Australian Government
Wine Australia

AWRI Australian Wine Research Institute

Low- and no-alcohol wine products – understanding technical and sensory-related challenges and opportunities



FINAL REPORT TO WINE AUSTRALIA

Project Number: 3.1.10

Principal Investigator: **Dr Wes Pearson**

Research Organisation: **Australian Wine Research Institute**

Date: **September 2022**

Project title: Project 3.1.10 – Low- and no-alcohol wine products – understanding technical and sensory-related challenges and opportunities

Authors: Dr Wes Pearson

Date: September 2022

Address: The Australian Wine Research Institute, Wine Innovation Central Building, Hartley Grove, cnr Paratoo Rd, Urrbrae (Adelaide), SA 5064

Disclaimer/copyright statement:

This document has been prepared by The Australian Wine Research Institute ('the AWRI') as part of fulfilment of obligations towards the Project Agreement AWR 1701-3.1.10 and is intended to be used solely for that purpose and unless expressly provided otherwise does not constitute professional, expert or other advice.

The information contained within this document ('Information') is based upon sources, experimentation and methodology which at the time of preparing this document the AWRI believed to be reasonably reliable and the AWRI takes no responsibility for ensuring the accuracy of the Information subsequent to this date. No representation, warranty or undertaking is given or made by the AWRI as to the accuracy or reliability of any opinions, conclusions, recommendations or other information contained herein except as expressly provided within this document. No person should act or fail to act on the basis of the Information alone without prior assessment and verification of the accuracy of the Information.

To the extent permitted by law and except as expressly provided to the contrary in this document all warranties whether express, implied, statutory or otherwise, relating in any way to the Information are expressly excluded and the AWRI, its officer, employees and contractors shall not be liable (whether in contract, tort, under any statute or otherwise) for loss or damage of any kind (including direct, indirect and consequential loss and damage of business revenue, loss or profits, failure to realise expected profits or savings or other commercial or economic loss of any kind), however arising out of or in any way related to the Information, or the act, failure, omission or delay in the completion or delivery of the Information.

The AWRI acknowledges and agrees that the Information was commissioned by Wine Australia under the terms of the Project Agreement and agrees to the provision of copyright permissions as required by this Agreement.

The Information must not be used in a misleading, deceptive, defamatory or inaccurate manner or in any way that may otherwise be prejudicial to the AWRI.

Table of contents

1. Abstract 4
2. Executive summary 4
3. Acknowledgements 5
4. Background 6
5. Project aims 6
6. Methods 8
7. Results and discussion 10
8. Outcome and conclusion 29
9. Recommendations 30
10. Appendix 1: Communication 30
11. Appendix 2: Intellectual property 31
12. Appendix 3: References 31
13. Appendix 4: Staff 32
14. Appendix 5: Other supporting material (including raw data, if appropriate) 32

1. Abstract

This project attempted to define the desirable sensory attributes of existing low- and no-alcohol wines or beverages in the market and use this information to support development of wine-like beverages with no- or low-alcohol that can satisfy consumer demands. No- and low-alcohol (NOLO) wines were found to lack some integral sensory attributes that are essential to wine, such as aroma/flavour characters and the textural, warming effect of alcohol. Chemical analysis also revealed that the de-alcoholisation process substantially reduced concentrations of most aroma/flavour compounds. An industry reference group was formed to help gauge interest and understand pain points within the category.

1. Executive summary

The category of no- and low-alcohol (NOLO) beverages has shown enormous growth over the past few years. Modern consumers are chasing products that contain all of the aroma, flavour and texture of traditionally produced alcoholic beverages but with little or no alcohol. A small number of Australian wine producers are embracing this market with much success, but the NOLO wine category is lagging behind both NOLO beer and spirits by value and volume, according to sales figures.

This report presents results from a two-year project on the opportunities and challenges associated with NOLO wines. It explores the current market offerings for NOLO wine in Australia, summarising sensory attributes, chemical composition and wine-likeness, as well as the opinions of varied wine industry professionals on where the category sits currently and where research and development efforts should be focused.

The project began by evaluating the NOLO products in the Australian marketplace. One hundred and twenty NOLO products including wine, wine-like products, grape-based products, cider, beer and spirits were evaluated. Initially, the wine and wine-like products were evaluated using a comparison scale, where the taster assessed the likeness to their concept of what wine should smell and taste like (the 'vinosity scale'). This preliminary assessment tool was used to screen potential products for inclusion in a more rigorous study involving descriptive sensory analysis and evaluating chemical composition. Initial sensory evaluations highlighted the lack of wine-likeness in most products, with the sparkling and white NOLO categories having higher mean vinosity scores than the red NOLO category.

From this group of NOLO products 10 sparkling, 16 white and rosé, and eight red wines were selected for more comprehensive analysis. The products underwent compositional analysis and sensory descriptive analysis. Concentrations of monoterpenes, low molecular weight sulfur compounds, norisoprenoids, oak volatiles, fermentation products, organic acids, glycerol, tannin and colour were all analysed.

The results of the sensory evaluations were then paired with the vinosity scores from the initial product assessments, to highlight the sensory attributes that are most associated with the vinosity of the NOLO wines. For the sparkling wines, vinosity was associated with the sensory attributes 'astringency' and 'banana confection', but more importantly it was negatively associated with the attribute 'sweet', with most of the products being too sweet for the panellists to call wine-like. Another interesting result was that viscosity had neither a positive nor negative association with vinosity, which was surprising, as it was thought that the viscosity of a product would be correlated with its alcohol content, and therefore would affect vinosity ratings. Similarly for the white NOLO products, viscosity was neither positively nor negatively associated with vinosity. However, the attribute 'warmth' on the palate was strongly associated with vinosity. The two most wine-like products (highest vinosity scoring) were found in this category and both were Sauvignon Blanc-based products, suggesting that this variety may have good potential for NOLO products. Red NOLO products were less uniform in their sensory

assessments with regard to vinosity, with three Shiraz and one Cabernet Sauvignon being the most vinous; however, with scores lower than the white examples. Sensory attributes related to lower quality or faulty wines ('cheesy', 'barnyard', 'cooked veg', 'bitter') were negatively associated with vinosity in this segment.

Compositional analysis highlighted one of the big issues in the dealcoholisation process, which is that the removal of alcohol from the product also removes most of the aroma/flavour component. Analysis of 66 different compounds showed that most were removed to concentrations well below their aroma thresholds. Some notable exceptions were 2-phenylethanol and ethyl butanoate, and the thiol compounds 3MH, 3-MHA and 4-MMP, which once again highlights the suitability of Sauvignon Blanc for these types of products, as these thiols are key contributors to Sauvignon Blanc flavour and aroma. The method of alcohol removal also appeared to affect the compositional make-up, with the wines produced using different methods exhibiting slightly different chemical fingerprints.

The product 'piquette' was also evaluated, from both a technical production and sensory standpoint. Piquette is a grape-based product made by fermenting rehydrated grape marc. Production of this product is difficult, as the marc is deficient in nutrients and sugar, and once primary fermentation is complete, the low alcohol concentrations do not protect the product microbiologically in the way that traditional wines are protected by their higher alcohol content. Over two years, multiple piquettes were produced from Shiraz, Chardonnay and Sauvignon Blanc marc, with different rehydration regimes, skin contact times, and fermentation on and off skins. These products tended to be between 2.5% and 6.5% alcohol (v/v) depending on the starting sugar level of the original must and the amount of water added at rehydration. Sensory evaluations of the various piquettes highlighted the lack of fermentation nutrients, as most piquette ferments without supplemental nitrogen exhibited reductive aromas and flavours. As a product, piquette shows good potential as a low-alcohol, grape-based beverage, with more savoury, herbal characteristics than traditional wine, and a 'sustainability' story regarding the use of what has traditionally been a waste product to produce a unique beverage.

Various flavour and textural additives were also evaluated for their effectiveness in recreating the sensory effects of ethanol in NOLO wines. Additives currently used in the NOLO beer industry were tested in a NOLO wine matrix, with varied results. Glycosides purified from spent grape marc were also evaluated in a NOLO wine matrix, as was the amino acid proline, which has been shown to increase the perception of sweetness in traditional wines. Proline additions were found to enhance flavour and the perception of sweetness in the NOLO wine matrix. The glycosides did not have a perceived effect when added on their own, but when combined with proline the NOLO wines appeared to have more flavour and more perceived sweetness than NOLO wines with just proline added. Additional work in this area is needed, however, there is some potential for the use of both of these compounds as flavour enhancers in NOLO wine production.

An important element of this project has been the formation of and collaboration with an industry reference group. This group involved industry members from across the breadth of the supply chain, ensuring a varied and comprehensive overview of industry wants and needs for NOLO wines. Regular interaction with this group helped to inform the direction of the project and has given confidence that the project deliverables and future projects are addressing the needs of the sector.

2. Acknowledgements

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

Collaborations with the University of Adelaide School of Business within the framework of the University of Adelaide/AWRI Friendship Fund resulted in a focus group study assessing the attitudes of consumers towards NOLO wines. Results of this study have helped better understand consumer perceptions and sentiments around this category. The flavour and fragrance company Firmenich also donated various additives that can be used as flavour and texture enhancers, for evaluation in a NOLO wine matrix.

3. Background

The category of no- and low-alcohol (NOLO) beverages has shown enormous growth over the past few years. Modern consumers are chasing products that contain all of the aroma, flavour and texture of traditionally produced alcoholic beverages but with little or no alcohol. A small number of Australian wine producers are embracing this market with much success, but the NOLO wine category is lagging behind both NOLO beer and spirits by value and volume, according to sales figures.

This report presents results from a two-year project on the opportunities and challenges associated with NOLO wines. It explores the current market offerings for NOLO wine in Australia, summarising sensory attributes, chemical composition and wine-likeness, as well as the opinions of varied wine industry professionals on where the category sits currently and where research and development efforts should be focused.

4. Project aims

This project sought to define the desirable sensory attributes of existing low- and no-alcohol wines or beverages in the market and use this information to support development of wine-like beverages that can satisfy consumer demands. The project also evaluated production practices, technologies and ingredients required to give low- and no-alcohol products the palate attributes found in full-bodied dry wine.

This industry and sensory-led project aimed to identify:

- desirable sensory attributes of existing low- and no-alcohol wine and beverages in the market to provide a basis for changing production approaches for wine-based and wine-like beverages made from grapes with zero and less than 5% alcohol
- production practices, technologies and ingredients required for low- and no-alcohol imitations of full-bodied dry wine.

2020-2021 Deliverables and associated activities

	Deliverables	Activities	Target date
A	Knowledge of sensory properties of commercially available low- and no-alcohol beers and no-alcohol imitations of spirits and wine.	1. Establish an Industry Reference Group to guide identification of reference products in market and understand market failures and development needs. 2. Source low- and no-alcohol wine, beer and no-alcohol imitations of spirits and wine, assess their sensory properties and identify desirable and undesirable sensory attributes in target products. 3. Characterise key compositional measures such as carbohydrates, residual alcohol and organic acids of products with outstanding sensory attributes. 1. Aim to identify relevant ingredients and flavour compounds in products with outstanding sensory attributes.	June 2021
B	Knowledge of production practices for commercially available low- and no-	1. Review production processes, technologies and ingredients used for products in the sensory study.	June 2021

	alcohol beer and no-alcohol imitations of spirits and wine.	2. Produce a technical report summarising product types, targeted products and their sensory properties with recommendations regarding sector needs and project direction based on Industry Reference Group consultation.	

2021-2022 Deliverables and associated activities

	Deliverables	**Activities**	**Target date**
A	Knowledge of sensory properties of commercially available low- and no-alcohol beer and no-alcohol imitations of spirits and wine.	1. Finalise compositional and sensory evaluation of products with outstanding sensory attributes and source relevant ingredients and flavour compounds. 2. Conduct sensory evaluation of components from grapes/wine, ingredients and flavours in model system(s) with less than 5% and 0.5% alcohol under wine-like conditions. 3. Discuss results to date and future plans with the Industry Reference Group.	June 2022
B	Knowledge of production practices for commercially available low- and no-alcohol beers and no-alcohol imitations of spirits and wine.	1. Evaluate the spinning cone and resin adsorbing column technologies for alcohol removal in wines by sensory and compositional analysis. 2. Assess the potential of grape skins from white grape varieties as a starting material for fermentation and/or for extraction of desirable components in the production of low- or no-alcohol wines. For example: assess the potential/stability of glycosides as flavour enhancers in a low- or no-alcohol matrix; assess the potential for a commercially viable flavour extraction from processed white grape skins; understand production, chemical composition and microbiological stability of 'piquette' wine-based products.	June 2022

5. Methods

5.1 NOLO wine sensory evaluations

Wines were selected for sensory evaluation based on availability. Wines were purchased through Australian retail outlets and every product available in the marketplace was purchased for initial screening. Sparkling, white, rosé and red NOLO wines, NOLO wine- and grape-based products, NOLO ciders and beer, and NOLO spirits were obtained for initial assessment.

