16	NV	PN, CH	Tas	55	cork
MT17*	2004	Ch, PN	Vic	55	cork
MT18	2009	Ch	Vic	41	crown seal
MT19*	2004	Ch, PN	Vic, Tas	90	cork
MT20*	2005	Ch, PN	Tas	53	cork
Tr01	2011	PN, CH	SE Australia	10	cork
Tr02	2011	Ch, PN	SA	17	cork
Tr03	2008	PN, CH	NSW and Vic	23	cork
Tr04	NV	Ch, PN	Vic, SA	18	cork
Tr05	NV	PN, Ch, PM	SA, Vic, NSW	25	cork
Tr06	2011	Ch, PN	Tas	30	cork
Tr07	NV	PN, CH	SA	28	cork
Tr08	NV	Ch, PN	Tas	31	cork
Tr09	NV	PN, CH, PM	Vic	20	cork
Tr10	NV	PN, CH	Tas	26	cork
Ch01	NV	Ch, PN	SE Australia	12	cork
Ch02	NV	Ch, PN	SE Australia	9	screw cap
Ch03	NV	PN, CH, PM	Vic	14	cork
Ch04	NV	Ch, PN	SE Australia	8	cork
Ch05	NV	Ch	SA	23	cork
Ch06	NV	PN, CH	Tas	22	cork
Ch07	NV	PN, Ch, PM	SE Australia	9	cork
Ch08	NV	Ch	Vic	22	cork
Ch09	NV	PN, CH	SA	18	cork
Ch10	NV	Ch, PN	NSW, Vic	11	cork
Ca01	NV	Sem, Ch	Australia	5	cork
Ca02	NV	Ch, CB	WA	12	cork
Ca03	NV	Ch, PN	SE Australia	7	cork
Ca04	2012	Ch	SA	14	Zork
Ca05	NV	Ch, Co	Australia	6	cork
Ca06	NV	Ch, Sem, SB	Australia	9	cork
Ca07	NV	Ch, Sem	Australia	9	cork
Ca08	NV	Ch, PN	Australia	8	cork
Ca09	NV	Ch, PN	SA	24	cork
Ca10	NV	Ch, PN	Vic	11	cork

MT = Méthode Traditionelle; Tr = Transfer; Ch = Charmat; Ca = Carbonated. NV = non-vintage. CB = Chenin Blanc; Ch = Chardonnay; Co = Colombard; PM = Pinot Meunier; PN = Pinot Noir; SB = Sauvignon Blanc; Sem = Semillon; NSW = New South Wales; SA = South Australia; SE = South Eastern; Tas =Tasmania; WA = Western Australia; Vic = Victoria. * = wines aged on lees for extended periods of time (≥ 6 years).

Supplementary Table 2. Mean intensity ratings for sensory attributes of the subset of Australian sparkling white wines.

	MT06	**MT09**	**Tr03**	**Tr10**	**Ch07**	**Ca03**	***P***
Citrus A	5.1	4.5	5.1	4.8	5.6	5.6	*ns*
Stone Fruit A	6.2abc	5.4c	6.0abc	5.7bc	7.6a	7.1ab	*0.0799*
Tropical A	4.3b	4.3b	4.7b	4.5b	8.8a	6.1b	*0.0002*
Pome Fruit A	6.4	6.1	6.7	7.2	6.8	6.0	*ns*
Floral A	3.3bc	2.7c	4.4b	4.4b	7.4a	6.9a	*< 0.0001*
Confectionary A	2.2cd	1.9d	4.7b	2.1d	6.2a	3.5bc	*< 0.0001*
Yeasty A	5.8ab	6.4a	3.8c	4.1bc	3.3c	3.8c	*0.007*
Toasty A	7.7a	5.8b	5.0bc	4.6bc	2.7d	3.4cd	*< 0.0001*
Meaty/Savoury A	5.2a	5.2a	1.8b	2.4b	1.1b	1.6b	*< 0.0001*
Mushroom/Earthy A	3.9ab	4.6a	2.1cd	2.8bc	1.3d	2.0cd	*0.0001*
Honey A	5.0a	3.0b	4.4a	3.8ab	3.7ab	4.1ab	*0.1062*
Vanilla/Caramel A	4.8a	3.0b	4.0ab	4.0ab	3.0b	3.8ab	*0.2246*
Aged/Developed A	6.0a	5.0ab	5.4ab	3.7bc	1.4d	2.1cd	*< 0.0001*
Tropical	5.4c	5.8bc	5.9bc	5.2c	9.4a	7.4b	*0.0002*
Floral	4.1bc	3.4c	5.0b	3.5c	7.7a	5.1b	*< 0.0001*
Confectionary	2.5c	2.4c	4.2b	3.1bc	6.1a	4.3b	*0.0003*
Meaty/Savoury	4.9a	4.5a	2.0bc	2.8b	1.4c	2.2bc	*< 0.0001*
Mushroom/Earthy	4.4a	4.3ab	2.9abc	3.6ab	1.8c	2.7bc	*0.0001*
Honey	4.4ab	3.2b	4.2ab	4.5ab	4.9a	4.0ab	*0.2479*
Yeasty	5.8a	6.0a	4.4ab	4.4ab	3.8b	5.1ab	*0.1865*
Toasty	7.3a	5.2b	5.3b	5.2b	2.4c	3.9bc	*< 0.0001*
Vanilla/Caramel	4.8a	2.2c	4.3a	4.1ab	3.0bc	2.8c	*0.0005*
Aged/Developed	6.6a	4.8b	4.9b	4.9b	2.0c	2.7c	*< 0.0001*
Sweetness	3.9c	3.3c	5.7ab	4.7bc	6.7a	4.5bc	*0.0002*
Acidity	9.3abc	9.7ab	8.3c	8.9bc	8.4c	10.4a	*0.0074*
Complexity	9.0a	7.1b	6.3b	7.0b	4.1c	5.9bc	*0.0002*

A = aroma attribute. Values are mean scores from three wine replicates presented to 10 judges in replicated sensory sessions. Means within rows followed by different letters are significantly different ($p = 0.05$, one way ANOVA, Tukey's LSD post hoc); ns = not significant.

Supplementary Table 3. Liking scores for the subset of Australian sparkling white wines for consumer clusters segmented according to gender, age, frequency of sparkling wine consumption and wine involvement.

	Hedonic ratings[a]					
	MT06	**MT09**	**Tr03**	**Tr10**	**Ch07**	**Ca03**
Gender						
Male (n=59)	4.6	4.4 a	4.7	4.6	5.3	4.2
Female (n=91)	4.4	3.9 b	4.1	4.4	5.0	4.6
Age (years)						
18-34 (n=59)	3.9	3.6	4.1	4.2	5.1	4.2
35-54 (n=54)	4.7	4.1	4.5	4.5	5.4	4.6
55+ (n=37)	4.7	4.7	4.6	4.9	4.9	4.7
Sparkling wine consumption[b]						
Low (n=65)	4.3	3.7	4.2	4.2	5.1	4.1
Medium (n=57)	4.4	4.3	4.6	4.7	4.8	4.6
High (n=28)	4.7	4.3	4.4	4.8	5.8	5.0
Wine involvement[c]						
Low (n=45)	5.1	3.6a	3.9a	4.0	5.5	4.2
High (n=105)	4.2	4.3b	4.5b	4.7	5.0	4.6

Means followed by different letters (within a column, by segmentation category) are significantly different (P = 0.05, one-way ANOVA).

[a] Hedonic ratings determined using a 9 cm line scale, with anchors from left (dislike extremely) to right (like extremely).

[b] Low being < once every 2 months; medium being once every 1-2 months; high being once a fortnight or more.

[c] Involvement determined using the wine involvement scale (Bruwer and Huang, 2012), with low < 4.0/7 and high ≥ 4.0/7.

Influence of production method on the chemical composition, foaming properties and quality of Australian carbonated and sparkling white wines.

The composition, foaming properties and quality of 50 sparkling white wines, representing the four key methods of production employed in Australia (i.e. Méthode Traditionelle, transfer, Charmat and carbonation), were measured to establish the variation amongst different styles of sparkling white wine, and to determine to what extent production method influences the compositional factors that drive sparkling wine style and quality.

Amino acid content of sparkling wines

The presence of amino acids, proteins and polysaccharides in sparkling wines and base wines has received considerable attention in recognition of their contributions to foaming properties, body and flavour (Brissonnet and Maujean 1993, López-Barajas et al. 2001) and therefore perceptions of quality (Martínez-Lapuente et al. 2015). In the current study, carbonated wines had significantly higher total amino acid levels than sparkling wines derived from other production methods (Table 10). This largely reflected the considerably higher proline levels of carbonated wines, as well as elevated levels of arginine and alanine (Figure 10, Supp. Table 4). Proline is generally accepted to be the predominant amino acid present in must and wine (Huang and Ough 1991, Lehtonen 1996, Waterhouse et al. 2016), although for some grape varieties, arginine (Huang and Ough 1991) or arginine and proline (Stines et al 2000) predominate. In a study of Italian sparkling wines (Casoli and Colagrande 1982), proline concentrations were up to ten times higher than the next most abundant amino acid. However, it should be noted that amino acid composition can vary according to vineyard management, water availability and nitrogen application (Bell and Henschke 2005); with proline accumulation considered to be a physiological response to stress (Bertamini et al. 2006). During alcoholic fermentation, amino acids provide nitrogen for yeast metabolism, either as free amino acids or via degradation of grape proteins; (Lehtonen 1996, Waterhouse et al. 2016) but they can also be released during yeast autolysis (Alexandre and Guilloux-Benatier 2006). Since most grape-derived amino acids are consumed during fermentation, the higher amino acid levels observed in carbonated wines (which do not undergo secondary fermentation and lees aging) were not unexpected. In contrast, sparkling wines produced via Méthode Traditionelle, transfer and Charmat (which do undergo secondary fermentation) had similar free amino acid concentrations, on average, being 931 to 976 mg/L (Table 10). Variation was nevertheless still observed amongst wines produced by the same production method. In the case of carbonated wines, amino acid levels ranged from 471 to 1924 mg/L, for example (Table 10); differences may be attributable to grape variety and/or vineyard management practices (Bell and Henschke 2005, Waterhouse et al. 2016). While the majority of the sparkling wines studied comprised

Table 10. Price, bottle weight, composition, foaming properties and quality ratings of Australian carbonated and sparkling white wines, by production method.

	Méthode Traditionelle (n=20)			transfer (n=10)			Charmat (n=10)			carbonated (n=10)		
	min	**max**	**mean**	**min**	**max**	**mean**	**min**	**max**	**mean**	**min**	**max**	**mean**
price (AUD$)	25	90	43 a ± 3.6	10	31	23 b ± 1.9	8	23	15 b ± 2.1	5	24	10 b ± 1.7
bottle weight (kg)	1.61	1.71	1.66 a ± 0.005	1.44	1.67	1.57 b ± 0.03	1.45	1.67	1.50 bc ± 0.03	1.45	1.67	1.47 c ± 0.02
pH	2.9	3.4	3.2 ± 0.02	3.1	3.5	3.2 ± 0.04	3.2	3.5	3.3 ± 0.03	3.1	3.4	3.3 ± 0.03
TA[a] (g/L)	6.4	9.6	8.0 a ± 0.2	5.8	7.6	6.9 b ± 0.2	6.1	7.4	6.8 b ± 0.2	6.4	9.2	7.6 ab ± 0.3
residual sugar (g/L)	0.5	13.1	8.8 b ± 0.8	3.9	15.8	12.0 ab ± 1.1	8.5	19	14.0 a ± 1.0	7.9	13.5	12.4 ab ± 1.2
alcohol (% abv)	11.2	13	12.3 a ± 0.1	11	13.1	12.0 ab ± 0.2	11	12.2	11.6 bc ± 0.1	10.3	12.5	11.1 c ± 0.2
total phenolics (au)	0.3	4.9	2.2 b ± 0.25	0.9	4.3	2.4 b ± 0.4	0.5	4.5	2.9 b ± 0.4	2.5	5.8	4.7 a ± 0.3
total free amino acids (mg/L)	450	1452	949 b ± 184	602	1168	931 b ± 56	665	1254	976 ab ± 68	471	1924	1274 a ± 136
proteins (mg/L)	7.0	160.6	67.3 a ± 10.5	7.7	76.7	28.8 b ± 6.5	8.7	70.1	34.9 ab ± 6.9	9.2	88.4	34.6 ab ± 8.5
total polysaccharides (mg/L)	36	193	108 ± 7	59	119	93 ± 6	51	120	99 ± 7	66	146	110 ± 8
max foam volume, Vf (mL)	53	147	91[b] ± 6	52	132	89 ± 8	54	111	81 ± 5	71	106	84 ± 4
foam stability, Lf (sec)	4.0	19.8	10.2[b] a ± 1.2	1.8	9.8	6.5 ab ± 0.8	1.5	14.5	5.7 b ± 1.1	4.0	32.9	11.2 ab ± 2.7
quality rating (/20)	13.9	17.4	15.8 a ± 0.2	14.1	15.6	15.0 b ± 0.1	14.4	15.2	14.7 b ± 0.1	14.1	15.2	14.6 b ± 0.1