5.1.1 Sample screening

Panellists consisted of 10 AWRI staff who were experienced tasters, with all but one of the 10 being current members of the AWRI technical quality panel. Tasters evaluated the products blind, making free choice notes on the various attributes of the samples, along with a 0-10 unstructured line scale rating of the product's 'vinosity', or how closely the product resembled wine, based on the taster's previous tasting experience.

5.1.2 Subset evaluations

A subset of wines was selected from the initial screening set of commercially available products. This subset was subjected to more comprehensive sensory analysis – Quantitative Descriptive Analysis (QDA) and Pivot Profile (PP). Wines were selected based on favourable assessments from the AWRI technical quality panel's vinosity assessments and commercial availability. Results were analysed using Principal Component Analysis for the QDA and Correspondence Analysis for the PP data. For the QDA results, vinosity scores were included as supplementary information to help understand which sensory attributes of the NOLO wines were related to high vinosity scores, and which attributes were negatively associated with vinosity scores.

5.2 NOLO wine compositional analysis

5.2.1 Basic chemical composition

The basic chemical composition of all wines from the Descriptive Analysis were determined by AWRI Commercial Services (now Affinity Labs), using methods as detailed in Iland et al. (2013). For all wines, pH, titratable acidity (TA), volatile acidity (VA), residual sugar (glucose + fructose, G + F), specific gravity and alcohol were measured using FTIR WineScan (FOSS, Hillerød, Denmark).

5.2.2 Wine volatiles

Forty-three volatile compounds, including esters, C6 compounds, lactones, monoterpenes and C13-norisoprenoids, were analysed according to validated methods based on headspace solid phase microextraction coupled with gas chromatography - mass spectrometry (HS-SPME-GC-MS) (Antalick et al. 2010, Šuklje et al. 2014, Šuklje et al. 2016), with slight modifications.

5.2.3 Oak volatiles

Oak volatiles were determined by gas chromatography-mass spectrometry using deuterated analogues of furfural, guaiacol, 4-MG, cis- and trans-oak lactone, vanillin and 4-EP as surrogate standards.

5.2.4 Colour/tannin

These measures were quantified by AWRI Commercial Services (now Affinity Labs) using standard methods (Iland et al. 2013). Tannin measurements were derived from a calibration developed from the methyl cellulose precipitable (MCP) tannin assay (Sarneckis et al. 2006).

5.2.5 Low molecular weight sulfur compounds

Volatile sulfur compound analysis was performed according to Siebert et al. (2010) using static headspace–gas chromatography–sulfur chemiluminescence detection (SHS-GC-SCD).

5.3 Piquette production

5.3.1 2021

Piquettes in 2021 were produced at a commercial winery in McLaren Vale, SA.

Piquette #1 was made from pressed McLaren Vale Shiraz skins that had been used for rosé wine production and contained no alcohol. The must from these grapes was measured at 13.8 Baumé. The skins were rehydrated at a 2:1 ratio of skins to water (2 kg:1 L). After 48 hours of rehydration, the piquette was inoculated with Lalvin Clos (Lallemand) yeast at 10 g/hL, with a 300 mg/L addition of diammonium phosphate (DAP). Fermentation lasted four days, and the piquette was drained with no pressing on day 4, with 100 mg/L SO_2 added. The piquette was then transferred to 2 x 55 L kegs, with samples collected for sensory and compositional analysis.

Piquette #2 was made from Adelaide Hills Sauvignon Blanc skins (must = 11.0 Baumé) processed at a commercial winery in McLaren Vale. Skins were collected and then rehydrated in two separate lots at a 1:1 water to skins ratio. The rehydration period was 48 hours, and then lot 1 was pressed off its skins and inoculated, while lot 2 was left to ferment on its skins. Both piquettes were inoculated with Cross Evolution yeast (Lallemand) at 10 g/hL. Fermentation again was completed in 48 hours. Post-ferment lot 2 was pressed off its skins, with 100 g/L SO_2 added and transferred to a 55 L keg. Lot 1 had 100 mg/L SO_2 added post-ferment and was then also transferred to a 55 L keg. Both piquettes were sampled for sensory evaluation and compositional analysis.

5.3.2 2022

Piquette in 2022 was produced from Chardonnay skins left over from processing trial wines for the AWRI's study on 'peach' aroma, from a vineyard in the Adelaide Hills. This trial was designed to examine the composition of piquette as the amount of water used for rehydration was varied. The skins were split evenly into 5 x 20 L vessels and rehydrated with water at the following ratios: 1 kg:0.5 L; 1 kg:1 L; 1 kg:1.5 L; 1 kg:2 L; 1 kg:3 L. The rehydration time was 48 hours, after which the must was pressed and cold settled for 72 hours, racked with light solids, and then inoculated with 25 g/hL PDM yeast(AB Biotek). All ferments were treated with 250 mg/L DAP and the 0.5 L and 1 L ferments were given a further 250 mg/L DAP on day 4 post-hydration. Post-fermentation the piquette ferments were racked off skins to 10 L plastic vessels, with samples taken for sensory and chemical analysis.

5.4 Flavour and texture additions

An initial sensory evaluation of flavour and texture additives was completed by the AWRI technical quality panel on 8 and 9 August 2021. This involved the evaluation of 18 different products currently used in NOLO beer production that had been provided by Firmenich. Products were added at 0.1% v/v concentrations to a 0.05% alc (v/v) Sauvignon Blanc from Australia for sensory analysis. Panellists evaluated the samples in a 'bench tasting' format, using Compusense sensory data collection software.

A second assessment was undertaken using Sauvignon Blanc that had been dealcoholised in the AWRI laboratory using roto-evaporation to an alcohol concentration of 2.4%. While not ideal, it was deemed to have had enough alcohol removed to properly evaluate the effectiveness of glycosides and the amino acid proline. Glycosides were obtained from Muscat Gordo Blanco grapes, as detailed in Pisaniello et al. (2022). L-Proline was obtained from Sigma Aldrich. Samples were evaluated in an informal bench tasting exercise on 9 June 2022. Additions of 2 g/L and 4 g/L of L-Proline were added to 50 mL pours of dealcoholised Sauvignon Blanc and then replicated with 400 mg/L glycoside additions, along with a control and control plus glycoside sample.

6. Results and discussion

6.1 Informal sensory evaluations

6.1.1 Sparkling products

The wines from the sparkling wine category consisted of 25 products made in various styles: sparkling wine products, sparkling grape products and sparkling wine-based products. Alcohol by volume (ABV) for the sparkling wine/wine-based products ranged from 9.0% (1), 5.0-5.5% (7), 0.5% (9), and 0.05% (8). The products originated from five different countries: Australia (18), Germany (6), France (1), Italy (1) and South Africa (1). Prices were between $8.55 and $29.99. Overall, this category had a mean vinosity score of 3.2 (SD 1.1, Figure 1) – the lowest of all the categories, suggesting that this group of products has room for improvement.

The sensory properties of these products varied from 'juice-like': predominantly grape and apple juice like on the palate, to floral and tea-like characters, to 'cardboardy' and oxidative characters. Almost all of the products had comments regarding the sweetness, with those rated highest for vinosity also having the lowest number of comments regarding sweetness. The three highest scoring products for vinosity were samples that contained alcohol at 9%, 5.5% and 5% v/v respectively, indicating that the effect of ethanol on the palate was significant for the tasters when it came to assessing a product's wine-likeness. For the product with 9% v/v (a Prosecco-style product), its alcohol content was likely as little as 2.5-3% lower than normal commercial examples, and therefore it would be expected to closely resemble a full-alcohol example. The lack of vinosity and associated quality in this group of products could be the result of producers not willing to invest capital and resources into a product category where they feel consumers are not willing to pay for quality products. This can be seen by the retail prices of the wines in this category, with the most expensive Australian product retailing for $15, and the imported wines being slightly higher.

Three piquette style products, all coming from producers who could be classified as small (<500 tonnes production), had been produced by re-hydrating pressed white grape marc and fermenting the remaining sugars, then bottling with a small amount of residual sugar remaining to add dissolved CO_2, similar to the petillant naturel style of sparkling wine. Piquette is not limited to a 'pet nat' style of beverage, but these three examples were made in that style. These products were described as the least wine-like products in the tasting, with some tasters highlighting strange aromas and flavours and indicating that the products were highly bitter. The other innovative product – a Shiraz wine watered down to 5.5% alcohol, then packaged in an aluminium can with dissolved CO_2, was also not thought of as wine-like. The innovation behind these products demonstrates the potential for novel low-alcohol products from smaller producers, and their low vinosity scores should not be interpreted as reflecting poorly made or low-quality products. Rather, they represent innovative products attempting to make unique beverages out of waste streams or using other creative means. The object of these products is not necessarily to replicate wine aromas/flavours and wine-likeness, but to create an alternative to wine that is thought of more as a grape-based alcoholic beverage. The inadequacies of the vinosity scale were highlighted by these scores.

The two sparkling grape products were not noted as wine-like by the panel but were noted as fresh and interesting and an alternative to de-alcoholised products. However, the very high levels of sugar in these products would disqualify them from being classified as 'healthy' alternatives, with analysis of one of the products showing 140 g/L of glucose and fructose, which would be significantly higher than the sugar concentration of Coca-Cola™ (106 g/L). These products are also already well established with wide distribution and consumer acceptance. Following discussion, many of the panellists indicated that they expected this category to be the one with the most potential, as it would offer the most tools for a winemaker to use to replicate the textural elements of alcohol.

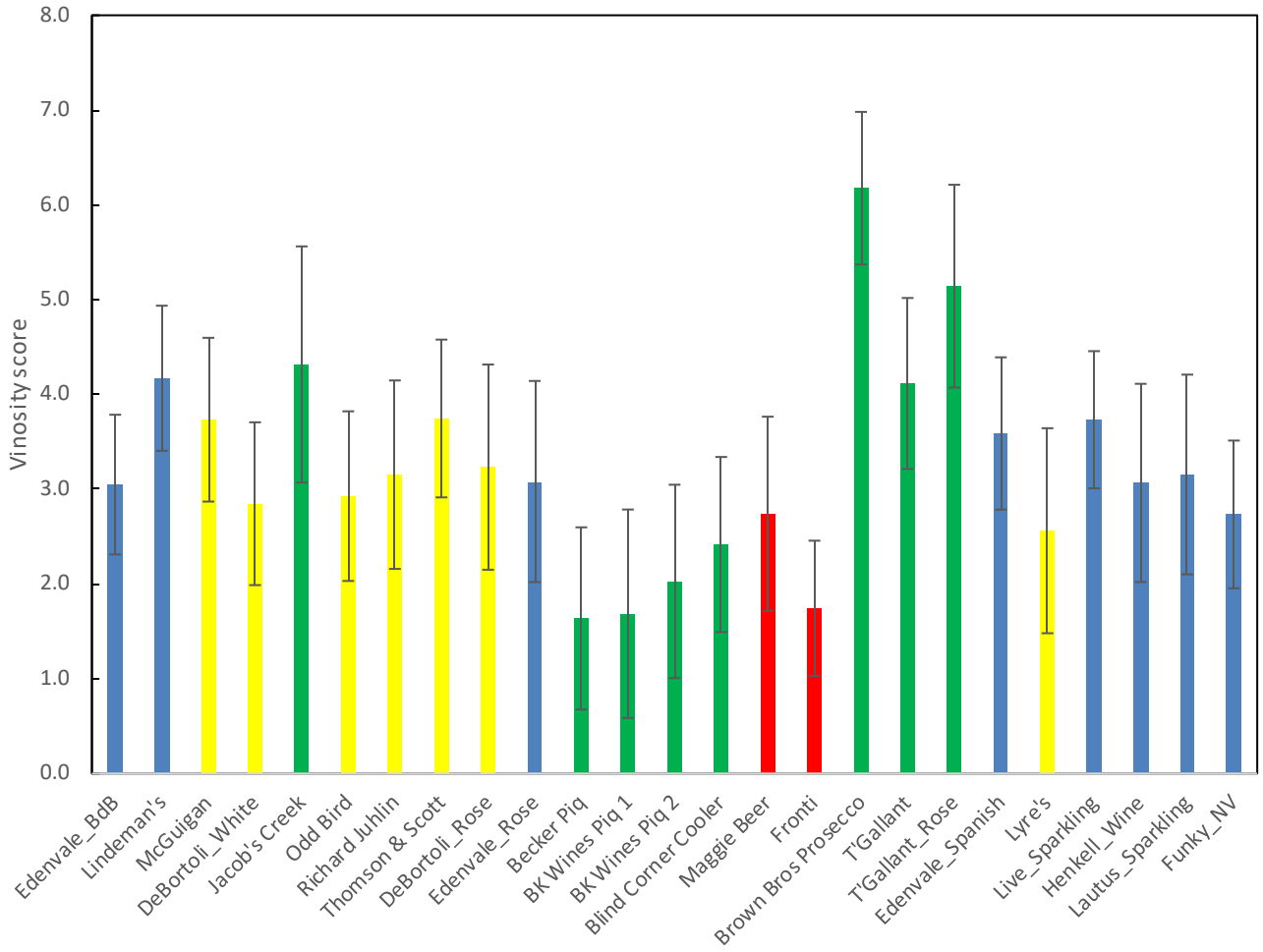


Figure 1. Panellists' mean vinosity (wine-like, 0-10) scores for sparkling NOLO wine products, with standard deviations. Colours signify alcohol content of the product: yellow <0.05% v/v, blue <0.5% v/v, green between 5.0% v/v and 10.0% v/v, red signifies grape juice-based products.

6.1.2 White wine products

The white wine category consisted of 30 products, with alcohol concentrations ranging from 7.0-9.5% (10), 5.5-6.0% (2), 0.5% (11) and 0.05% (7). The products originated from Australia (13), New Zealand (8), Germany (4), France (2), Spain (1), Chile (1) and South Africa (1). Varietal breakdown was as follows: Sauvignon Blanc and blends thereof (13), Chardonnay and blends thereof (6), Pinot Gris/Grigio (6), Riesling (4) and Muscat (1). Prices for the products ranged from $7.77 to $63, with all but three products less than $18. Two of the three products priced >$20 were Rieslings made from ultra-premium producers, with a German example from what might be considered one of the great Riesling vineyards in the world, and an Australian example made in a similar style from an equally reputable producer. These two wines were produced by arresting the fermentation process with sugar remaining, leaving a lower alcohol content (7.5% and 6% respectively), which was a different production method from all the

other products tasted. As these two wines are legitimate products well established in the wine world, it does highlight more shortcomings of the vinosity scale used in these assessments, as these two products were rated 4.5 and 3.9 in vinosity (one above and one below the mean vinosity score of 4.2). However, these products also had the largest standard deviation values of the group, signifying that some of the panel would have identified these as proper wines, while others would not have been familiar with the style.

The Sauvignon Blanc and Sauvignon Blanc blends were the most numerous in the tasting, and with the mean vinosity score over 5, were the most wine-like of all the products tasted over all categories. The top-scoring wine for vinosity in this category also had the lowest standard deviation of all the products, signifying strong panel agreement. The four most wine-like products also shared a similar production strategy, as they were not de-alcoholised wines, but were harvested at lower sugar levels with alcohol levels between 7.0 and 8.5%. Three of the four were from New Zealand. Panellists noted classic varietal Sauvignon Blanc aromas and flavours as well as balanced sweetness and acidity and a viscous, bitter and warm palate suggesting the presence of alcohol. Also scoring high on the vinosity scale was a 0.5% alcohol Sauvignon Blanc from NZ, with the sixth highest vinosity score out of the 30 products. This product was rated more wine-like than six other products with >5.5% v/v. Panellists again commented on the expression of Sauvignon Blanc varietal character, with well-balanced acidity and sweetness. Comments also included references to a thin palate and lack of viscosity, heat and bitterness from alcohol.

Panellists were less convinced that the Chardonnay and Chardonnay blends were wine-like, with a mean vinosity score for the group at 3.6. The most wine-like product was a 0.0% Chardonnay that was described by panellists as having very high oak aromas and flavours, with balanced sweetness and acidity. This was the third highest vinosity score for a white wine with 0.5% alcohol or lower. The lowest scoring examples in this category (both French) were two of the five lowest scoring products for vinosity across all the products.

The next group was the Pinot Gris examples (6). Generally, this category was scored lower for vinosity compared to the other varieties, even with almost half of the products tasted containing an alcohol higher than 5.5% (v/v). Only one example, an Australian product, scored within the top products for vinosity (fifth highest). One had the second lowest score for vinosity and the other was the fourth highest. Some of the lower-scoring products exhibited multiple wine faults (volatile acidity, reductive characters) and appeared to be good examples of poor starting materials leading to sub-standard products.

The last product in the category was a 0.5% Muscat-based product, which at 5.5 was the fifth highest scoring wine in this set for vinosity. This was also a reasonably polarising product, with a relatively high standard deviation (2.9). Some panellists thought it was very wine-like, high in terpene aromas, with a balanced, viscous palate and good flavour concentration. Others thought it was too sweet, thin and dull.

Overall, the white NOLO wines showed promise and potential when comparing them to typical white wine. With some of the products it is easy to see a clear path to refining and optimising current processes to achieve realistic wine-like alternatives.

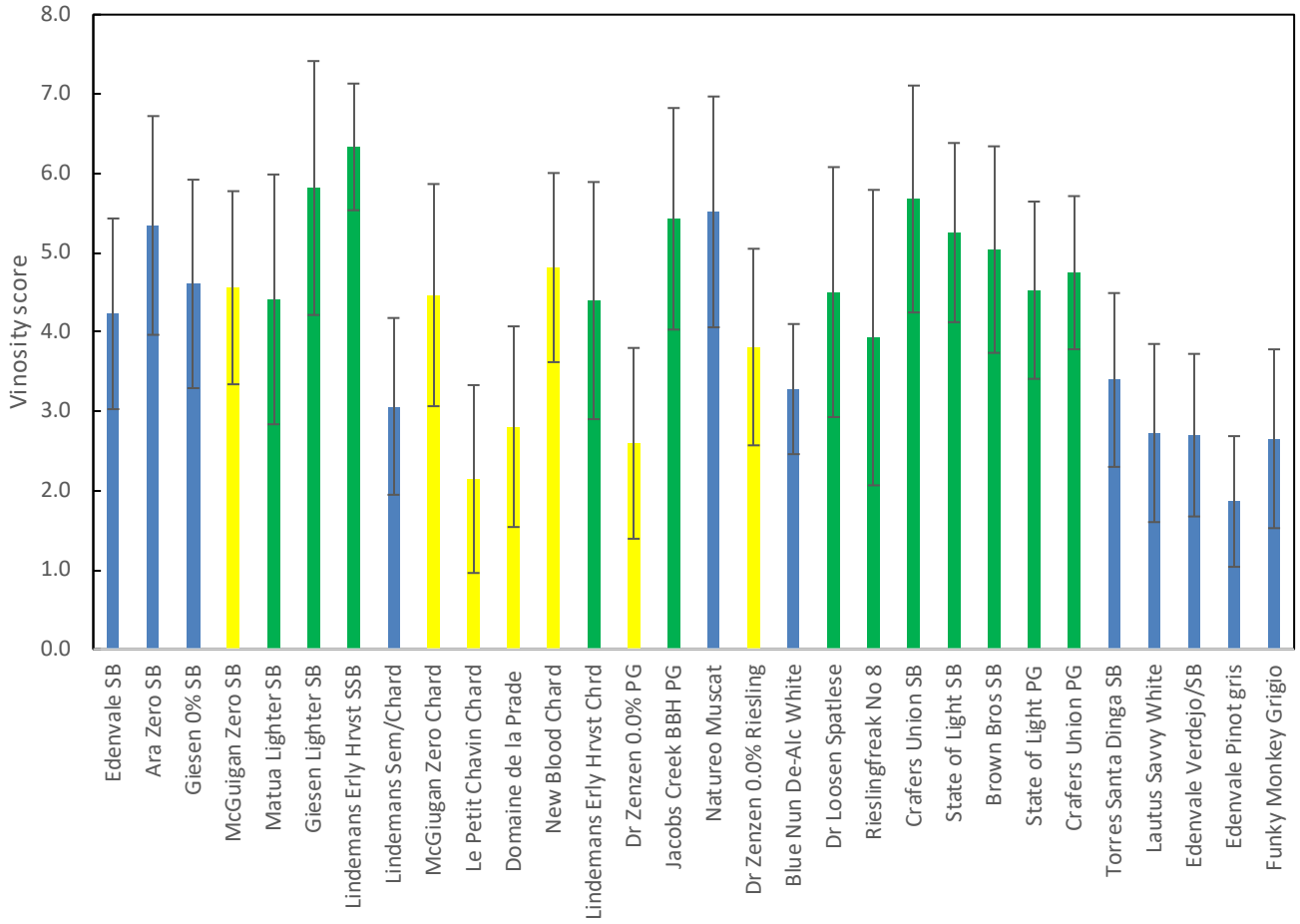


Figure 2. Panellists' mean vinosity scores for white NOLO wine products, with standard deviations. Colours signify alcohol content of the product: yellow <0.05%, blue <0.5%, green between 5.0% and 10.0%.

6.1.3 Red and rosé wine products

This group was made up of 19 products, with six rosé wines and 13 red wine examples. The products originated from Australia (8), Spain (2), France (2), South Africa (2), Germany (2), USA (1), New Zealand (1) and Portugal (1). The products ranged in price from $10 to $24.95. Six rosé wine products were tasted, with three of the six products falling beneath the mean score for vinosity for this group (3.8). Two of the three products that scored above the mean contained >5% ABV, highlighting that the 0.5% and zero alcohol options in this category were lacking in wine-like characters. However, the third product to score above the vinosity group mean was an Australian-produced <0.05% product, suggesting that well made, zero alcohol products are possible in this space.

The 13 red products encompassed a wide range of vinosity scores, with both highly vinous and least vinous included in this group. Overall, eight of the 13 red products were under the group mean for vinosity (3.9). Two of the three most vinous products were Shiraz wines from Australia. They were described as having floral, dark fruit, oaky and vanilla aromas. On the palate they were described as sweet and lush, with fruit and oak flavours, light weight with slight astringency. Another notable consensus wine-like product was from Germany, made from the grape variety Dornfelder. This product was reductive on the nose, with cheesy, rancid butter and smoky aromas. However, on the palate this wine was found by the panellists to be textured, with some palate weight and good sugar/acid balance and an astringent finish. This highlights the potential for using alternative or lesser-known grape varieties for NOLO products to achieve more wine-like outcomes. The other well-regarded red examples were a red blend from South Africa and a Cabernet Sauvignon from the USA. These products were characterised by some aromas, with plum, dark fruit, red fruit and confection. On the palate they were described as

astringent, medium bodied, with wine-like flavours. The least vinous products of this category were described as strange-smelling, weird, grape juice concentrate, vinegar, unpleasant, cooked vegetables and off-meat. On the palate they were described as bitter, drying, thin, sour and vinegary. These wines clearly suffered from either poor winemaking or poor starting materials or both and exhibited some basic wine faults.