Means followed by different letters within rows are significantly different ($P = 0.05$, one way ANOVA, Tukey's LSD post hoc).
[a]TA measured as g/L of tartaric acid; proteins measured as mg/L of thaumatin; total polysaccharides measured as mg/L of 50kDa dextran.
[b]n=19, one wine could not be measured because the bottle did not fit the robotic pourer.
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the classic grape varieties, Chardonnay, Pinot Noir and Pinot Meunier (or blends thereof), several carbonated wines comprised Chardonnay blended with non-classic varieties. It should also be noted that carbonated wines are more likely to be produced from higher yielding vines, lower quality fruit and/or riper fruit, with fruit maturity being another factor that influences amino acid concentrations (Stines et al. 2000). Fruit destined for carbonated wine might also originate from warmer climates and would therefore be more likely to be harvested from vines subject to temperature and/or water stress, which, as previously indicated, can also influence proline accumulation (Bell and Henscke 2005, Bertamini et al. 2006). Finally, winemaking practices, in particular the addition of diammonium phosphate, may also influence amino acid metabolism during fermentation. Previous studies have shown that amino acid levels can fluctuate considerably during bottle aging and yeast autolysis, so there are likely multiple factors at play. Additionally, amino acids are known aroma precursors (Feuillat and Charpentier 1982), so their degree of conversion to aroma compounds will also influence wine amino acid concentrations.

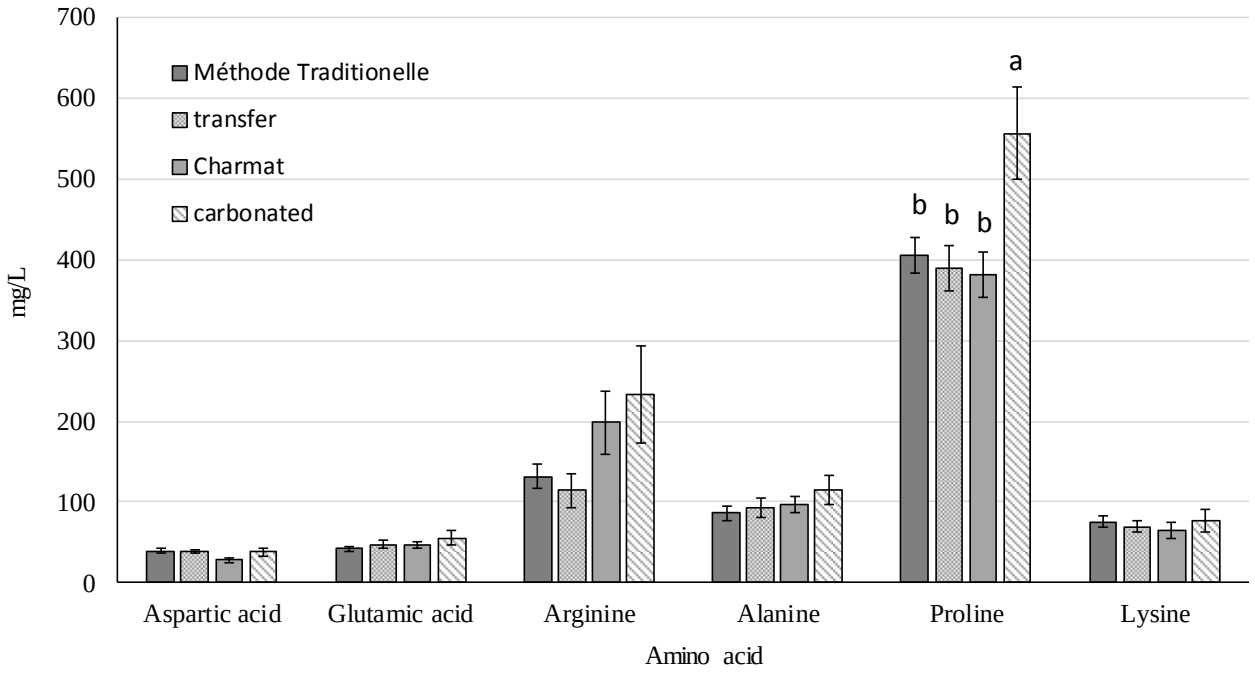


Figure 10. Mean concentrations for the most abundant amino acids for 50 Australian sparkling white wines according to their production methods. Letters indicate statistical significance (P = 0.05, one-way ANOVA, Tukey's LSD post hoc). Reprinted from Culbert et al. 2017b. Copyright 2017 American Chemical Society.

Protein content of sparkling wines

The method of sparkling wine production greatly impacted the protein content of finished wine, particularly for Méthode Traditionelle wines, which on average, contained significantly more protein

(P<0.05) than other wines (Table 10). The HPLC-based analytical method employed in this study specifically measured chitinases and thaumatin-like proteins (TLPs), i.e. the two protein classes associated with the majority of haze formation in wine, for which molecular weights range between 21 and 32 kDa (Waterhouse et al. 2016). Other spectrophotometric-based protein methods, such as the Bradford method, may be limited in wine analysis due to interferences from non-protein wine constituents, ethanol and phenolic compounds in particular (Marchal et al. 1997). Previous studies have shown that the majority of proteins present in Champagne base wines were chitinases and TLPs (Brissonnet and Maujean 1993). However, of the fifty sparkling wines analysed in this study, all contained TLPs and only one contained chitinases. This is mostly likely due to the reduced stability of chitinases compared with TLPs. Research concerning the fate of these proteins during Champagne production suggests reduced chitinase activity during fermentation and no detectable chitinase activity in the final wine (Manteau et al. 2003). The Méthode Traditionelle wines studied here were found to contain, on average, two-fold higher protein concentrations compared to sparkling wines made via other methods (Table 10), which may relate to bentonite fining of base wines prior to carbonation or secondary fermentation. Bentonite fining removes wine proteins and therefore impacts on foam quality and persistence (García et al. 2009). Stabilisation treatment during the different stages of sparkling wine production, such as bentonite addition, have been shown to remove around 75% of wine protein and peptides (Luguera et al. 1998). The higher protein levels observed in Méthode Traditionelle wines from the current study, might therefore reflect less stringent fining of base wines, relative to other production methods, in order to achieve the organoleptic characteristics (e.g. foaming) associated with higher quality sparkling wines.

Polysaccharide content of sparkling wines

Production method significantly influenced polysaccharide composition (Figure 11), although average total polysaccharide concentrations were not statistically different (Table 10). On average, bottle fermented Méthode Traditionelle and transfer wines contained a greater proportion of higher molecular weight polysaccharides (i.e. 200 kDa), which typically represent yeast-derived mannoproteins (Bindon et al. 2003), while Charmat and carbonated wines comprised a greater proportion of low molecular weight polysaccharides (i.e. 10–50 kDa), which typically represent rhamnogalacturonans (Bindon et al. 2003) (Figure 2). Mannoproteins are yeast-derived and so bottle fermented wines that are aged on yeast lees were expected to contain more high molecular weight polysaccharides, compared to batch fermented production methods, such as Charmat and carbonation. However, mannoproteins can degrade with age and/or enzyme activity, so greater lees aging does not necessarily equate to an increase in mannoproteins. This may explain the low concentration of mannoproteins in the three Méthode Traditionelle wines (MT06, MT17 and MT19) that were aged on yeast lees for extended periods of time (≥ 6 years), being 41, 46 and 55 mg/L of 50 kDa dextran equivalents, relative to total

polysaccharide concentrations of 86, 114 and 193 mg/L of 50 kDa dextran equivalents, respectively. Furthermore, these three wines did not contain the highest mannoprotein levels, which indicates other factors may influence polysaccharide concentration and composition. The polysaccharide content of base wines may increase where wine remains in contact with residual yeast prior to secondary fermentation, but may decrease as a consequence of stabilization and/or filtration (López-Barajas et al 2001).

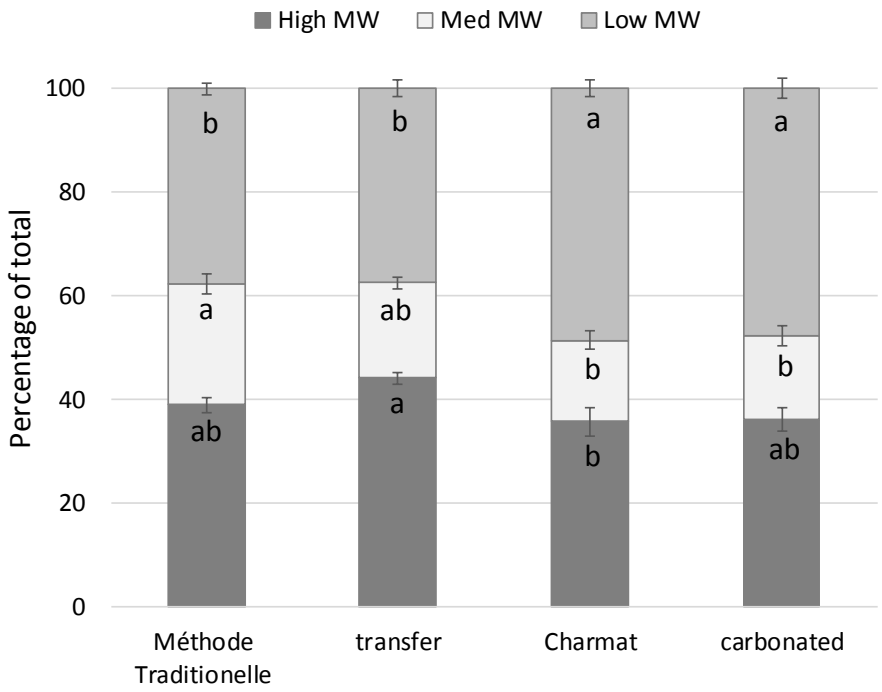


Figure 11. Polysaccharide content of Australian sparkling wines based on percentage contribution of each of the high, medium and low molecular weight polysaccharides, by production method. Note: High MW = 200 kDa; Med MW = 100 kDa; and Low MW = 50, 20 and 10 kDa. Letters indicate statistical significance (P = 0.05, one-way ANOVA, Tukey's LSD post hoc).
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Wine polysaccharides can vary considerably between wines, but direct comparisons of results from previously published studies needs to account for the analytical method used for quantitation of polysaccharides, which can otherwise influence results (Alexandre et al 2006). A recent study into changes in polysaccharide composition during the production of Champagne found the highest concentrations of mannoproteins and polysaccharides rich in AGP were measured in wines aged for 6 months (Martínez-Lapuente et al 2013). Increased polysaccharide concentrations are desirable, given polysaccharides are associated with foamability, stability and mouthfeel (Alexandre et al 2006).

Fatty acid content of sparkling wines

Fatty acids are released into wine during yeast autolysis and can also influence sparkling wine foaming properties. As such, the influence of production method on the free fatty acid content, i.e. hexanoic, octanoic and decanoic acids and their corresponding ethyl esters, of sparkling wines was investigated (Table 11). Irrespective of the method of production, sparkling wines were found to contain similar quantities of hexanoic acid and ethyl hexanoate. Carbonated and Charmat wines were more abundant in decanoic and octanoic acids, together with their corresponding ethyl esters, compared to Méthode Traditionelle and transfer wines, with larger differences observed for decanoic acid and ethyl decanoate (Table 11). However, the ratio of fatty acids to ethyl esters was similar, regardless of production method. A previous study has suggested the foamability of sparkling wine is directly proportional to the ester–fatty acid ratio (Gallart et al. 2002), but relatively consistent esterification ratios were observed in this study. Ethyl hexanoate was approximately three-fold more abundant than hexanoic acid for all production methods: 3.18 for carbonation; 3.30 for Charmat; 3.45 for transfer; and 3.50 for Méthode Traditionelle). Decanoic acid was approximately twice as abundant as ethyl decanoate; ester to acid ratios were: 0.50 for carbonation 0.50; 0.52 for Charmat; 0.47 for transfer; and 0.45 for Méthode Traditionelle. Ethyl octanoate was approximately 10-15% more abundant than octanoic acid; ester to acid ratios were: 1.12 for carbonation; 1.15 for Charmat; 1.11 for transfer; and 1.16 for Méthode Traditionelle). These results suggest a relationship between free fatty acids and their ethyl esters independent of production method. However, it wasn't surprising that higher ethyl ester concentrations were observed in fruit driven styles of sparkling wine (i.e. Charmat and carbonated wines).