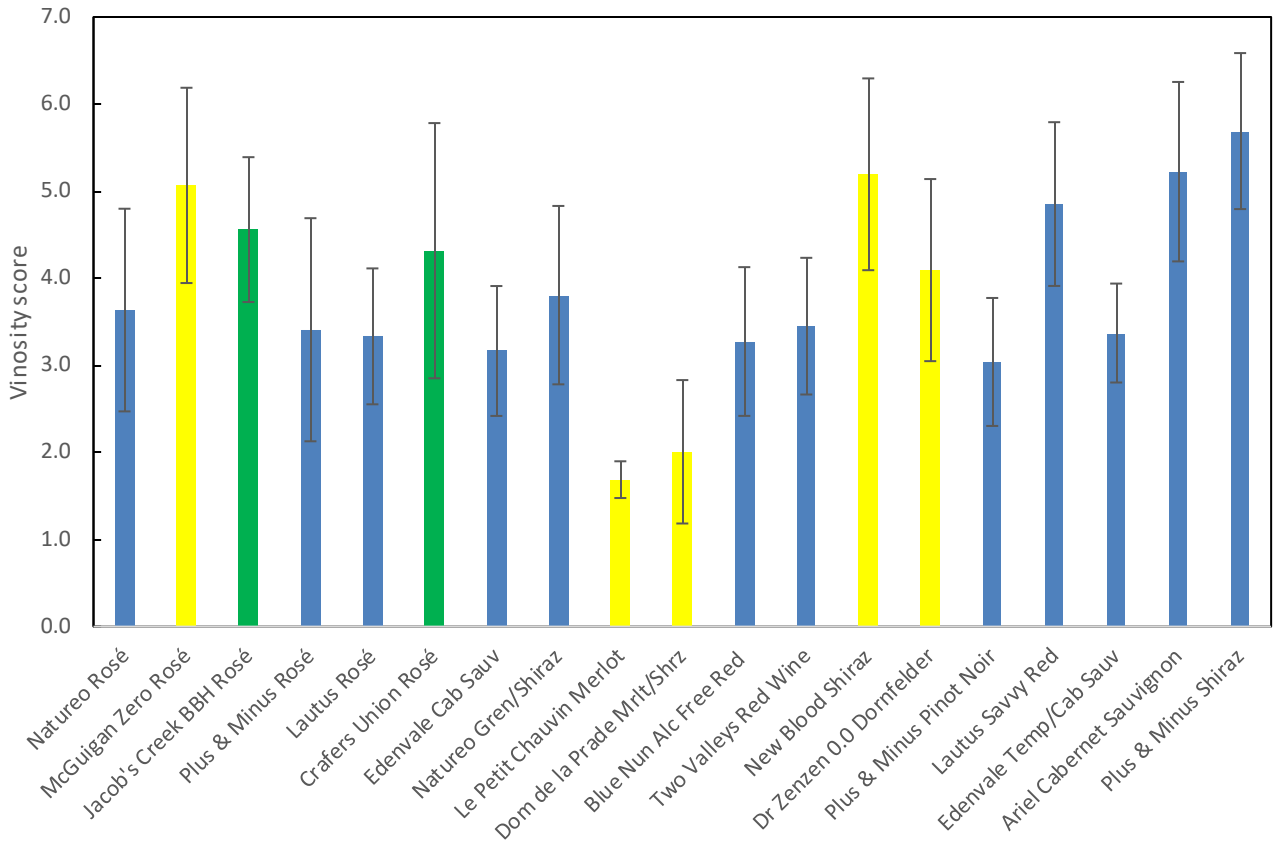


Figure 3. Panellists' mean vinosity scores for rosé and red NOLO wines, with standard deviations. Colours signify alcohol content of the product: yellow <0.05%, blue <0.5%, green between 5.0% and 10.0%

6.1.4 NOLO beer and cider

The beer and cider portion of the tasting included beer from three large companies, and their respective 0.0% alcohol alternatives. It also included two products from a non-alcoholic brewer based in the UK but now brewing in Victoria, and a cider producer's alcoholic example and their non-alcoholic product. All three of the non-alcoholic beer products originating from large producers were of excellent quality and were described as very beer-like by panellists. This category highlighted how NOLO wine products exhibit a much larger gap between their traditionally made products than NOLO beer and cider products.

6.2 Formal sensory analysis

6.2.1 Sparkling products

The 10 sparkling NOLO wines were assessed using the descriptive analysis sensory evaluation method. Analysis of variance was completed on the results, with 18 of the 24 attributes found to be significant at $p < 0.05$ across the products. Two additional attributes (banana confection aroma and bruised apple palate) were significant at $p < 0.1$ and were included in further analysis. The remaining four attributes with p values > 0.1 were not included in further analysis. Principal Component Analysis (PCA) of the mean scores from the analysis is shown in Figure 4.

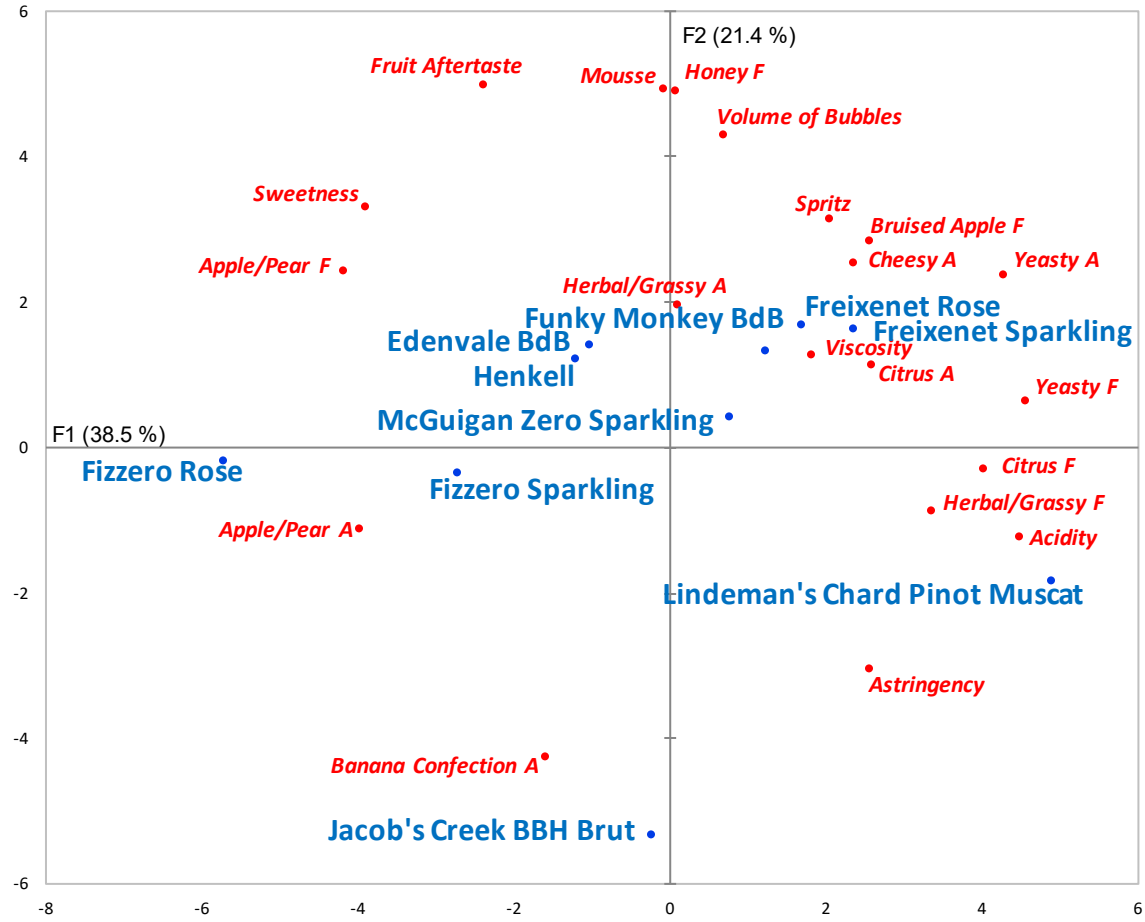


Figure 4. Principal Component Analysis biplot of factors 1 and 2 of sensory results for sparkling NOLO wines, with attributes in red and products in blue

The PCA for the sparkling NOLO wines explained nearly 60% of the variance in the model with the first two principal components. PC1 separated the samples based on fruity attributes and sweetness (on the left of the biplot) and yeasty, herbal/grassy and citrus aromas and flavours (right of the biplot). PC2 separated the samples based on banana confection aroma and astringency (bottom) and fruit aftertaste, honey flavour, sweetness, and the textural terms mousse, spritz and volume of bubbles. The samples were reasonably well distributed about the biplot, with four of the samples separated far from the origin, and the remaining samples clustered closer together near the centre of the biplot. The two Fizzero products, located close together on the left of the biplot, were both made using a herbal tea infusion, and therefore their separation from the other products is logical. However, the attributes herbal/grassy aroma and flavour are opposed to the location of these products, signifying lower scores for these attributes.

Some basic chemical analysis was undertaken to better understand the compositional make-up of the wines. When evaluated with the sensory analysis, these data can help give insights into production of these products, particularly sugar and acid concentrations, and the use of compounds such as glycerol.

Table 1. Basic chemical composition of nine NOLO sparkling wines.

Product	Alcohol (% v/v)	Glucose + fructose (g/L)	Glycerol (g/L)	pH	Sulfur dioxide (free, mg/L)	Sulfur dioxide (total, mg/L)	Titratable acid (g/L, pH 8.2)
Lindeman's Chardonnay Pinot Noir Muscat	0.5	29.2	5.3	3.36	12	113	7.2
McGuigan Zero Sparkling	0.05	48.7	4.7	3.12	22	158	7
Jacob's Creek BBH Brut	5.5	5.1	5.7	3.09	18	105	6.1
Fizzero Rose	0	57.4	0.2	3.03	0	0	4.8
Funky Monkey BdB	0.5	43.3	1.6	2.84	18	146	4.4
Henkell	0.5	64.1	3.7	2.91	29	150	6.8
Edenvale BdB	0.5	55.5	4.8	3.25	11	118	6.9
Freixenet Sparkling	0.5	52.2	4.7	2.89	14	112	6.9
Freixenet Rose	0.5	53.5	4.7	2.88	12	106	6.9

Evaluating the chemical data did not reveal too many unexpected results, with high sugar levels and low pH and TA values to be expected for products in this category. Glycerol was clearly a tool being used for creating mouthfeel and texture in many of these products. Acid profiles were consistent with what would be expected for traditional sparkling wines. The Fizzero sample, with very little glycerol and no sulfur dioxide, was compositionally the outlier in this set.

6.2.2 White and rosé wine products

The 16 white and rosé NOLO wines were also assessed using the descriptive analysis sensory evaluation method. Analysis of variance was completed on the results, with 22 of the 24 attributes significant at $p < 0.001$ across all samples. The remaining two attributes (tobacco aroma and vanilla aroma) with p values > 0.5 were not included in further analysis. Principal Component Analysis (PCA) of the mean scores from the analysis is shown in Figure 5.

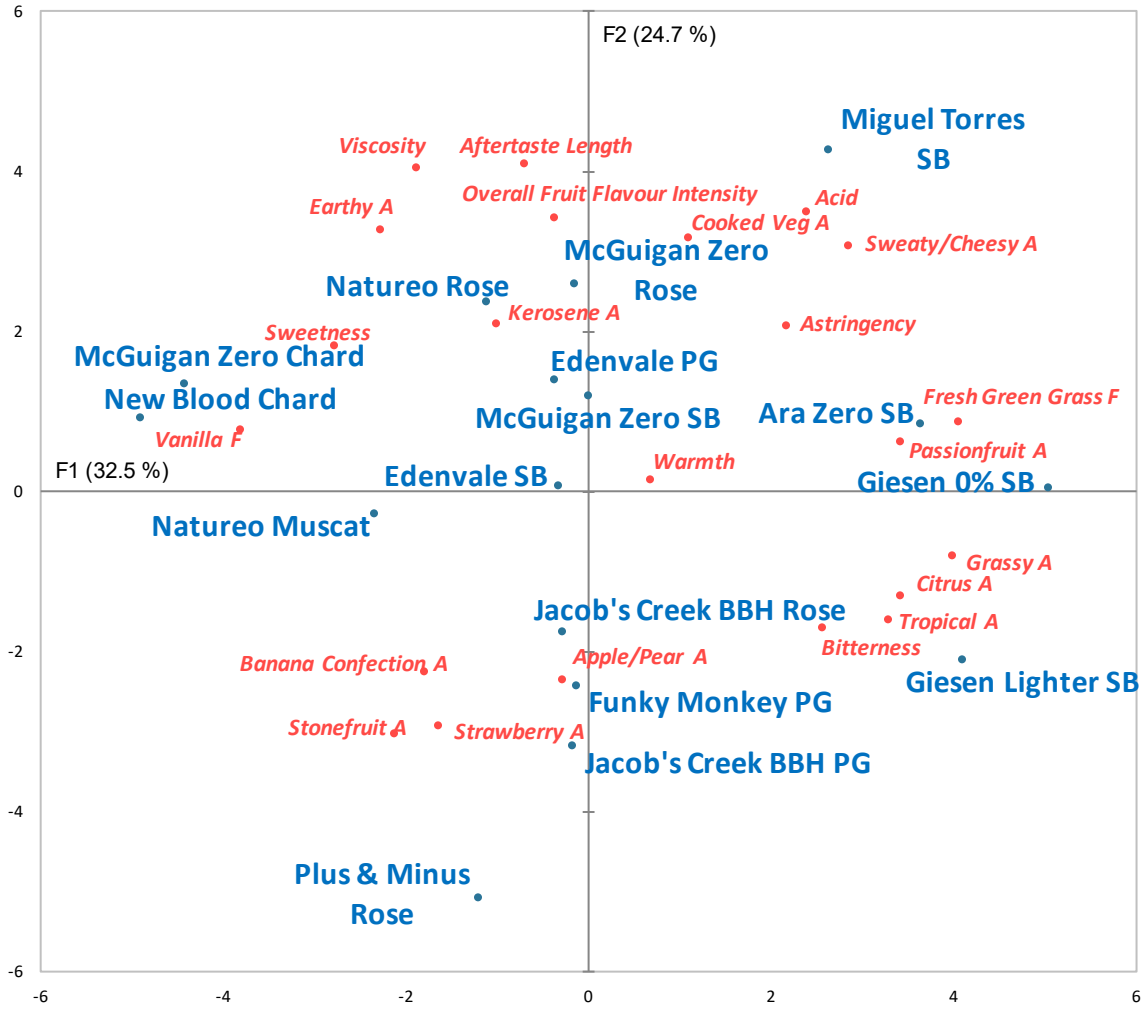


Figure 5. PCA biplot of factors 1 and 2 of sensory data for white and rosé NOLO wines, with attributes in red and samples in blue