Table 11. Mean peak areas for C6, C8 and C10 fatty acids and their ethyl esters in Australian carbonated and sparkling white wines, by production method.

	Méthode Traditionelle (n=20)	**transfer (n=10)**	**Charmat (n=10)**	**carbonated (n=10)**
hexanoic acid (C6)	1.59	1.61	1.67	1.70
octanoic acid (C8)	8.34 b	9.22 b	10.79 a	11.10 a
decanoic acid (C10)	1.39 d	1.92 c	3.50 b	4.18 a
ethyl hexanoate	5.45	5.34	5.40	5.34
ethyl octanoate	9.71 b	10.23 b	12.27 a	12.41 a
ethyl decanoate	0.63 c	0.93 b	1.85 a	2.09 a

Values are presented as peak area divided by 10^7.
Means within a row followed by different letters are significantly different (P = 0.05, one-way ANOVA, Tukey's LSD post hoc).
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Foaming properties of sparkling wines

The average maximum foam volumes (V*f*) for Méthode Traditionelle and transfer wines were 91 and 89 mL respectively, but these results were not statistically significant to those of Charmat and carbonated wines, being 81 and 84 mL respectively (Table 10). The maximum foam volume of Méthode Traditionelle wines was found to vary the most (by as much as 94 mL), whereas variation amongst transfer, Charmat and carbonated wines was from 80, 57 and 35 mL respectively. Interestingly, no correlations were observed between maximum foam volume and price, bottle weight, compositional parameters or quality ratings (data not shown).

The foam stability, on average, was highest for carbonated wines (11.2 sec) followed by Méthode Traditionelle wines (10.2 sec), transfer wines (6.5 sec) and Charmat wines (5.7 sec). Foam stability was expected to be highest for Méthode Traditionelle and transfer wines, since these wines were highest in proteins and polysaccharides, i.e. sparkling wine constituents which have previously been associated with foam stability (Brissonnet and Maujean 1991, Malvy et al. 1994, Luguera et al. 1998, López-Barajas et al. 2001, Manteau et al. 2003, Martínez-Lapuente et al. 2013); although some studies suggest foamability is inversely correlated with foam stability, and is therefore negatively correlated with protein content (Andrés-Lacueva et al. 1996a, 1996b; López-Barajas et al. 1998). However, while carbonated wines rated higher in foam stability overall, it should be noted that one carbonated wine, which also contained significantly higher concentrations of TLPs, gave a foam stability measurement of 32.9 sec. If this wine is deemed to be an outlier and is excluded from the carbonated wine dataset, the average foam stability time for the remaining carbonated wines becomes 8.7 sec. This is still higher than for transfer wines, and possibly reflects the elevated free amino acid concentrations of carbonated wines. Correlation analysis revealed significant correlations for foam stability against proteins (r = 0.393), TA (r = 0.369), alcohol (r = –0.308) and the three amino acids, histidine (r = 0.443), arginine (r = 0.325) and tyrosine (r = 0.332), but not fatty acids or their ethyl esters. Free fatty acids C8, C10, and C12 and the ethyl esters of octanoic, decanoic and dodecanoic acids have previously been shown to have no influence on the stability time of foam (Gallart et al. 2002). This observation was supported by our findings which found no relationship between hexanoic, octanoic and decanoic acids and their corresponding fatty acids to foam stability. Other studies suggest ethanol content may have a bigger impact than lipids for higher alcohol wines (Dussaud et al. 1994).

Price, bottle weight and quality ratings of sparkling wines

The price, bottle weight and quality ratings of sparkling wines, by method of production, are provided in Table 10. Bottle prices ranged from $7 to $90, with mean prices increasing according to production method, i.e. from $10 per bottle for carbonation, to $15, $23 and $43 per bottle for Charmat, transfer and Méthode Traditionelle, respectively. Bottle weights for Méthode Traditionelle wines were

significantly higher (P<0.05) than for the other production methods, followed by transfer, Charmat and carbonated wines. This is likely due to the levels of dissolved carbon dioxide in sparkling wine being influenced by production method; i.e. bottle fermentation typically generates 5–7 atmospheres of pressure, compared to 3–4 for carbonated wines. Thus, wines with higher bottle pressures require sturdier bottles (i.e. thicker glass) which consequently increases bottle weight. However, a previous study reported an association between bottle weight and wine quality, which provides an extrinsic cue for estimating price and quality (Piqueras-Fiszman and Spence 2012). In the current study, both price and bottle weight were positively correlated with quality ratings; with sparkling wines produced via traditional methods being awarded higher quality scores, packaged in heavier bottles and commanding higher prices.

Table 12. Correlation coefficients for sparkling wine quality ratings against price, bottle weight, foaming properties and compositional parameters.

Parameter	**Coefficient (*r*)**	***P* value**
price	**0.715**	**< 0.0001**
bottle weight	**0.534**	**< 0.0001**
pH	-0.166	0.249
TA	0.177	0.220
residual sugar	**-0.441**	**0.001**
alcohol	**0.479**	**< 0.001**
total phenolics	**-0.279**	**0.050**
total free amino acids	-0.020	0.891
aspartic acid	**0.346**	**0.014**
proteins	**0.466**	**0.001**
total polysaccharides	-0.046	0.751
RG-I/RG-II (10 kDa)	**-0.396**	**0.004**
max foam volume (V*f*)	-0.005	0.971
foam stability (L*f*)	0.166	0.255
hexanoic acid	-0.176	0.225
octanoic acid	**-0.547**	**< 0.0001**
decanoic acid	**-0.425**	**0.002**
ethyl hexanoate	0.132	0.367
ethyl octanoate	**-0.538**	**< 0.0001**
ethyl decanoate	**-0.353**	**0.013**

Values in bold are significantly different from 0 (α=0.05).
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The average quality ratings for Méthode Traditionelle wines (15.8/20) were significantly higher than those for transfer, Charmat and carbonated wines, being 15.0, 14.7 and 14.6/20 respectively (Table 10). Correlation analysis was performed on price, bottle weight, compositional parameters and

foaming properties in order to identify any correlations, either positive or negative, with quality ratings (Table 12). The strongest positive correlations with quality were for price and bottle weight (r = 0.715 and 0.534, respectively), but positive correlations were also observed for alcohol (r = 0.479), aspartic acid (r = 0.346) and proteins (r = 0.466). The strongest negative correlations with quality were for octanoic acid and its corresponding ethyl ester (r = –0.547 and –0.538, respectively). Negative correlations with quality were also observed for residual sugar (r = –0.441), total phenolics (r = –0.279), low molecular weight RG's (r = –0.396), decanoic acid (r = –0.425) and ethyl decanoate (r = –0.353).

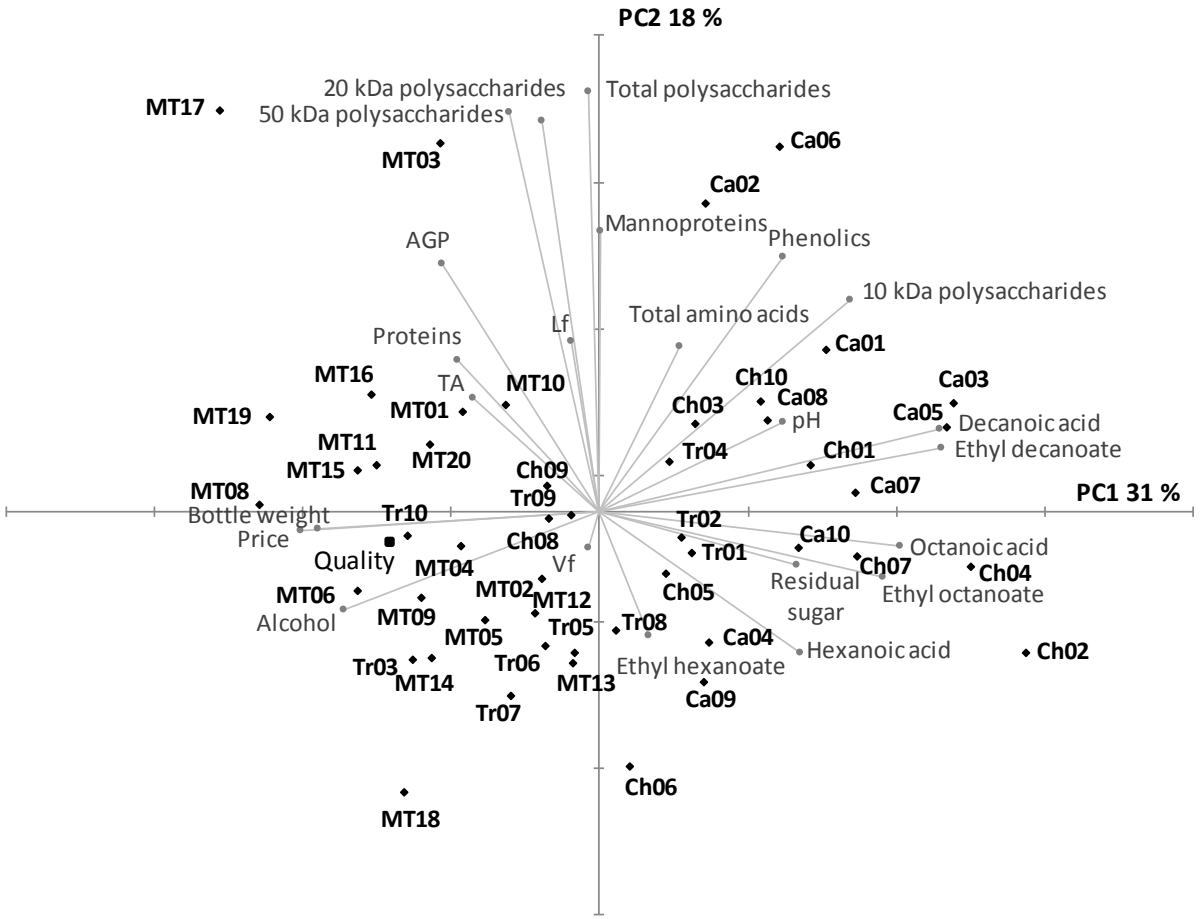


Figure 12. PCA biplot of price, bottle weight, composition, foaming behaviour and quality ratings for fifty Australian sparkling white wines. Ca = carbonated wines, Ch = Charmat wines, Tr = transfer wines, MT = Méthode Traditionelle wines. Reprinted from Culbert et al. 2017b. Copyright 2017 American Chemical Society.

Principal component analysis (PCA) was performed on the price, bottle weight, compositional parameters, foaming properties and quality ratings of each of the fifty sparkling wines, to determine the extent to which different chemical and physical parameters influenced quality and how samples clustered based on these attributes. The first and second principal components explained 31% and 18% of variation, respectively (Figure 3). In agreement with correlation analysis, quality was found to be

closely associated with alcohol content, price and bottle weight, and to a lesser extent protein and AGP levels. These attributes were found on the left of the PCA biplot and were mainly accounted for by PC1. Wines were clearly positioned on the PCA biplot according to production method; with Méthode Traditionelle wines located in the two left quadrants and, with the exception of two Charmat wines (Ch08 and Ch09), Charmat and carbonated wines located in the two right quadrants. The majority (n=6) of transfer wines were located amongst the Méthode Traditionelle wines in the left quadrants, with the remaining four transfer wines (Tr01, Tr02, Tr04 and Tr08) located just right of the y-axis. PC2 tended to separate wines of the same production method and was mainly driven by differences in polysaccharide profiles (Figure 12).

Results from this study have demonstrated that production method plays a key role in the chemical composition, foaming properties and quality of Australian sparkling white wines. Similarities were observed in the composition of Méthode Traditionelle and transfer wines, as well as in Charmat and carbonated wines. Méthode Traditionelle wines had elevated concentrations of protein and high molecular weight polysaccharides, and were considered to be of superior quality. These wines therefore commanded higher retail prices, which mitigate the increased costs associated with more involved production processes; i.e. hand-harvesting, whole-bunch pressing of cool climate fruit, bottle fermentation and/or lees aging. In contrast, carbonated wines tended to contain higher levels of fatty acids and phenolics, and were considered to be of comparatively lower quality. Collectively, these findings enable industry to better understand the impact of decisions made throughout production on both sparkling wine style and quality. Compositional variations observed between wines made from the same production method could form the basis of future studies, together with a more detailed investigation into the compositional parameters driving sparkling wine foaming properties.

A manuscript based on this study has been published in the Journal of Agricultural and Food Chemistry: Culbert, J.A., McRae, J., Condé, B.C., Schmidtke, L., Nicholson, E., Smith, P.A., Howell, K.S., Boss, P.K. and Wilkinson, K.L. (2017) Influence of production method on the chemical composition, foaming properties and quality of Australian carbonated and sparkling white wines. Journal of Agricultural and Food Chemistry **65**, 1353–1364.

Supplementary Table 4. Amino acid concentrations (mg/L) in Australian carbonated and sparkling white wines, by production method.

	Méthode Traditionelle (n=20)			transfer (n=10)			Charmat (n=10)			carbonated (n=10)		
	min	**max**	**mean[a]**	**min**	**max**	**mean[a]**	**min**	**max**	**mean[a]**	**min**	**max**	**mean[a]**
aspartic acid	13.8	62.5	39.1	27.5	52.1	39.2	15.0	36.9	28.0	15.0	66.4	37.9
asparagine	11.8	45.0	30.0	16.0	54.3	33.1	15.2	41.5	30.1	13.8	39.7	30.1
Serine	3.2	37.7	16.7	6.8	36.1	17.4	4.7	24.4	14.3	6.1	38.9	21.5
glutamic acid	12.4	66.7	42.0	22.9	69.9	47.2	28.2	65.6	46.8	19.0	100.1	55.8
histadine	3.3	18.1	10.7 b	5.5	12.4	9.6 b	3.5	16.8	9.6 b	3.4	41.2	17.6 a
glycine	4.5	15.0	9.6	6.7	13.9	9.3	7.6	14.8	9.7	3.4	14.3	8.8
arginine	20.1	277.1	131.2	31.9	236.8	114.0	40.9	469.5	198.8	18.5	646.8	232.6
threonine	6.3	30.2	17.9	8.7	42.3	20.9	8.9	23.9	16.2	7.6	36.6	22.4
alanine	17.5	172.0	85.9	43.1	152.4	92.9	48.1	135.7	97.2	42.8	189.3	115.2
proline	259.3	620.9	405.6 b	227.3	520.5	389.9 b	285.2	568.8	381.4 b	271.6	883.8	556.7 a
tyrosine	3.1	30.2	17.5	9.4	23.3	16.6	12.3	24.3	18.1	0.0	35.2	19.5
Valine	3.8	26.3	12.9	10.0	20.9	14.9	8.0	17.8	12.5	4.6	30.1	16.8
Lysine	32.6	133.6	75.7	39.0	106.0	69.1	19.9	114.4	64.8	14.7	166.9	77.3
Isoleucine	0.0	10.8	3.3	1.2	6.6	3.8	0.0	8.4	2.4	0.0	15.0	5.6
Leucine	11.9	52.5	30.0	24.0	42.4	31.3	12.8	43.4	26.4	9.1	57.9	34.2
phenylalanine	8.3	32.8	21.2	18.1	28.6	22.1	11.0	27.3	19.4	6.5	33.3	22.4

[a]Values are means of two wine replicates per wine per production method. Values followed by different letters within rows are significantly different (p = 0.05, one way ANOVA, Tukey's LSD post hoc). Reprinted from Culbert et al. 2017b. Copyright 2017 American Chemical Society.

Part C: Objective measures of the style and quality of Australian Moscato.

Sensory profiles and consumer acceptance of different styles of Australian Moscato.

Composition, price and quality of Moscato wines

Twenty four Australian Moscato wines, comprising both sparkling and semi-sparkling, and white (*n*=10) and pink (*n*=14) wine styles, were sourced commercially or from industry. Wines were selected with input from an industry reference group and comprised wines that reflected a range of price points ($8 to $30 per bottle), Australian wine regions, and brands prominent in the domestic market (i.e. high volume sellers). Compositional and sensory analyses were performed to: (i) characterise the chemical, sensory and quality diversity amongst the different Moscato wines; and (ii) identify a subset of wines representative of that diversity, for use in consumer acceptance trials.

The composition, price and quality ratings of individual Moscato wines are reported in Table 13. Collectively, wines were characterised by low pH (2.8 to 3.3), high acidity (TA ranged from 7.5 to 10.4 g/L), high residual sugar content (56.5 to 114.8 g/L) and low alcohol content (4.6 to 10.0% v/v), which are typical of Moscato; with statistically significant differences observed amongst wines. As expected, there was a large negative correlation between alcohol and residual sugar content (R = –0.70, *P < 0.001*), which likely reflects the early arrest of secondary fermentation. Certainly those wines with the highest residual sugar content, being M03, M12 and M22 (with ≥ 110 g/L), had some of the lowest alcohol levels (i.e. 4.6 to 6.4% v/v). However, in some instances, for example M05, M11 and M21, higher residual sugar and alcohol levels might reflect sugar adjustment (for example via the addition of juice or juice concentrate). High levels of acidity are important for sweet wines, to achieve balance and avoid a cloying sensation (Iland et al. 2009), and so the high TA levels observed were also anticipated; but TA and residual sugar were not strongly correlated (R = 0.40, *P = 0.055*). Phenolic substances ranged considerably, from 0.9 au for M03 to 9.2 au for M17. The phenolic content of sparkling white wines can indicate quality, with higher quality Méthode Traditionelle wines tending to have lower phenolic content (due to hand-picking, whole-bunch pressing and fermentation of lighter press fractions), relative to sparkling wines made via the Charmat method or carbonation (Culbert et al. 2017). In the current study, there was only a weak (negative) correlation between phenolic substances and quality ratings (R = –0.38, *P = 0.064*), suggesting any negative impacts of high phenolic content were masked by the high residual sugar content.

The colour of Moscato wines was broadly classified as white or pink based on visual assessments, but CIELAB measurements were performed to enable more detailed comparisons of wine colour (Supp.

Table 13. Vintage, region, price, closure type, composition and quality ratings of Moscato wines.

Wine code	Vintage	Region	Price[a] (AUD)	Closure type	pH	TA (g/L)	Residual sugar (g/L)	Alcohol (% v/v)	Total phenolics (au)	Quality ratings[b] (/20)
M01[c]	NV	SA	10	cork	3.1 abc	8.9 def	56.5 k	8.8 c	6.0 c	14.4 ab
M02	2013	SA	21	screw cap	3.1 abc	9.3 cde	71.5 hij	8.7 cd	8.9 a	15.2 ab
M03[c]	2014	NSW	30	screw cap	3.2 ab	8.8 efg	114.8 a	6.4 k	7.0 b	14.3 ab
M04	NV	SA	9	cork	3.0 abc	8.7 fg	78.8 efghi	5.8 m	3.5 gh	14.5 ab
M05[c]	NV	Vic	16	cork	3.2 ab	7.8 jkl	92.4 bcd	6.4 k	2.7 ij	15.5 ab
M06	NV	Vic	16	cork	3.3 a	7.7 kl	76.9 fghi	7.2 i	4.7 e	15.2 ab
M07	NV	Vic	16	cork	3.1 abc	8.3 ghi	89.1 bcde	6.5 jk	2.1 j	15.7 a
M08	NV	Vic	16	cork	3.2 ab	7.6 l	82.5 defgh	7.6 g	5.7 cd	15.0 ab
M09	2013	SA	16	screw cap	3.1 abc	9.4 c	73.8ghij	7.8 g	3.9 fg	16.3 a
M10	2013	SA	16	screw cap	3.1 abc	8.8 fg	74.1 fghij	8.0 f	6.1 c	14.9 ab
M11	2014	Vic	22	screw cap	3.1 abc	9.7 bc	93.8 bcd	6.2 l	7.0 b	13.3 b
M12	2014	Vic	20	crown seal	2.8 c	9.9 ab	113.8 a	5.3 n	4.2 ef	14.9 ab
M13	NV	SA	8	cork	3.3 ab	7.5 l	74.9 fghij	8.5 de	0.9 k	15.4 ab
M14	NV	SA	8	cork	3.2 abc	7.5 l	76.6 fghi	8.5 e	2.7 ij	15.4 ab
M15[c]	2013	SE Australia	10	screw cap	3.2 ab	8.1 hijk	70.5 hij	8.5 e	3.1 hi	14.7 ab
M16	NV	SE Australia	9	cork	3.1 abc	8.8 def	69.9 ij	9.3 b	3.7 fgh	14.7 ab
M17	2014	WA	19	screw cap	3.3 a	8.2 hij	98.4 b	7.4 h	9.2 a	14.9 ab
M18	2013	SA	25	crown seal	3.1 abc	7.9 ijkl	85.9 cdef	8.4 e	3.6 fgh	15.5 ab
M19	2014	SA, Vic	20	crown seal	3.1 abc	8.5 fgh	72.1 hij	8.4 e	6.1 c	14.6 ab
M20[c]	2014	Vic	21	crown seal	3.1 abc	9.3 cd	97.5 bc	6.6 j	9.2 a	14.9 ab
M21	2013	SA	18	screw cap	3.1 abc	8.3 hij	85.4 defg	10.0 a	3.4 gh	14.8 ab
M22	2014	SA	18	crown seal	2.9 bc	10.4a	113.2 a	4.6 o	7.0 b	15.2 ab
M23	2013	SE Australia	11	cork	2.9 bc	8.9 def	76.3 fghij	7.7 g	5.3 d	15.6 a
M24[c]	NV	SE Australia	15	cork	3.0 abc	8.2 hij	64.3 jk	7.3 hi	1.4 k	15.3 ab

TA measured as g/L of tartaric acid. Values are the means of three replicates, with the exception of price and quality ratings.
Means within a column followed by different letters are significantly different ($P = 0.05$, one-way ANOVA).
[a] Prices are for 750 mL bottles, with the exception of M17 (375 mL) and M22 (500 mL).
[b] Quality ratings determined by an expert panel (n=9) using a 20 point scoring system.
[c] Wines selected for consumer acceptance testing.

Table 5). Principal component analysis (PCA) of the CIELAB colour coordinates L*, a* and b*, gave the biplot shown in Figure 13. The 10 white Moscato wines (M04, M05, M07, M09, M13, M15, M16, M18, M21 and M24) were closely clustered near the x-axis on the right side of the biplot indicating the similarity amongst their colours, whereas the remaining 14 wines were distributed predominantly across the left-hand quadrants, reflecting their greater colour diversity (i.e. from orange to pink to light red). M11 was the only pink Moscato located on the right side of the biplot, which was attributed to its distinct pale orange colour. The first principal component explained 91.8% of the observed variation in wine colour, with separation of white Moscato wines based on lightness (i.e. L* > 98) and the absence of pink hues. Separation of pink Moscato wines was based on both reduced lightness (i.e. L* of between 87.1 and 95.4) and the intensity of red (a*) and yellow (b*) hues (Supp. Table 5), and accounted for a further 7.7% of the variation observed.