The first two factors of the PCA for the white and rosé NOLO products explained 57.2% of the variance in the model, with factor 3 explaining an additional 12.6% and factor 4 a further 10.4%. Broad separation of both attributes and products signified a wide range of sensory profiles for these samples. There did appear to be a trend by variety, as almost all of the Sauvignon Blanc-based samples sat on the right-hand side of factor 1, while the Chardonnay-based samples sat far to the left of the biplot. The Pinot Gris samples sat in the middle of F1, along with the rosé samples. The only Muscat-based sample sat to the left of F1, closer to the Chardonnay samples. The attributes associated with samples generally are logical as well, with the Sauvignon Blanc samples showing higher values for the attributes fresh green grass flavour, sweaty/cheesy aroma, passionfruit aroma, grassy aroma, tropical aroma and citrus aroma. The Chardonnay-based samples contrasted this by having lower values for these attributes and higher values for vanilla flavour, stone fruit aroma, banana confection aroma and sweetness. The Pinot Gris and rosé samples, while well separated along F1 were better separated by F2, with the Pinot Gris samples showing almost no separation at all along F1. The Jacob's Creek and Funky Monkey Pinot Gris samples were associated with the attributes apple/pear aroma, stone fruit aroma and banana confection aroma, as were the Jacob's Creek rosé and Plus & Minus rosé. Different from the sparkling products, there was an association between the attributes sweetness and viscosity, with the two attributes tracking close together through the biplot.

Table 2. Basic chemical composition of sixteen NOLO white and rosé wines

Product	Alcohol (% v/v)	Glucose + fructose (g/L)	Glycerol (g/L)	pH	Titratable acid (g/L, pH 8.2)	Sulfur dioxide (free, mg/L)	Sulfur dioxide (total, mg/L)

Ara Zero SB	0.5	30.8	5.7	3.38	7.5	20	109
Edenvale SB	0.5	40.8	4.7	3.13	6.5	22	123
Edenvale PG	0.5	36.1	5	3.34	7.3	20	135
Funky Monkey PG	0.5	36.9	1.5	2.83	4.4	14	68
Giesen 0% SB	0.5	14.6	6.3	3.29	8.3	19	106
Giesen Lighter SB	9.0	9.8	4	3.09	6.4	24	120
Jacob's Creek BBH PG	5.5	3.3	5.3	3.13	5.9	25	114
Jacob's Creek BBH Rose	5.5	4	5.7	3.11	6.0	24	115
McGuigan Zero Chardonnay	0.05	42.5	5.1	3.20	6.4	28	176
McGuigan Zero Rose	0.05	45.3	4.9	3.10	7.8	30	172
McGuigan Zero SB	0.05	43.8	5.6	3.07	7.4	31	188
Miguel Torres SB	0.5	41.9	8.1	3.02	9.2	12	122
Natureo Rose	0.5	45.6	6.5	2.98	6.4	22	105
Natureo Muscat	0.5	48.4	5.9	3.01	6.3	13	163
New Blood Chardonnay	0	13.8	12.5	3.32	7.0	24	126
Plus & Minus Rose	0.5	21.1	0.8	3.25	2.7	19	76

Composition of the white wines is consistent through the sample set, with most products showing similar levels of sugar and acid, and regular use of glycerol. Notably different were the wines containing some level of alcohol, with significantly lower levels of G+F. The New Blood Chardonnay was also quite different from the other samples, with lower G+F values, and double the glycerol of the other samples.

6.2.3 Red wine-based products

Eight red wine-based products were evaluated using the Pivot Profile method (PP), a rapid sensory evaluation technique. The eight products were evaluated using the Torres Natureo Grenache/Shiraz de-alcoholised red as the control or 'Pivot' wine. This category consisted of products made from the following grape varieties: Shiraz, Cabernet Sauvignon, Pinot Noir, Dornfelder and a Tempranillo/Cabernet Sauvignon blend, and came from Australia (5), Germany (1), USA (1) and Spain (1). Principal Component Analysis (PCA) of the mean scores from the analysis is shown in Figure 6.

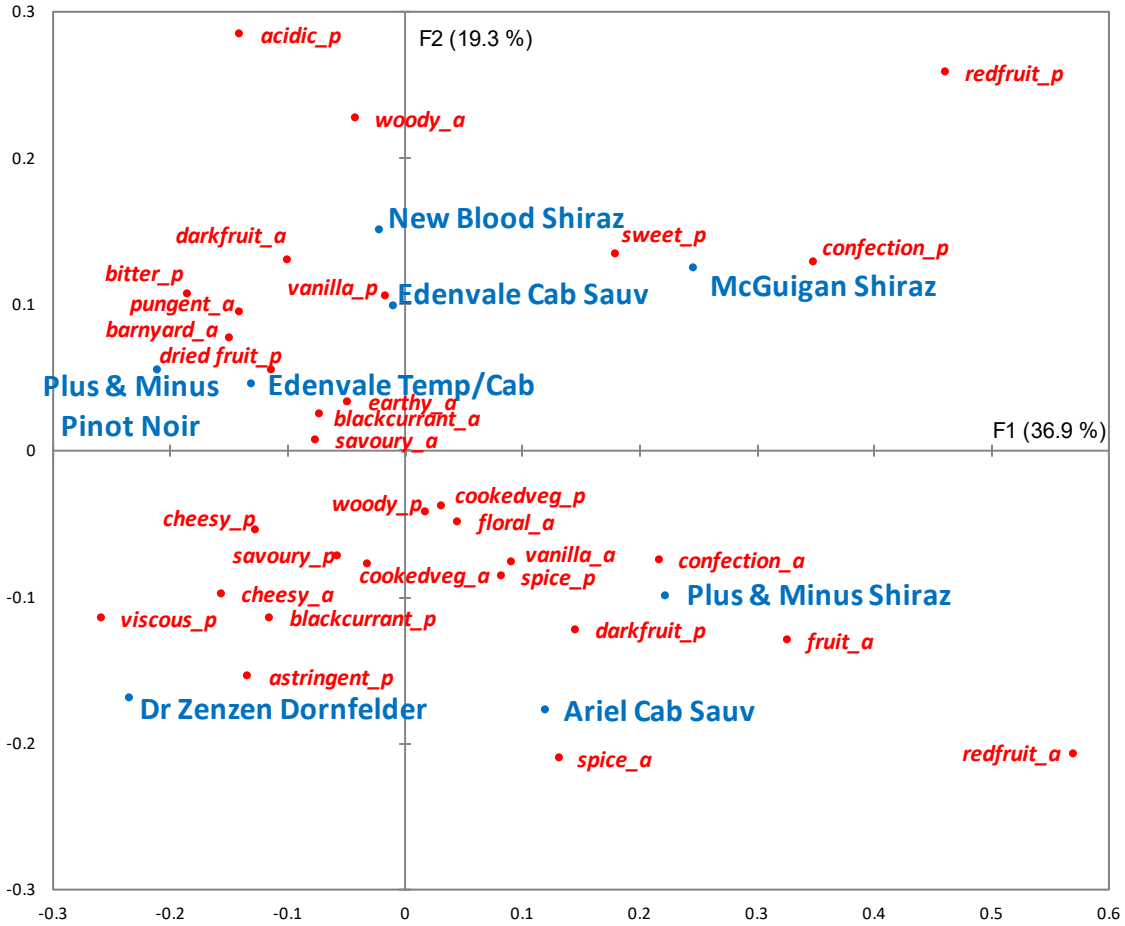


Figure 6. Correspondence analysis biplot of factors 1 and 2 of sensory data for red NOLO wines, with attributes in red and samples in blue

The biplot shows a typical spread of products and attributes in all four quadrants, signifying a broad sensory profile for all the products. Factor 1 best describes the attributes red fruit, fruit and confection aromas and red fruit, confection and dark fruit flavours. Factor 2 describes the attributes acidic, red fruit and woody palate, and red fruit and spice aromas and astringent palate.

Unlike the white NOLO products, there did not appear to be a trend of these products to be grouped by variety, with both Shiraz and Cabernet Sauvignon-based products spread out over the biplot. The Dr Zenzen sample was rated higher in viscosity and astringency, albeit with cheesy aromas and flavours and a cooked veg aroma. The use of this variety not well known outside of Germany is curious, however, as the variety is known for high levels of anthocyanins and polyphenols, its use as a NOLO wine has potential. The Plus & Minus Shiraz and Ariel Cabernet Sauvignon were rated higher for red fruit, fruit, confection, and spice aromas, and were rated lower for dark fruit aroma bitter and acidic palates. The McGuigan Shiraz was rated higher for the attributes sweet, confection and red fruit palate, while being lower in viscosity and astringency. It was also rated highly for acidic and woody palate. The New Blood and Edenvale Cabernet Sauvignon samples were rated highly for woody, vanilla and dark fruit aromas and acidic and sweet palate and were also rated low in astringency. The Edenvale Cabernet Sauvignon was also rated low for viscosity. The Edenvale Tempranillo/Cabernet Sauvignon was rated higher in earthy and barnyard aromas and was the only sample to be rated highly for both astringency and acidity.

Table 3. Basic chemical composition of nine NOLO red wine products

Product	Alcohol (% v/v)	Glucose + fructose (g/L)	Glycerol (g/L)	pH	Sulfur dioxide	Sulfur dioxide	Titratable acid (g/L, pH 8.2)

					(free, mg/L)	(total, mg/L)	
Natureo Grenache Shiraz (Pivot)	0.5	37.2	11.3	3.41	12	55	3.9
New Blood Shiraz	0	26.1	20.9	3.51	14	58	2.5
Dr Zenzen Dornfelder	0	43.8	7.2	3.53	16	41	3.0
Plus & Minus Shiraz	0.5	28.9	3.7	3.30	24	72	2.5
Ariel Cabernet Sauvignon	0.5	39.8	5.1	3.21	15	60	2.4
Edenvale Cabernet Sauvignon	0.5	42.8	8.2	3.41	22	88	3.9
Edenvale Tempranillo/Cabernet Sauvignon	0.5	30.8	8.9	3.51	15	54	4.4
Plus & Minus Pinot Noir	0.5	36.5	4.7	3.38	15	123	4.4
McGuigan Shiraz	0.05	41.5	8.4	3.24	25	80	6.0

Generally, the NOLO red wines all had similar basic composition – use of sugar, acid and glycerol was consistent throughout the sample set. Only the New Blood sample with its elevated glycerol level stood out as different.