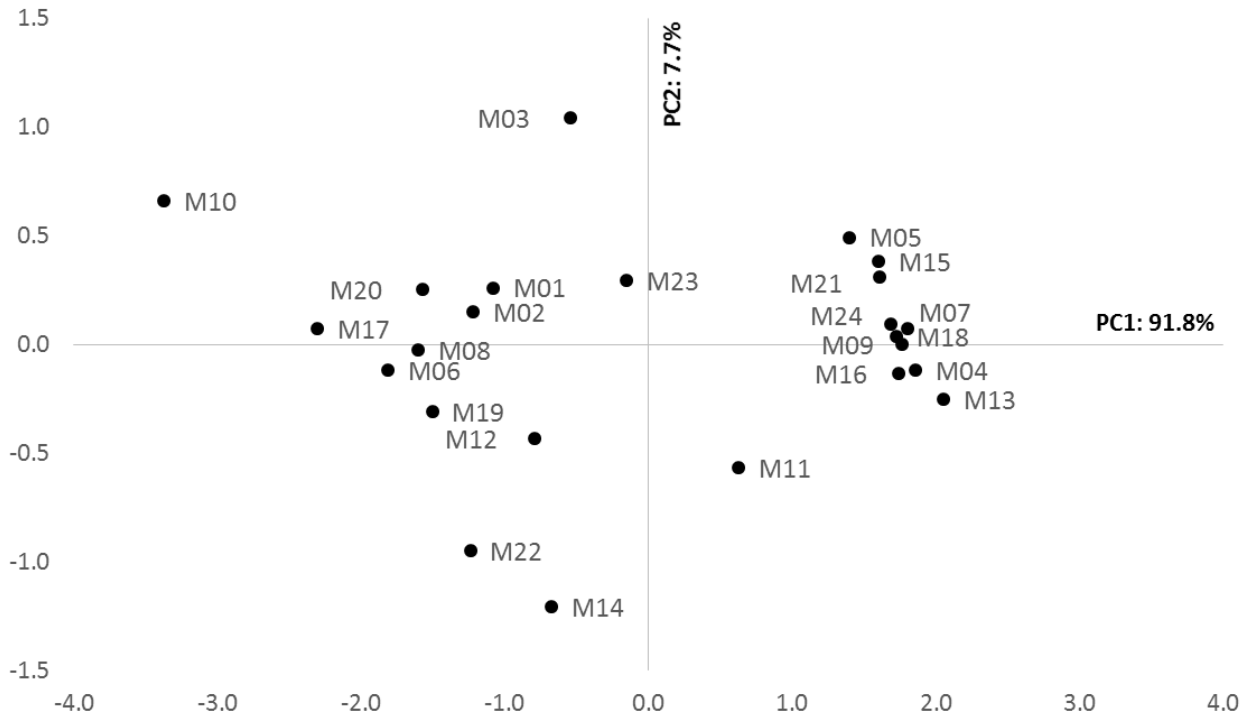


Figure 13. PCA biplot of CIELAB colour coordinates for Moscato wines. Reproduced from Culbert et al. 2018. Copyright 2018 Australian Society of Viticulture and Oenology Inc.

Bottle price and quality ratings ranged from $8 to $30 and 13.3 to 16.3, respectively (Table 13). Wine quality was determined by an expert panel of sparkling winemakers, who indicated they rated wines according to the intensity of varietal aroma and flavour attributes; the balance between sweetness and acidity; the palate structure (texture) and viscosity (weight); and in the case of older, more developed wines, ‘prominence of an attractive honey note’ and ‘retention of freshness and vibrancy’. Whereas a recent study found the quality of sparkling white wine closely reflected the method of production

(carbonation, Charmat, transfer or Méthode Traditionelle), and therefore bottle price (Culbert et al. 2017a), in this study, there was no correlation between price and wine quality (R = –0.21, P = 0.325). Indeed, the most expensive Moscato, M03, received the second lowest quality rating (i.e. 14.3), while the two least expensive Moscatos, M13 and M14, were both rated 15.4, putting them amongst the 7 most highly rated wines. However, only quality ratings for M07, M09 and M23 were found to be statistically significant from M11.

The carbon dioxide content of wines wasn't directly measured, but effervescence (bubble size and flow) was evaluated by DA (described below). Closure type was considered likely to reflect the degree of carbonation, with screw-cap closures being suitable for semi-sparkling (lightly carbonated) wines, but cork or crown seal required for more highly carbonated wines, i.e. to account for increased bottle pressure. Carbonation did not appear to influence wine quality, with the wines considered to be of highest and lowest quality, i.e. M09 and M11 respectively, both sealed under screw-cap (suggesting both were semi-sparkling wines).

Sensory profiles of Moscato wines

The sensory profiles of Moscato wines were determined by DA, with the intensity of 27 aroma and/or flavour attributes being rated, together with viscosity/body, bitterness, sweetness, acidity and effervescence (Table 14). Significant differences were observed for 24 of these attributes, which were then subjected to PCA. The initial PCA biplot showed two Moscato wines, M12 and M21, as clear outliers, i.e. these wines were positioned well away from both each other, and the remaining 22 wines (data not shown); with M12 exhibiting prominent dried fruit characters, while M21 exhibited intense oak, kerosene and aged characters. These wines did not exhibit the varietal expression typically expected of Moscato and so the decision was made to omit these wines from both the PCA of sensory data and the subsequent I-optimal prime statistical analysis (which would likely have resulted in selection of both these wines for consumer acceptance testing). PCA was performed on sensory data for the remaining 22 wines which gave the biplot shown in Figure 14. The first principal component explained 35% of variation and separated wines based on the prominence of fruity, floral and confectionary notes (i.e. stone fruit, tropical, apple/pear, floral/perfume, honey and confectionary aromas and flavours) vs. complex characters (i.e. oaky/woody, yeasty/bready and kerosene/aged characters). Three Moscatos, M10, M11 and M15, still exhibited a high degree of complexity and as such, they were clustered together on the left side of the biplot; with another 3 wines, M01, M20 and M23 also showing complexity, but to a lesser extent. In contrast, six Moscatos, M03, M05, M06, M07, M09, M18, were positioned on the right side of the biplot, driven by intense fruity, floral and confectionary aromas and flavours. The remaining wines were positioned around the origin, indicative of sensory profiles that comprised a combination of both varietal and developed characters. The second

Table 14. Sensory attributes and reference standards used for descriptive analysis of Moscato wines.

Attribute	Definitions	Reference standard[a]
Intensity	Perceived intensity of overall aroma or flavour	Not applicable
Confectionary	Turkish delight, bubble gum, musk, sherbet, strawberries and cream	3.5 g lollies (half each of yellow, green and red 'snakes', cut in pieces) and turkish delight (¼ of a Cadbury's square)
Red fruit	Strawberry, raspberry	Half a strawberry and a raspberry
Stone fruit[b]	Apricot, nectarine, peach, white peach	8.3 g dried peach and apricot mixture, 4.2 g fresh nectarine, 3.8 g fresh peach and 3.0 g fresh apricot
Tropical	Pineapple, melon, lychee, banana, passionfruit	5.8 g rock melon (pulp and seeds), 2.3 g lychee, 1 mL lychee juice, 5.6 g pineapple, 1 mL pineapple juice and 3.0 g passionfruit
Citrus[b]	Lemon, grapefruit, lime, orange, mandarin	4.5 g grapefruit, 3.0 g lemon, 2.0 g lime and 3.0 g orange
Apple/pear[b]	Apple, pear	6.0 g apple and 6.0 g pear
Floral/perfume	Rose, perfume, blossom, honeysuckle	½ tablespoon of rose water, two jasmine flower petals, two rose flower petals and 0.3 g rose flower stamen
Dried fruit	Dried fruit	Dried peach and apricot mixture 8.3 g and raisins 3.0 g
Honey	Honey	1.35 g honey
Green	Green, grassy, herbal	Mixture of grass clippings, parsley, tomato leaf and basil (0.2 g of each)
Yeasty/bready	Dough	0.1 g dried yeast
Kerosene/aged	Nutty, kerosene, developed	Aged sparkling white wine with an apparent kerosene note
Oaky/woody	Oaky, woody	2 untoasted oak chips
Viscosity/body	Overall perception of palate weight	Not applicable
Bitterness	Perception of bitterness	Not applicable
Sweetness	Perception of sweetness	Not applicable
Acidity	Level of acid perceived	Not applicable
Effervescence	Overall perception of bubble size and flow	Not applicable

[a] Standards prepared in 20 mL of neutral dry white wine (except for the kerosene/aged standard).
[b] All components were used, i.e. pulp and peel.

principal component explained an additional 19% of variation and may have be driven more by taste and palate attributes, such as viscosity/body, bitterness, sweetness, acidity and effervescence. When intensity ratings for effervescence were considered by closure type, wines under cork had the highest effervescence ratings (being 8.1 to 9.6), followed by wines under crown seal (4.8 to 7.8), while wines under screw cap had the lowest effervescence ratings (2.5 to 5.3), suggesting they were only lightly carbonated, semi-sparkling wines. The Moscato wines under cork (i.e. M01, M04–M08, M13, M14, M16, M23 and M24) were all positioned in the lower half of the PCA biplot, suggesting effervescence may have influenced separation within the second dimension (Figure 14). A further 12% of variation was explained by the third principal component (data not shown), with variation in this dimension attributed to overall aroma intensity.

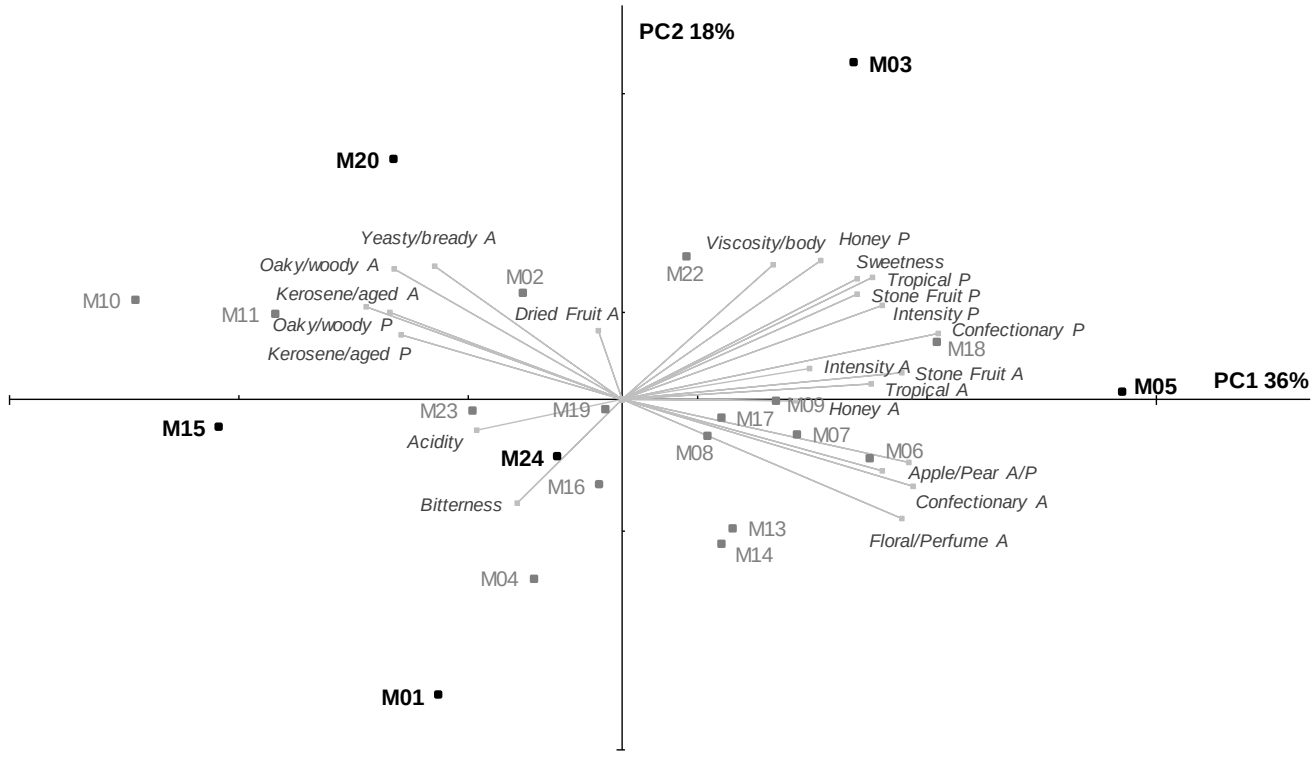


Figure 14. PCA biplot of selected sensory attribute ratings for Moscato wines (excluding M12 and M21); A = aroma attribute and P = palate attribute. Reproduced from Culbert et al. 2018. Copyright 2018 Australian Society of Viticulture and Oenology Inc.

When wine quality was taken into account, wines with higher quality ratings (i.e. ratings ≥15.0/20) tended to be positioned in quadrants on the right of the biplot; with the exception of M03 and M17, which were given ratings of 14.3 and 14.9 respectively. Conversely, the majority of wines located in quadrants on the left (8 of 11) were rated <15.0/20. Interestingly, the wines given the highest

quality ratings, i.e. M05, M07, M09, M13, M14, M18 and M23 (being ≥15.4/20), were not clustered especially close together. Most were associated with varietal aromas and flavours, but M23 instead exhibited moderate complexity, suggesting the expert panel valued an array of sensory properties. PLSR analysis of DA data against mean quality ratings indicated aroma intensity, confectionary, tropical fruit, apple/pear and floral/perfume aromas and apple/pear flavour were positively correlated with Moscato quality, while stone fruit aroma and viscosity/body negatively influenced quality (Figure 15).