6.2.4 Vinosity

In order to give the above sensory analyses some frame of reference, the vinosity scores from the initial sensory assessments performed by AWRI tasters were included as supplementary information with the PCA analyses for the sparkling and white NOLO products and was added to the PP analysis by virtue of increasing font size with increasing vinosity. Both sparkling and white NOLO biplots were also denoted with increasing font size for increased vinosity. The biplot for the sparkling products is shown in Figure 7.

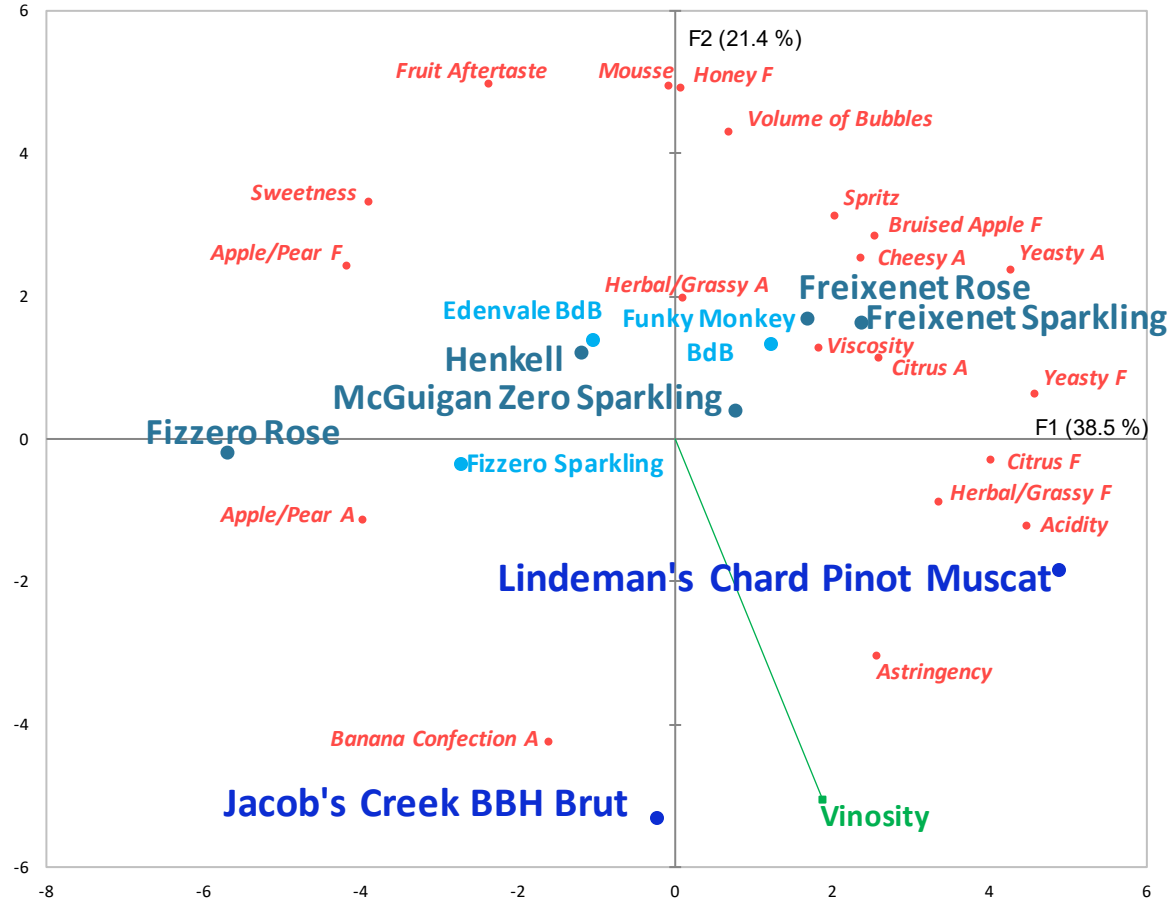


Figure 7. PCA biplot of factors 1 and 2 of sparkling NOLO wines, with attributes in red, samples in blue, and vinosity in green. A larger font for a sample denotes a higher vinosity score, and samples with similar vinosity scores are shown in similar shades of blue.

The vinosity vector points strongly into the bottom right quadrant, close to the attributes astringency, acidity and banana confection aroma. Evaluating mean scores for these products confirmed astringency and acidity as being influential in the vinosity rating. Vinosity was also opposed to the attribute sweetness, meaning that the least sweet wines were found by the panel to be the most vinous, and this was confirmed by the mean scores for sweetness, with the three least sweet products rated highest for vinosity. Apple/pear and honey aroma were also negatively associated with vinosity. The attribute viscosity is located orthogonal to the vinosity vector, suggesting that the two are not related for this product category. This is an interesting result, as it could have been suggested that high viscosity might replicate the textual mouthfeel of alcohol. It appears that in this case that vinosity and viscosity are not correlated. The fact that the Jacob's Creek product was rated highest in vinosity and was the only product in the group to contain more than 0.5% alc (v/v), highlighted the mouthfeel effect of alcohol and its importance in replicating the wine sensory experience.

The white wine-based products were also then analysed with vinosity scores as supplementary information, and the biplot can be seen in Figure 8.

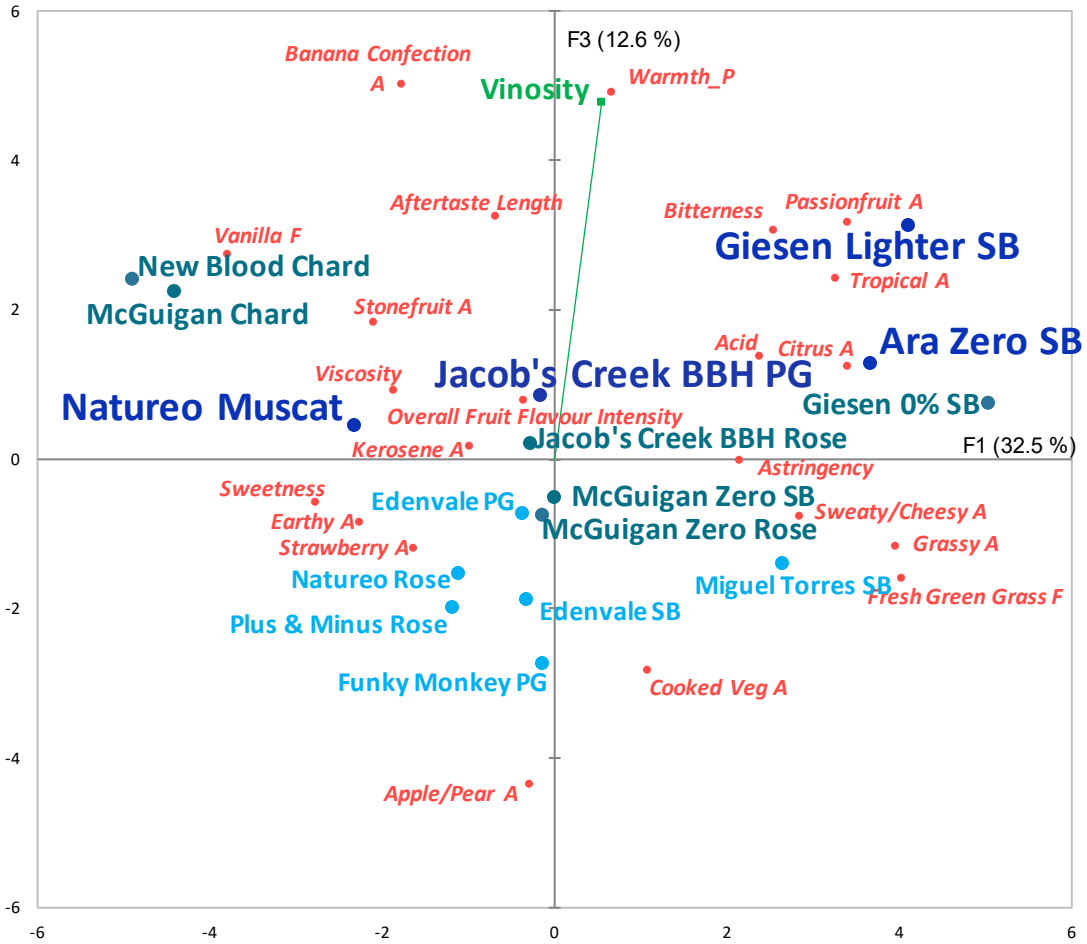


Figure 8. PCA biplot of factors 1 and 3 of sensory data for white and rosé NOLO wines, with attributes in red, samples in blue, and vinosity in green. A larger font for a sample denotes a higher vinosity score, and samples with similar vinosity scores are shown in similar shades of blue.

The vinosity vector described by factor 2 was very short and did not effectively describe the attribute. However, factor 3 was much more effective at describing vinosity. The main attribute it was associated with was warmth palate, which is a logical association, as NOLO products are known to be deficient in the warming effect of alcohol. Therefore, any products that exhibit this character (or the semblance thereof) might be thought of as more vinous than a product that

lacks this character. Interestingly, viscosity was orthogonal to vinosity in this biplot (and by association warmth palate as well), which agreed with the previous assessment with the sparkling NOLO products that the attribute viscosity was not an accurate measure of the textural effect that alcohol provides. The Giesen Lighter sample had the highest scores for this attribute, and as the sample with the highest alcohol in the set (9.0% alc/vol), it was no surprise that the two are closely associated. However, examining which other samples were being rated higher for this character that have < 0.5% alc (v/v) is interesting, and every sample with a warmth palate score above the mean also had a vinosity score above the mean, except for one (Ara SB). This suggested that warmth palate might be a good measure and potentially predictor of vinosity. There was at least one example from every grape variety used to make these products that was scored higher than the mean for vinosity, signifying that grape variety was perhaps less important and production methods more important when it comes to producing vinous products.

The red products were analysed using the PP method, which is a frequency-based method and therefore vinosity scores cannot be added to the analysis in the same way as the descriptive analysis scores. However, in Figure 9 samples that scored high for vinosity are shown in larger fonts and darker blue, and the samples with the lower scores are shown in the smaller font and lighter blue, and with the groups of similarly scored samples in similar colours.

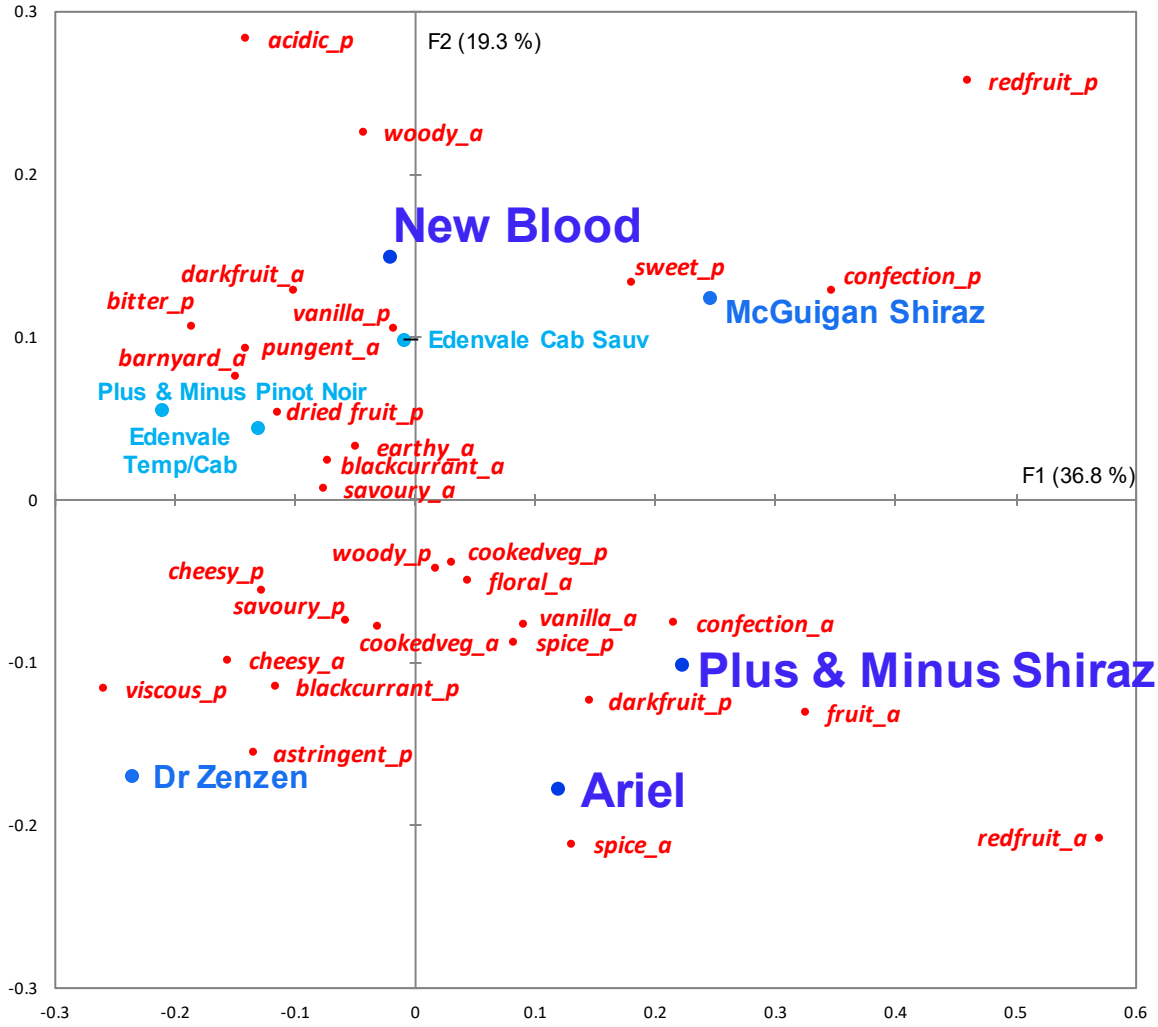


Figure 9. Correspondence analysis biplot of factors 1 and 2 of Pivot Profile sensory data for red NOLO wines, with attributes in red, samples in blue. A larger font for a sample denotes a higher vinosity score, and samples with similar vinosity scores are shown in similar colours.

The vinosity scores for the products included in the PP analysis were more polarising than the samples in the other categories. Only the Dr Zenzen Dornfelder and McGuigan Zero Shiraz occupied the middle ground in regards to vinosity scores. All other samples were substantially

lower or substantially higher than the mean vinosity scores. The three most vinous products all scored over 5 for vinosity, and as a group had higher scores for the attributes vanilla aroma, fruit aroma, red fruit and dark fruit aroma, spice aroma and palate, woody aroma and acid palate. They were also consistently low for the attributes barnyard, cheesy and cooked veg aromas. Interesting, and unlike the sparkling wines, the attribute sweet was somewhat positively associated with vinosity. Overall, it can be said that the most vinous wines had the most fruit and oak aromas, and lacked the off-aromas of barnyard, cheesy and cooked vegetables. It seems that vinosity in this instance was better associated with intensity of aromas, as all the more vinous products were located away from the origin, signifying higher intensities, while the least vinous products were located much closer to the origin, indicating lower overall intensities. The Dr Zenzen product, which scored near the mean for vinosity, had many of the characters that the other vinous products had, but also was very high in cheesy and cooked veg aromas, which potentially hurt its overall vinosity score. The fact that the variety used was Dornfelder, a variety little known outside its native Germany and associated with deep colours and high yields, highlighted the potential for using different and lesser-known grape varieties as NOLO products successfully.

6.3 Compositional analysis of commercially available NOLO wine products

Compositional analysis was performed on the 34 NOLO wines that underwent sensory analysis, as well as an additional 13 products. The NOLO wines were analysed for fermentation products, C-6 compounds, norisoprenoids, monoterpenes, low molecular weight sulfur compounds, volatile thiols, oak volatiles, as well as basic wine chemistry.

6.3.1 Sparkling products

Eleven sparkling NOLO wines were analysed, with the products having various levels of alcohol present (5.5%, 0.5%, 0.05%). Concentrations of C6 compounds were low, with all but one compound (Z3-hexenol) below its aroma threshold, and that was only in one sample (Henkell).

Fermentation products also showed low levels across the board. Differences based on alcohol content (5.5% vs 0.5% vs 0.05%) were evident. The 5.5% sample (Jacob's Creek) had substantially higher concentrations of most of the fermentation products, sometimes by a factor of 10. One interesting observation was that when both ethyl ester and its associated organic acid were measured, the Jacob's Creek product is higher in the ester form than the other products, with similar or lower concentrations of the organic acid. This has potential implications for the aroma of these products, as some of these organic acids (such as hexanoic acid or butanoic acid) can have aromas described as 'sweaty socks' and 'cheesy', while the esters have aromas that could be described as 'fruity'. One exception was 2-phenylethanol, where the Jacob's Creek sample had much lower concentrations than the other samples. For all samples, it appeared that this compound was unaffected by the alcohol removal process.

Monoterpene concentrations for this group of products were all quite low, with most approaching the limits of detection of the instruments. One sample (Tread Softly) had a linalool concentration marginally above threshold. Norisoprenoids were also mostly well below thresholds, with four samples showing levels of TDN close to aroma threshold levels and β-damascenone levels also close to or slightly above thresholds.

Low molecular weight sulfur compounds were reasonably abundant, with methional, dimethyl sulfide and methanethiol near or above thresholds in nearly all samples. Most of the sparkling samples contained a fair amount of sugar (around 50 g/L G+F), with only one sample containing less than 20 g/L G+F. Glycerol levels were low, with most samples containing 5 g/L or less, which, is slightly lower than the white and red categories. The pH values for these samples tended to be similar to those of traditional sparkling wines (around pH 3.0). Thiols and oak volatiles were not measured in the sparkling samples.

6.3.2 White and rosé wine products

Nineteen white and rosé NOLO wines were analysed. Alcohol contents were as follows: 1 x 9%, 2 x 5.5%, 7 x 0.5%, and 9 x 0.05%. Only one sample (9% Sauvignon Blanc) had a C6 compound concentration above aroma threshold (Z3-hexanol), suggesting that this class of compound is sensitive to the alcohol removal process, and likely plays a very small role in the aroma of dealcoholised wines. Generally speaking, fermentation products were seen in similar concentrations to the sparkling samples.

The trend of the samples with higher alcohol concentrations containing higher amounts of fermentation products continued and was perhaps even more obvious with the white and rosé samples. The three samples with alcohol concentrations greater than 0.5% were the only samples found to be above aroma threshold for ethyl 2-methylpropanoate, 3-methylbutanol, and ethyl 3-methylbutanoate, and were substantially higher in almost all other fermentation products. The concentrations of fermentation products in the 9% sample were also generally higher than the 5.5% samples. This suggests that the more alcohol removed from a sample, the more drastic the effect on the fermentation products, as the 9% sample was produced without removing alcohol. The two 5.5% samples were produced using reverse osmosis, but because the remaining 0.5% or lower samples were all produced using a Spinning Cone Column (SCC), it is difficult to say if it is the processing method or the alcohol not being completely removed from the sample that helps retain fermentation product concentrations. Again, 2-phenylethanol concentrations appeared stable through processing, as half of the samples had concentrations above threshold, and they did not appear to be related to alcohol concentrations.

Monoterpene concentrations were similar to the sparkling wines, with most samples having little to no compounds with concentrations approaching sensory thresholds. There were a couple exceptions in this group, however, with the Muscat-based sample having cis-rose oxide and α-terpineol concentrations above threshold, and one Chardonnay and one Pinot Grigio both having similar concentrations of linalool, cis-rose oxide, and α-terpineol. The Chardonnay also contained an above threshold concentration of geraniol. It seems likely, however, that these compounds were added post processing individually or as some kind of group aroma addition. Norisoprenoid concentrations were for the most part non-existent, with only two samples with β-damascenone concentrations above threshold.

Volatile thiol concentrations were prolific throughout the white sample set, with the Sauvignon Blanc samples having similar concentrations of 4MMP, 3-MH and 3MHA to that of traditional wines of this variety. The concentrations of these compounds do not appear to be related to alcohol concentrations, suggesting that they are reasonably unaffected by the SSC or RO alcohol removal processes. This also highlights the suitability of the Sauvignon Blanc variety for NOLO products made using the current alcohol removal technologies.

LMWS compounds were varied, but similar to the sparkling samples. Methional and methanethiol were above threshold for all white samples, and all but one sample were similarly above threshold for DMS. This, combined with the lack of ester-based fermentation products and the abundance of organic acids above threshold suggests that the potential for off-aromas and flavours likely to be perceived as egg, drain, cooked vegetable or sweaty socks is high. Care must be taken during primary fermentation to avoid these compounds, as post-dealcoholisation they have the potential to negatively affect these products.

One Chardonnay sample contained concentrations of vanillin at 100-fold higher than the rest of the white samples, and glycerol concentrations three-fold higher. Only one other sample had any measurable oak volatiles. G&F concentrations varied between 3.3 g/L and 48.3 g/L, with more than half the samples between 35 and 45 g/L. Volatile acidity, pH, SO_2 and titratable acidity values all resembled those of traditional wines.

6.3.3 Red wine products

Eighteen red samples were analysed. All samples were 0.5% alcohol (v/v) or less. At least three methods of alcohol removal had been employed to produce these samples: RO, SCC and packed column vacuum distillation (Memlo, VA Filtration, Barossa Valley). Also included in this set was the Ariel Cabernet Sauvignon produced by J Lohr Estates in California. This product has been produced since 1987 and is likely the most refined NOLO wine product globally.

Similar to the white and sparkling categories, the C6 compounds all had concentrations well below aroma thresholds. The fermentation products were generally found to have slightly higher concentrations than the white and sparkling categories, but still most compounds were below aroma thresholds. Looking at individual products, the VNO Shiraz and Dr Zenzen Dornfelder were both found to be deficient in most of the fermentation products. The VNO sample was below the limit of detection (LOD) for 13 of the 21 fermentation products measured. The McGuigan Shiraz and Dr Zenzen also exhibited similar chemical fingerprints, having substantially lower concentrations of the same products compared to the rest of the sample set. These three products were also the most deficient in fermentation esters, where the acid forms of the esters were still prevalent. Conversely, the Ariel Cabernet Sauvignon was highest in nine of the 21 fermentation products measured and was above average in concentration for all compounds except two. Interestingly, the Ariel and VNO samples were both produced using similar RO/nanofiltration methods. The Hardy's Zero Shiraz was produced using the Memlo system of alcohol removal, and the concentrations of fermentation products in this wine were very similar to the rest of the sample set, suggesting that the performance of this technology is on par with the current industry standard SCC for alcohol removal.

Monoterpene concentrations were generally below thresholds, with only a few cases of above for 1,8-cineole and linalool. There were also some samples at or slightly about threshold for cis-rose oxide. Most samples had β-damascenone in concentrations above aroma threshold, but the other norisoprenoids were below the LOD.

Similar to the previous categories, the reds had above-threshold concentrations of low molecular weight sulfur compounds DMS, methional and methanethiol. The Ariel sample had three times the concentration of DMS compared to the other red samples.

As would be expected, there were higher concentrations of oak volatiles in the red sample set. Above threshold concentrations of vanillin, oak lactone, guaiacol and eugenol were all found in three particular samples (Ariel, McGuigan, New Blood). The origin of these compounds (pre- or post-dealcoholisation) is unknown, although it is suspected that they may have been added as flavourings post processing.

Basic chemical composition appeared mostly similar to traditional red wines, except for titratable acidity, as some samples had lower TA values than would be expected. Post-dealcoholisation there is a concentration effect in the product as up to 30% of the volume is removed (alcohol and steam), thereby lowering the pH and raising the TA. These low TAs suggest that there has been a treatment to adjust the levels of acidity.

6.4 Piquette

6.4.1 2021 piquette

Results of basic compositional analysis from the three piquettes are presented in Table 4.

Table 4. Compositional analysis of piquettes made in vintage 2021.

Sample	Alcohol (% v/v)	pH	Titratable acidity pH 8.2
Rosé piquette	7.5	3.50	7.4
Sauvignon Blanc on skins	4.7	3.81	3.8
Sauvignon Blanc off skins	4.6	3.78	3.8

The piquette produced from the rosé grape marc contained a much higher alcohol percentage than the piquettes made from Sauvignon Blanc. A combination of the higher harvest Baumé of the Shiraz grapes (13.8 Bé) compared to the Sauvignon Blanc (11.0 Bé), and the 2:1 marc to water rehydration ratio for the Shiraz vs 1:1 for the Sauvignon Blanc are the likely causes for these differences. Informal sensory evaluation of the Shiraz based piquette showed a hot palate with low flavour but some wine likeness. Colour was pretty much that of red wine – dark and vibrant purple.