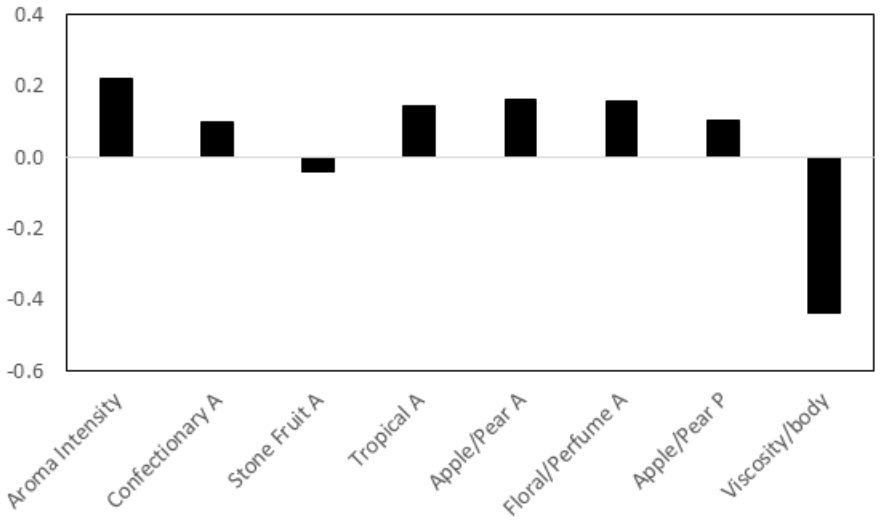


Figure 15. PLSR coefficients for selected sensory attributes and chemical parameters vs. mean quality ratings of Moscato wines; A = aroma attribute and P = palate attribute. Reproduced from Culbert et al. 2018. Copyright 2018 Australian Society of Viticulture and Oenology Inc.

Correlation analysis confirmed several relationships between chemical measurements and the intensity of taste and/or palate attributes. As expected, sweetness was positively correlated with residual sugar (R = 0.53, *P = 0.002*) and negatively correlated with alcohol (R = –0.56, *P = 0.004*); acidity was positively correlated with TA (R = 0.76, *P = 0.0001*) and negatively correlated with pH (R = –0.73, *P < 0.0001*); and bitterness was positively correlated with alcohol (R = 0.93, *P < 0.0001*) and negatively correlated with residual sugar (R = –0.72, *P < 0.0001*). Viscosity/body was positively correlated with residual sugar (R = 0.53, *P = 0.0008*), but negatively correlated with alcohol content (R = –0.44, *P = 0.032*), which further supported the large negative correlation observed between alcohol and residual sugar content.

Consumer acceptance of different styles of Moscato

Statistical analysis (I-optimal prime) was performed on sensory data to identify a subset of Moscato wines, representative of the sensory diversity observed for all wines, for evaluation by consumers in

acceptance tests. M01, M03, M05, M10, M19 and M20 were initially selected, but since 5 of these were pink Moscatos, the decision was made to substitute M10 and M19 with M15 and M24 respectively, to give 3 white and 3 pink Moscato wines. The final subset of six wines (highlighted in bold in Figure 14) ranged in price from $10 to $30, and displayed the intended variation in composition, sensory profiles and quality (Table 13, Figure 14). pH ranged from 3.0 to 3.2, TA from 7.8 to 9.3 g/L, residual sugar from 56.5 to 114.8 g/L, alcohol content from 6.4 to 8.8% v/v and phenolic substances from 1.4 to 9.2 au. Quality ratings varied from 14.3 to 15.5, but as indicated above, were not significantly different. Importantly, quality ratings also varied, from 14.3 to 15.5. Key sensory differences observed between the subset of Moscatos included both varietal (confectionary, apple/pear, floral/perfume, stonefruit and tropical) and developed (oaky/woody, honey, kerosene/aged) characters, as well as viscosity/body, bitterness, sweetness and effervescence.

One hundred and forty consumers were recruited to participate in acceptance tests (Table 15), with a considerably higher proportion of females being recruited than males (68% vs 32%). This was not entirely surprising given the perception that sparkling wine is a 'female drink' (Charters et al. 2011) and the self-selecting nature of recruitment, and was consistent with the gender bias (in favour of female participants) experienced in several other recent sparkling wine-related studies involving consumer trials (Culbert et al. 2016, 2017, Verdonk et al. 2017). A higher proportion of younger consumers (aged 18 to 34 years) was also recruited, being 40% compared to 31.4% and 25.7%, for 35-54 year olds and ≥55 year olds, respectively. Almost 56% of consumers held tertiary qualifications and just over one third had household incomes >$100,000 per annum. Most consumers (almost 70%) consumed sparkling wine at least once every 1–2 months. Significant differences were observed between the liking scores given to the subset of Moscato wines, which ranged from 4.7 to 5.6 (Table 16). On average, the fruit driven Moscato, M05, was liked the most, followed closely by M24, while M01, the wine that exhibited the most acidity and bitterness, was liked least; albeit only the liking scores for M01 and M05 were significantly different. The extent to which factors such as gender, age, frequency of sparkling wine consumption and wine involvement might influence consumer wine preferences was also considered, but surprisingly, no statistically significant differences in liking scores were not observed when consumers were segmented by demographic factors (Supp. Table 6).

Table 15. Demographics, consumption and involvement of consumers and hedonic clusters.

	Total sample[a] **(*n*=140)**	**Cluster 1**[a] **(*n*=69)**	**Cluster 2**[a] **(*n*=71)**
Gender			
Male	32.1	26.1	38.0
Female	67.9	73.9	62.0
Age (years)[a]			
18-34	40.0	43.5	36.6
35-54	31.4	27.5	35.2
55+	25.7	26.1	25.4
Education			
High school/certificate/diploma	44.3	53.6	35.2
Bachelor's degree	41.4	34.8	47.9
Postgraduate	14.3	11.6	16.9
Household income (AUD)			
<$30,000	7.1	8.7	5.6
$30,001-$50,000	13.6	13.0	14.1
$50,001-$75,000	21.4	24.6	18.3
$75,001-$100,000	20.7	20.3	21.1
$100,001-$200,000	31.4	29.0	33.8
>$200,000	5.7	4.3	7.0
Sparkling wine consumption			
Once a fortnight or more	25.0	23.2	26.8
Once every 1-2 months	44.3	43.5	45.1
< Once every 2 months	30.7	33.3	28.2
Wine involvement[b]			
Low (<4.0)	45.0	47.8	42.3
High (≥4.0)	55.0	52.2	57.7

Values represent percentage of consumers.
[a] Data missing for 4 consumers (2 in each cluster).
[b] Involvement determined using the wine involvement scale (Bruwer and Huang, 2012), with low < 4.0/7 and high ≥ 4.0/7.

Recognising the inherent diversity typically observed amongst consumers, segmentation was performed based on consumers' individual liking scores, and two distinct clusters comprising consumers with opposing preferences for the subset of Moscato wines were identified (Tables 15 and 16). Cluster 1 comprised 69 consumers, who liked M03, M05 and M20 equally, but disliked M01; whereas Cluster 2, which comprised 71 consumers, most liked M01 and M24, i.e. the wines liked least by Cluster 1. Demographic data indicated Cluster 1 comprised higher proportions of younger, female and less educated consumers than Cluster 2. The majority of consumers from Cluster 2 held tertiary qualifications and were more involved with wine than Cluster 1 consumers.

Table 16. Consumer liking scores for subset of Moscato wines.

	Hedonic ratings[a]		
	Total sample (*n*=140)	**Cluster 1 (*n*=69)**	**Cluster 2 (*n*=71)**
M01	4.7 b	4.3 d	5.0 ab
M03	5.1 ab	6.5 a	3.8 c
M05	5.6 a	6.5 a	4.7 bc
M15	4.9 ab	5.4 bc	4.4 bc
M20	5.0 ab	6.4 ab	3.7 c
M24	5.5 ab	5.0 cd	6.0 a

Means within a column followed by different letters are significantly different (P = 0.05, one-way ANOVA).
[a] Hedonic ratings determined using a 9 cm line scale, with anchors from left (dislike extremely) to right (like extremely).

Cluster 2 consumers did not find fruity, confectionary characters or sweetness particularly appealing, but instead preferred more acidic, less sweet Moscato wine styles, i.e. M01 (Table 13). This is further supported by the comparatively lower liking scores given to the Moscatos with the highest residual sugar content and perceived sweetness, i.e. M03 and M20. Cluster 1 consumers liked most of the subset of Moscato wines, but did not find the complexity of M01 to their liking.

PCA was also performed on a combination of sensory data, liking scores (by consumer cluster) and quality ratings for the Moscato wine subset, to determine the extent to which different sensory attributes influenced consumer wine preferences (Figure 16). The first and second principal components explained 44% and 37% of variation observed respectively, and the opposing stylistic preferences of each cluster were clearly evident: Cluster 1 was positioned in the top right quadrant in close proximity to M03, the wine with the most prominent fruit, honey and confectionary characters and marked sweetness and viscosity/body; whereas Cluster 2 was positioned near the y-axis at the bottom of the biplot, in proximity to M01 and M24, i.e. the wines which exhibited greater acidity, varietal aromas and less apparent sweetness.

Considerable diversity was observed amongst the composition and sensory profiles of the Moscato wines studied, with some exhibiting more prominent varietal characters, while others displayed complex, developed notes. Mean hedonic ratings for the subset of Moscato wines ranged from 4.7 to 5.6, but segmentation of consumers according to their individual liking scores enabled

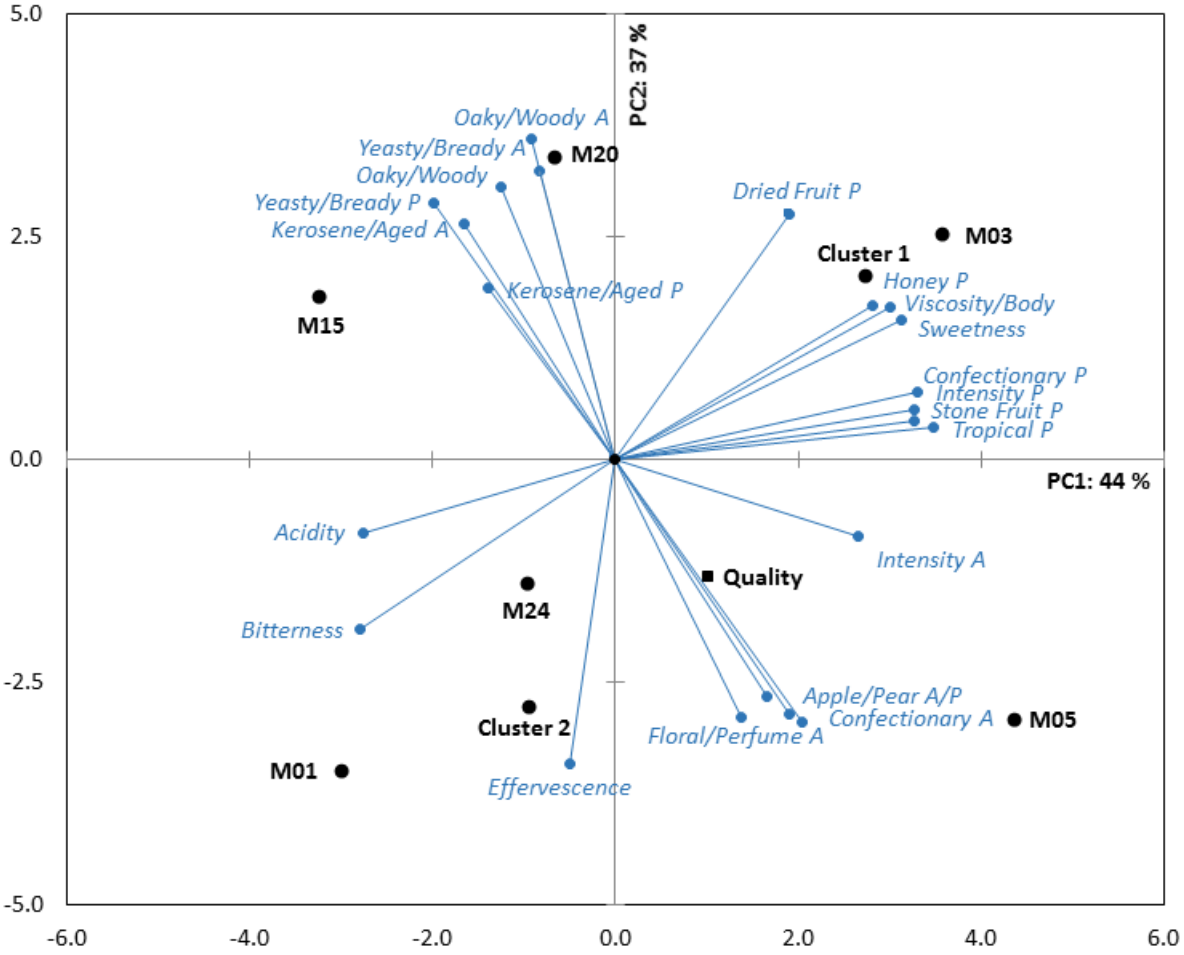


Figure 16. PCA biplot of sensory attribute ratings, liking scores (for consumer clusters) and quality ratings for subset of Moscato wines; A = aroma attribute and P = palate attribute. Reproduced from Culbert et al. 2018. Copyright 2018 Australian Society of Viticulture and Oenology Inc.

identification of two consumer clusters with opposing preferences for the different styles of Moscato. While purchasing decisions are likely to be influenced by an array of competing factors, including extrinsic factors such as price, brand and occasion, insight into the sensory attributes driving consumer preferences for different styles of Moscato will enable industry to tailor wine styles and marketing strategies to specific segments of the target market. While results from this study did not identify preferences based on gender, age or wine involvement, anecdotal evidence and published research alike, suggests gender and/or generational based differences in the consumption patterns and/or perceptions of sparkling wine (and Champagne). Similar perceptions of Moscato seem likely. Ongoing research efforts therefore aim to determine consumer perceptions of Moscato, relative to other sparkling wine styles, in order to further characterise the domestic Moscato consumer market.

A manuscript based on this study has been accepted for publication in the Australian Journal of Grape and Wine Research: Culbert, J.A., Ristic, R., Ovington, L.A. Saliba, A.J. and Wilkinson, K.L. (2018) Sensory profiles and consumer acceptance of different styles of Australian Moscato. Australian Journal of Grape and Wine Research (*in press*).

Supplementary Table 5. CIELAB colour coordinates (L*, a* and b*) for Moscato wines.

	L*	a*	b*
M01[a]	91.7	8.5	9.1
M02	91.9	10.1	9.1
M03[a]	94.4	4.8	10.1
M04	98.9	-0.5	4.0
M05[a]	98.4	-0.8	6.0
M06	88.8	11.5	9.3
M07	99.2	-0.7	4.5
M08	89.0	10.0	9.1
M09	98.6	-0.8	4.3
M10	87.1	16.1	13.4
M11	95.4	5.3	4.8
M12	91.9	9.9	7.2
M13	99.5	-0.5	3.4
M14	91.7	12.3	5.4
M15[a]	98.9	-1.0	5.4
M16	98.3	-0.4	4.1
M17	88.4	13.3	10.5
M18	98.6	-0.7	4.5
M19	89.7	11.4	8.4
M20[a]	90.7	10.6	9.8
M21	98.7	-0.9	5.3
M22	90.5	13.5	6.8
M23	94.7	5.8	7.9
M24[a]	98.6	-0.7	4.7

[a] Wines selected for consumer acceptance testing

Supplementary Table 6. Liking scores for the subset of Moscato wines for consumers segmented according to gender, age, frequency of sparkling wine consumption and wine involvement.

	Hedonic ratings[a]					
	M01	**M03**	**M05**	**M15**	**M20**	**M24**
Gender						
Male (n=45)	5.0	5.0	5.8	4.4	4.9	5.7
Female (n=95)	4.5	5.2	5.5	5.1	5.1	5.4
Age[b] ***(years)***						
18-34 (n=56)	4.1	5.2	5.8	4.8	5.0	5.2
35-54 (n=44)	5.1	5.3	5.9	5.1	4.9	5.8
55+ (n=36)	5.2	4.5	4.8	4.8	5.2	5.4
Sparkling wine consumption						
Low (n=35)	5.1	4.7	6.1	5.0	5.2	5.3
Medium (n=62)	4.5	5.2	5.5	5.2	5.1	5.7
High (n=43)	4.6	5.3	5.4	4.4	4.8	5.4
Wine involvement[c]						
Low (n=63)	4.7	5.5	5.8	4.8	4.9	5.4
High (n=77)	4.7	4.8	5.5	5.0	5.2	5.6

[a] Hedonic ratings determined using a 9 cm line scale, with anchors from left (dislike extremely) to right (like extremely).
[b] Data from four consumers who did not specify their age is missing.
[c] Involvement determined using the wine involvement scale (Bruwer and Huang, 2012), with low $< 4.0/7$ and high $\geq 4.0/7$.

Part D: Objective measures of sparkling wine style and quality.

A key objective of this project was to develop objective measures by which sparkling wine style and quality can be determined. As such, correlation analysis was performed in an attempt to determine to what extent parameters such as price, bottle weight, chemical composition, foaming properties and/or intensity of sensory attributes influenced the quality ratings of sparkling white wines (Table 17) and Moscatos (Table 18).

For physical and chemical parameters of sparkling white wines, the highest positive correlations with quality were for price and bottle weight, being r=0.715 and 0.534, respectively. Other positive correlations with quality included alcohol content (r=0.479), aspartic acid concentration (r=0.346) and wine protein (r=0.466). Whereas the highest negative correlation with quality were observed for octanoic acid and its corresponding ethyl ester, being r=–0.547 and –0.538, respectively. Other negative correlations with quality included sugar content (r=–0.441), total phenolics (r=–0.279), low molecular weight (i.e. 10 kDa) RG's (r=–0.396), decanoic acid (r =–0.425) and ethyl decanoate (r=–0.353).

Meaningful correlations with quality (both positive and negative) were also observed for the intensity of many sensory attributes. Expert panellists indicated they rated wine quality according to: the size and persistence of the bead (bubble); the elegance of palate structure and prominence of complexity (i.e. presence of developed characters derived from yeast autolysis and ageing); the balance of sweetness, acidity and phenolics; and the absence of faults or imbalance. This is consistent with the correlations calculated for the sensory attributes of sparkling white wines. The highest positive correlations with quality were observed for developed characters such as, mushroom/earthy aroma (r=0.643), yeasty aroma (r=0.681), toasty aroma (r=0.717), aged/developed aroma (r=0.727), meaty/savoury flavour (r=0.670), mushroom/earthy flavour (r=0.673), yeasty flavour (r=0.597), toasty flavour (r=0.666), aged/developed flavour (r=0.747), and palate complexity (r=0.680). In contrast, many of the fruity, floral and confectionary aromas and/or flavours, together with sweetness, gave highly negative correlations (i.e. $r \leq$–0.435).

Far fewer meaningful correlations were observed for Moscato wines (Table 2). Indeed, of the parameters measured, only aroma intensity (r=0.450), confectionary aroma (r=0.585), tropical aroma (r=0.504), floral/perfume aroma (r=0.522) and apple/pear flavour (r=0.451) were correlated with quality.

Table 17. Correlation coefficients for sparkling white wine quality ratings against price, bottle weight, foaming parameters, chemical composition and sensory properties.

Parameter	Coefficient (*r*)	*P*	Parameter	Coefficient (*r*)	*P*
Price	**0.715**	**<0.0001**	Hexanoic acid	-0.176	0.225
Bottle weight	**0.534**	**<0.0001**	Decanoic acid	**-0.547**	**< 0.0001**
pH	-0.166	0.249	Octanoic acid	**-0.425**	**0.002**
TA	0.177	0.220	Ethyl hexanoate	0.132	0.367
Sugar	**-0.441**	**0.001**	Ethyl decanoate	**-0.538**	**< 0.0001**
Alcohol	**0.479**	**<0.001**	Ethyl octanoate	**-0.353**	**0.013**
Phenolics	**-0.279**	**0.050**	citrus A	**-0.518**	**< 0.001**
Total amino acids	-0.020	0.891	stone fruit A	**-0.557**	**< 0.0001**
Asp	**0.346**	**0.014**	tropical A	**-0.478**	**< 0.001**
Asn	0.144	0.320	pome fruit A	-0.171	0.236
Ser	0.170	0.239	floral A	**-0.623**	**< 0.0001**
Glu	-0.031	0.829	confectionary A	**-0.498**	**< 0.001**
His	-0.072	0.619	meaty/savoury A	**0.651**	**< 0.0001**
Gly	0.239	0.095	mushroom/earthy A	**0.643**	**< 0.0001**
Arg	-0.038	0.795	honey A	0.116	0.424
Thr	0.110	0.447	yeasty A	**0.681**	**< 0.0001**
Ala	0.076	0.599	toasty A	**0.717**	**< 0.0001**
Pro	-0.107	0.460	vanilla/caramel A	**0.435**	**0.002**
Tyr	0.105	0.470	aged/developed A	**0.727**	**< 0.0001**
Val	0.074	0.611	citrus P	-0.229	0.110
Lys	-0.018	0.901	tropical P	**-0.552**	**< 0.0001**
Ile	0.008	0.954	floral P	**-0.527**	**< 0.0001**
Leu	0.013	0.927	confectionary P	**-0.540**	**< 0.0001**
Phe	0.098	0.498	meaty/savoury P	**0.670**	**< 0.0001**
Proteins	**0.466**	**0.001**	mushroom/earthy P	**0.673**	**< 0.0001**
Total polysaccharides	-0.046	0.751	honey P	-0.125	0.385
Mannoproteins	0.018	0.903	yeasty P	**0.597**	**< 0.0001**
AGP	0.186	0.197	toasty P	**0.666**	**< 0.0001**
RG 1	0.012	0.933	vanilla/caramel P	**0.371**	**0.008**
RG 2	-0.051	0.725	aged/developed P	**0.747**	**< 0.0001**
RG 3	**-0.396**	**0.004**	sweetness	**-0.549**	**< 0.0001**
V*f* (mL)	-0.005	0.971	acidity	**0.371**	**0.008**
L*f* (s)	0.166	0.255	complexity	**0.680**	**< 0.0001**

Values in bold are different from 0 with a significance level α=0.05.
A = aroma attribute; P = palate attributes.

Table 18. Correlation coefficients for Moscato quality ratings against composition and sensory properties.

Parameter	Coefficient (*r*)	*P*	Parameter	Coefficient (*r*)	*P*
L*	0.193	0.367	kerosene/aged A	-0.134	0.532
a*	-0.178	0.406	oaky/woody A	-0.144	0.503
b*	-0.188	0.379	intensity P	0.238	0.263
% Alcohol	0.099	0.646	confectionary P	0.260	0.220
pH	0.023	0.913	red fruit P	0.039	0.858
TA	-0.253	0.234	stone fruit P	0.125	0.561
Phenolics	-0.387	0.062	tropical P	0.275	0.193
Sugar	-0.145	0.498	citrus P	0.387	0.061
intensity A	**0.450**	**0.027**	apple/pear P	**0.451**	**0.027**
confectionary A	**0.585**	**0.003**	dried fruit P	0.158	0.461
red fruit A	0.149	0.488	honey P	0.195	0.361
stone fruit A	0.329	0.117	green P	-0.092	0.669
tropical A	**0.504**	**0.012**	yeasty/bready P	-0.114	0.595
citrus A	0.399	0.053	kerosene/aged P	-0.148	0.489
apple/pear A	0.401	0.052	oaky/woody P	-0.146	0.495
floral/perfume A	**0.522**	**0.009**	effervescence P	0.352	0.092
dried fruit A	0.218	0.306	viscosity/body P	-0.106	0.621
honey A	0.379	0.068	bitterness P	0.045	0.836
green A	-0.110	0.609	sweetness P	0.021	0.924
yeasty/bready A	-0.195	0.361	acidity P	-0.069	0.748

Values in bold are different from 0 with a significance level α=0.05.
A = aroma attribute; P = palate attributes.

Completion of two additional peer-reviewed publications describing the volatile composition of sparkling white wines and Moscato wines is anticipated following submission of this final report and correlation analysis of volatile data may identify other wine constituents that influence sparkling wine quality (either positively or negatively), particularly given the extent to which sensory properties seemed to be meaningfully correlated with quality scores.

Outcomes and Conclusion:

The key objectives of this project were to characterise the relative importance of different segments of the Australian sparkling wine sector, to gain insight into consumer preferences for different styles of sparkling wine and their sensory properties, and to develop objective measures by which sparkling wine style and quality can be determined.

Many of the activities outlined in the original proposal (or approved project variations) were completed as planned. Market sales data was obtained and used to determine the relative importance of different segments of the sparkling wine sector; with results published as a paper in an industry technical journal. Importantly, this data also informed the scope and direction of subsequent chemical and sensory analyses (i.e. the focus on sparkling white wines in Years 1 and 2, and Moscato in Years 2 and 3, as indicated above).

Chemical and sensory analysis of sparkling wines was largely performed as proposed, albeit a larger number of wines were analysed by ATR MIR than initially intended: i.e. 139 Australian sparkling wines, comprising sparkling white (n=50), rosé (n=25), red (n=25), Prosecco (n=14) and Moscato (n=25) wines. However, this enabled compositional differences between different sparkling wine segments to be observed, and following principal component analysis (PCA), enabled discrimination of wines according to both sparkling wine style, and in the case of sparkling white wines, by method of production (and to a lesser extent, wine quality). Chemical and sensory analyses of a considerably larger number of sparkling white wines was undertaken, than initially proposed (i.e. n=50). However, this ensured a diverse range of sparkling white wines, representative of the four key methods of production, a range of price points, Australian wine regions and brands were analysed. Opportunities arose to undertake additional compositional analysis of the 50 sparkling white wines, i.e.: protein and polysaccharide analysis in collaboration with the Australian Wine Research Institute; amino acid profiling in collaboration with CSIRO; and measurement of foaming properties in collaboration with The University of Melbourne. Chemical and sensory analysis of Moscato wines was completed as planned. Collectively, this has culminated in three peer-reviewed papers (Culbert et al. 2015, 2017a, 2017b); with an additional paper currently under review. As indicated above, two additional manuscripts (describing the volatile composition of sparkling white wines and Moscato wines, respectively) are anticipated following submission of this final report. As such, the project will have delivered the research outputs outlined in the original proposal (in terms of the number and nature of publications), pending successful review and acceptance of manuscripts (but may still yield at least two additional papers).

In terms of practical outcomes for the Australian wine industry, the project's outcomes have demonstrated the diversity in not only the sensory profiles of different styles of sparkling white wine and Moscato, but also the diverse preferences of different segments of sparkling wine consumers. Expert panel ratings demonstrated sparkling wine quality is closely associated with prominent toasty, yeasty, aged/developed notes (i.e. attributes associated with yeast autolysis and lees aging typical of the traditional method of sparkling wine production); whereas carbonated and Charmat sparkling wines were typically fruit-driven styles and were generally considered to be of lower quality. Irrespective of quality ratings, each of the sparkling white wines evaluated by consumers during acceptance tests were considered favourably by at least one of the consumer clusters identified by segmentation (based on individual liking scores). This highlights the diversity inherent amongst wine consumers and suggests different marketing strategies might be needed to influence the consumption behavior and/or purchasing decisions of consumers from different segments of the target market. This was also evident following acceptance testing of Moscato wines. Although only two consumer clusters were identified (based on segmentation according to individual liking scores), the two clusters were found to have opposing preferences for the subset of Moscato wines. Surprisingly, neither study identified meaningful preferences based on gender, age, frequency of sparkling wine consumption or wine involvement, despite previous studies suggesting sparkling wine is often considered a 'female drink' and/or symbolic of celebration and prestige to younger consumers (Charters et al. 2011). Several studies have shown consumers rely on extrinsic cues, country of origin and brand in particular, when evaluating the perceived quality and value of sparkling wines (Lange et al. 2002, Combris et al. 2006, Vignes and Gergaud 2007, Culbert et al. 2017a). Sparkling wine producers might therefore need to exploit factors such as geographical origin, occasion and self-worth when marketing sparkling white wines. In the case of Moscato, and despite the findings of the current study, it seems likely that the sweet, fruity and refreshing characters typical of this segment of sparkling wine is likely to appeal to younger and/or female consumers, including the Millennials, because these sensory attributes are both familiar and approachable (Lesschaeve 2008, Dodd et al 2010). Moscato could therefore be considered an entry level wine for consumers with limited wine experience; consumers whose wine preferences will continue to evolve over time, as they gain greater experience, knowledge and involvement with wine (Dodd et al. 2010). Consumer purchasing decisions will continue to be influenced by extrinsic factors, so understanding consumers' attitudes towards different sparkling wine segments, including any preconceived expectations of particular sparkling wine styles, remains the focus of ongoing research (being undertaken by PhD candidate, Naomi Verdonk).

Recommendations:

A key finding from this project was the extent to which the prominence of developed characters (derived from yeast autolysis and/or ageing) influenced the quality ratings of sparkling white wines. Indeed, the expert panel indicated complexity was one of the factors against which they based their quality evaluations and this was further demonstrated through correlation analysis; i.e. the highest positive correlations with quality were observed for yeasty, toasty, developed/aged characters.

Traditional sparkling winemaking involves two successive fermentations: primary fermentation transforms grape must into base wine, while secondary fermentation generates carbon dioxide under pressure to achieve the 'bubble'. However, it's the compositional changes that occur when sparkling wine is subsequently aged on yeast lees, and their impact on the sensory and foaming properties of wine, that ultimately determine sparkling wine quality. Whilst there have been extensive studies on yeast autolysis, particularly concerning the influence of different conditions (e.g. fresh yeast vs. active dry yeast, temperature, pH, and model wine systems vs. wine) on the autolysis process, some results are contradictory. Furthermore, the complex nature of sparkling wine has hindered identification of the key volatile compounds responsible for the aroma and flavour expected of traditional sparkling wines. The mechanisms responsible for the induction of autolysis and cellular pathways involved during the degradation of yeast cell walls are also poorly understood. Many of the volatile compounds identified in traditional sparkling wines to date have been found in table wines, including wines made without lees ageing. As such, the volatile compounds specifically derived from autolysis of yeast, and their individual contributions to sparkling wine aroma and flavour, remain unclear. Factors such as grape variety, region of origin (and climate), yeast strain, tirage age and storage conditions will likely influence wine composition, and therefore sensory properties. Therefore, research that improves our understanding of the autolysis process is essential to enable identification of: (i) the odour-active compounds released during lees aging and their specific organoleptic impact(s); and potentially (ii) methods for accelerating the autolysis process.

Appendix 1: Communication

Research findings have been formally communicated via publication in peer-reviewed scientific journals and industry technical journals, and presentations at national and international conferences:

Peer-Reviewed Journal Articles:

Culbert, J.A., Ristic, R., Ovington, L.A. Saliba, A.J. and Wilkinson, K.L. (2018) Sensory profiles and consumer acceptance of different styles of Australian Moscato. Australian Journal of Grape and Wine Research (*in press*).

Culbert, J.A., Ristic, R., Ovington, L.A. Saliba, A.J. and Wilkinson, K.L. (2017a) Influence of production method on the sensory profiles and consumer acceptance of different styles of Australian sparkling white wine. Australian Journal of Grape and Wine Research **23**, 170–178.

Culbert, J.A., McRae, J., Condé, B.C., Schmidtke, L., Nicholson, E., Smith, P.A., Howell, K.S., Boss, P.K. and Wilkinson, K.L. (2017b) Influence of production method on the chemical composition, foaming properties and quality of Australian carbonated and sparkling white wines. Journal of Agricultural and Food Chemistry 65, 1378–1386.

Verdonk, N., Wilkinson, J., Culbert, J., Ristic, R., Pearce, K. and Wilkinson, K. (2017) Towards a model of sparkling wine buyer behaviour. International Journal of Wine Business Research **29**, 58–73.

Culbert, J., Verdonk, N., Ristic, R., Olarte Mantilla, S., Lane, M., Pearce, K., Cozzolino, D. and Wilkinson, K. (2016) Understanding consumer preferences for Australians sparkling wine vs. French Champagne. Beverages **2**, 19.

Culbert, J.A., Cozzolino, D., Ristic, R. and Wilkinson, K.L. (2015) Classification of sparkling wine style and quality by MIR spectroscopy. Molecules **20**, 8341–8356.

Industry Journal Articles:

Verdonk, N.R., Culbert, J.A. and Wilkinson, K.L. (2015) All that sparkles: Consumer perceptions of sparkling wine. Wine and Viticulture Journal **30**, 71–73.

National Conference Presentations:

16th Australian Wine Industry Technical Conference, Adelaide, Australia, July 2016

Compositional variation amongst Australian sparkling white wines (*oral presentation, invited speaker*) Culbert, J.A., McRae, J., Schmidtke, L., Nicholson, E., Boss, P., Smith, P.A., Wilkinson, K.L.

Compositional variation amongst Australian sparkling white wines (*poster presentation)* Culbert, J.A., McRae, J., Schmidtke, L., Nicholson, E., Boss, P., Smith, P.A., Wilkinson, K.L.

Crafty consumer mapping: Understanding consumer preferences for Australian sparkling wine (*workshop presentation*) Wilkinson, K.L. and Culbert, J.A.

2014 Crush Grape and Wine Symposium, Adelaide, Australia, November 2014

Evaluating the quality of Australian sparkling wine (*oral presentation*) Culbert, J.A., Cozzolino, D., Ristic, R., Pearce, K.L., Schmidtke, L., Saliba, A., Ovington, L., Wilkinson, K.L.

15th Australian Wine Industry Technical Conference, Sydney, Australia, July 2013

The Australian sparkling wine market: A snapshot (*poster presentation*)

Wilkinson, K.L., Ristic, R., Culbert, J.A., Wilkinson, J.W., Pearce, K.L.

International Conference Presentations:

In Vino Analytica Scientia, Trento, Italy, July 2015

Understanding consumer preferences for Australian sparkling wine vs. French Champagne

Culbert, J.A., Verdonk, N.R., Lane, M.J., Pearce, K.L., Ristic, R., Cozzolino, D., Wilkinson, K.L. (*poster presentation*)

Macrowine 2014, Stellenbosch, South Africa, September 2014

Classification of Australian sparkling wine style and quality by ATR-MIR spectroscopy (*poster presentation*) Culbert, J.A., Cozzolino, D., Ristic, R., Pearce, K.L. and Wilkinson K.L.

SenseAsia 2014, Changi, Singapore, May 2014

Consumer preferences for French Champagne and Australian sparkling wine (*poster presentation*) Culbert, J.A., Ristic, R., Verdonk, N.R., Lane, M.J., Pearce, K.L., Wilkinson, J.W. and Wilkinson K.L.

Appendix 2: Intellectual Property

The intellectual property arising from this project comprises knowledge regarding: (i) the extent to which wine constituents (e.g. organic acids, proteins, polysaccharides, amino acids, fatty acids and their ethyl esters, and volatile compounds) influence the sensory attributes (e.g. aroma, flavour, taste, mouthfeel and/or foaming properties) and quality of sparkling white wine and Moscato; and (ii) the sensory attributes driving consumer preferences for different styles of sparkling white wine and Moscato. There is no requirement for intellectual property to be patented or subject to other forms of IP protection. The majority of the project's research findings are published in either peer-reviewed scientific journals or industry technical journals.

Appendix 3: References

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Appendix 4: Staff

The University of Adelaide:

- Associate Professor Kerry Wilkinson
- Dr Julie Culbert
- Dr Renata Ristic
- Dr Daniel Cozzolino
- Naomi Verdonk (PhD student)

Charles Sturt University:

- Professor Anthony Saliba
- Dr Leigh Schmidtke
- Linda Ovington

The University of South Australia:

- Dr John Wilkinson
- Dr Karma Pearce
- Melissa Lane (Honours student)

Compositional analyses were also undertaken in collaboration with staff and/or students from other research organisations:

The Australian Wine Research Institute:

- Dr Paul Smith
- Dr Jacqui McRae

CSIRO:

- Dr Paul Boss
- Emily Nicholson

The University of Melbourne:

- Dr Kate Howell
- Bruna Condé

Appendix 5: Budget Reconciliation

The financial statement for this project has been submitted online via AGWA's Clarity Investment Management System.