The two Sauvignon Blanc-based piquettes were substantially different from a sensory perspective, with fermentation on skins appearing to lead to different sensory outcomes. The piquette fermented on skins had a wine-like green hue and post-settling looked just like traditionally made Sauvignon Blanc. The piquette fermented without skins had a much darker hue, with brown tinges. It appears that the skins provided an extra level of protection from oxidation. These products were quite different sensorially, with the skins ferment showing more complex, herbal and capsicum-like flavours. The off-skins ferment was more dull and less complex, with reductive aromas prevalent.

Both of these products were not wine-like, with watery palates and more herbal, savoury characters and less fruit characters found in traditional wines. While the rosé piquette had some wine-likeness, the two Sauvignon Blanc piquettes highlighted the large differences between these products and traditional wine and show that piquette is its own product category and not a wine replacement or substitute. It was also observed that these products are particularly susceptible to microbial spoilage, as the lack of alcohol allows for many more spoilage organisms to proliferate. As soon as fermentation had completed and CO_2 was no longer being produced, within 24h bacterial growth was observed in both Sauvignon Blanc piquette ferments. Timely post fermentation SO_2 additions are imperative for maintaining the integrity of the product for all piquettes. Another production observation related to yeast nutrition. As most of the nutrients have been removed from the marc after pressing (or fermentation for red marc), additional nitrogen supplementation to support a healthy ferment and prevent reductive aromas and flavour is potentially necessary. Acid concentrations also must be monitored, as depending on rehydration regime, the piquette could have higher pH/lower TA leading to a higher susceptibility to microbial spoilage, which is already high because of the lower alcohol percentage.

6.4.2 2022 piquette

The 2022 piquettes were made from Chardonnay grape marc obtained from an Adelaide Hills vineyard. Fifty kilograms of marc was split into five vessels (10 kg each) and rehydrated with different amounts of water: 5 L, 10L, 15 L, 20 L, and 30 L. Basic compositional analysis of the piquettes can be seen in Table 5.

Table 5. Compositional analysis of piquettes made in vintage 2022

Sample	Alcohol (% v/v)	pH	Titratable acidity pH 8.2
10 kg/5 L	8.2	4	3.5
10 kg/10 L	6	3.9	3
10 kg/15 L	4.6	3.88	2.8
10 kg/20 L	4	3.81	2.7
10 kg/30 L	2.9	3.77	2.3

As would be expected, the alcohol percentages dropped from the products with the lowest amount of water used for rehydration (and therefore highest concentration of sugar) to the most amount of water used. Interestingly, the piquette with the highest titratable acidity was also the sample with the highest pH. This could perhaps be due to buffering from compounds extracted from the skins (potassium, sodium) in larger amounts due to the lower rehydration volume. The relationship between water addition and alcohol percentage was not quite perfectly linear but very close ($R^2 = 0.95$), and the relationship with pH was also almost linear ($R^2 = 0.96$).

Informal sensory evaluation was completed by a small group of experienced wine tasters, all members of the AWRI technical quality panel. The piquettes were quite varied over the sample set, with the 30 L sample being quite water-like and low in flavour. The 5 L sample was also substantially different, as it was found to be astringent and bitter, with a hot finish. The 10 L, 15 L and 20 L samples were more likely the kind of products that could be found commercially, with the small group of assessors preferring the 15 L sample as the most palatable.

Further evaluations on the 15 L sample, adding back small amounts of residual sugar in a 'sweet spot' exercise, found that a 15 g/L addition of sugar made the product quite a reasonably interesting and quality product, and an interesting alternative to a beer, RTD, or similar product with an alcohol concentration of 3-5%. The WIC Winemaking Services team also commented on the instability of the product post-fermentation, due to the potential for microbial spoilage. They also commented on the need for additional nitrogen sources for fermentation as the two most concentrated ferments (5 L and 10 L) needed additional DAP additions mid-ferment.

Overall, the potential for piquette to become a popular product category is good. It is a product that requires almost no financial inputs, as the only required ingredient is a waste product of the wine industry, and therefore is cost-effective as well as being sustainable. It produces a product that is low in alcohol, and still has some wine-likeness to it, which gives wine drinkers more options when it comes to choosing products in the low alcohol space. Piquette, however, is not wine, and therefore has the potential to be marketed without the constraints of traditional wine, such as in more innovative packaging formats.

6.5 Flavour and texture additions

Two sensory evaluations were undertaken to examine additives with potential for flavour and texture benefits regarding NOLO wine products. The first tasting involved products donated from Firmenich, tasted in a 0.05% alc (v/v) Sauvignon Blanc. These products are currently part of the company's offering to the brewing industry for NOLO beer products. Table 6 lists the products and their associated sensory attributes.

Table 6. Firmenich products and their associated comments from the sensory panel

Product	Attributes
Alcohol Astringency Flavour	Lighter colour, apple/pear, astringent, pithy, bitter
Distilled Spirit Flavour	Banana, more wine-like, lemon/lime flavours
Astringent Flavour	Less sweet, some wine flavour, more sour, less viscous
Modulasense Flavour	Cloudy, metallic, fullness, more viscous, less sweet
Beer Enhancer Flavour	Intense grapefruit, more bitter, apricot, oats, trigeminal tingle
Alcohol Bitter Key Flavour	Astringent, spicy, savoury, olive, high bitter
Alcohol Fuminess Key Flavour	Creamy texture, less viscous, heat lingers
Alcohol Booster Flavour	Musty, bitter, astringent, spice builds, chilli
Alcohol Warming Flavour	Chilli, hot, lingering heat
Grape Juice Flavour	Foxy grape aroma/flavour, not particularly wine-like
Alcohol Replacer Flavour	Herbal, woody, textural finish
Mouthfeel Enhancer Flavour	Astringent, stone fruit, longer finish, more viscous, roundness
Modulator A Flavour	Vanilla, oaky, sweeter palate
Alcohol Bitterness Flavour	Dried herbs, high bitterness
Alcohol Enhancer Flavour	Pyrazine, bitter, chilli burn, less sweet, spice
Taste Improver Flavour	Sweaty, hops, chilli heat to finish
Chilli Flavour	Chilli burn builds over time, but doesn't suppress sweetness

The general comments from the sensory panel regarding these additives were that they were not particularly wine-like, and on their own did little to replicate the sensory effect of ethanol in wine. However, there may be value in the blending together of these products to better optimise their wine-like characters.

The second tasting involved adding the amino acid L-proline to dealcoholised wine to evaluate its potential for use as a flavour enhancer. Proline has been shown to enhance taste, mouthfeel and flavour in wine (Espinase Nandorfy 2022). Proline was added to dealcoholised Sauvignon Blanc at 2 g/L and 4 g/L, and also to the samples of dealcoholised Sauvignon Blanc containing 400 mg/L of Muscat Gordo Blanco glycosides at the same concentration. Samples were assessed along with a control sample in an informal sensory session at the AWRI with members of the technical quality panel.

Tasters found the addition of L-proline did not enhance the sweetness of the proline-only samples; however the samples were thought to be less acidic than the control. The proline + glycoside samples were perceived as higher in flavour as well as lower in acid than the control and proline-only samples, with the 4 g/L addition of proline with glycosides showing the highest flavour concentration. The use of proline as a flavour enhancer does show some potential, both as an additive but also for production through viticultural practices. As proline is produced by grapes but not consumed during fermentation, varieties that produce more proline than others could be selected for use in NOLO products, or irrigation practices or other viticulture techniques that aid in the grapevine's production of proline could be adopted for grapes grown specifically for NOLO products.

6.6 Industry Reference Group

Consultation with the NOLO Industry Reference Group began in November 2020, with the goal of investigating the wants and needs of industry stakeholders across the supply chain. Members included winemakers, marketers, the head of production of one of the biggest wine companies

in Australia, a MW, a world-renowned wine journalist, an AWRI Board member, the Managing Director for a global wine additives company, the Managing Director of one of Australia's oldest family-owned wine companies and a university professor teaching wine business, among others.

All members were provided with a questionnaire with around 30 questions tailored to their specific role in the industry. Intermittent phone conversations allowed for members to further elaborate on their responses. Questions varied from impressions of the category and experience with the products, to more detailed and specific questions appropriate to their expertise. Those involved in productions were asked about technology, product development, future directions and researchable questions. Marketers and retailers were asked about consumer awareness and preferences, experience with packaging, directions for products and divisions between low- and no-alcohol products.

All members of the group communicated a positive attitude towards the category, with members with a commercial interest in the wine industry either expressing their willingness to develop products or that they were currently making products for this category. One member working in a marketing capacity in the wine industry commented "We need to keep wine drinkers in the wine category when they choose a NOLO product".

Group members' comments regarding research and development for this category stated the focus should be working on wine and not grapes or must, while attempting to "not denature the starting product, particularly with reds", and that 0% alcohol products should be the focus. Sparkling, aromatic whites and rosé categories have the most potential for 'quick wins' or 'are the low hanging fruit', with those categories also showing strong market demand according to the group members with products currently in the market. Replacing the sensory effect of alcohol in the products was viewed as most important, and changes to viticultural management deemed less important. "Viticulture treatments work well for the low category (8%), as it leaves the processing step out of it, but good products made in this way already exist in the market". Work on flavour and textural additions was also deemed important to the development of these products by the technical group members.

Members with technical expertise and experience with the category commented on the technology, indicating that Spinning Cone Column was the equipment to focus on in future research and development. "SCC is the only way to go" and "SCC is the only current viable option for no-alcohol wines" were two of the comments from the group.

Another consistent theme from group members was the desire to better understand consumers in this segment, with a lack of understanding of the wants and needs of consumers in the category, along with consumer demographics being younger and less traditional.

Group members also commented on the need for these products to be 'a replacement' for traditional wine, with similar packaging and to be consumed on 'wine occasions', with less focus on 'wine-based beverages'

7. Outcome and conclusion

This project was successful in setting the scene for research into the many facets of NOLO wine production. The goals for this study were to better understand the products available in the market and their sensory deficiencies, to better understand the technical processes that are available for removing alcohol from wine, and to understand the pain points for industry in regards to these products. Prior to this study, no work appears to have been published on technical know-how in NOLO wine production and sensory evaluation. This project has provided valuable information on the challenges being faced in this product category, and with continued industry engagement further research can potentially solve the many issues that surround these products.

8. Recommendations

Further investigations are needed to help the sector develop NOLO products that meet consumer requirements. This includes a better understanding of consumer requirements for this category of products. Process optimisation in the dealcoholisation step is essential, as well as incorporation of varietal selection and viticulture/winemaking practices that can help these products achieve higher levels of consumer acceptance. Preliminary studies on the sensory effect of proline in NOLO wines is a good example of where further research could be targeted. The regulatory framework surrounding these products is also unclear and confusing and this is a further area that needs consideration along with new product development and consumer research. While this project is now complete, a new NOLO wines project is beginning in 2023 that will have access to dealcoholisation equipment and other related NOLO tools to further facilitate research and product development in this area.

9. Appendix 1: Communication

As most of the outcomes for this project were to understand the NOLO sector and better develop effective researchable questions for a larger project beginning in 2022/23, no peer-reviewed journal articles were published. There were, however, a significant number of mainstream press and wine press articles regarding this topic and in particular this research project, as well as a number of presentations at industry conferences and seminars.

Media:

ABC News feature 29 June 2022. Available from: https://www.youtube.com/watch?v=CHEvw9T_fcY&t=12s

Australian Financial Review, Max Allen, 17 June 2022. https://www.afr.com/life-and-luxury/food-and-wine/why-more-alcohol-free-drinks-are-now-pouring-at-a-venue-near-you-20220512-p5akqp

ABC News Online, 29 June 2022. Available from: https://www.abc.net.au/news/2022-06-29/adelaide-research-into-best-way-to-make-low-alcohol-wine/101191974

Australian & New Zealand Grapegrower & Winemaker, Sonya Logan, 2 August, 2021. Available from: https://winetitles.com.au/in-pursuit-of-the-holy-grail/

ABC Central Victoria Breakfast Radio interview, Matt Tribe, 9 July 2022.

Presentations:

Low and no alcohol wine – insights and innovations. Presentation, University of Newcastle Sustainable Food Future Conference, 17 June 2021.

Low and no alcohol wine – why you should be paying attention. ASVO 2021 Oenology Seminar: Navigating new winemaking trends – finding solutions to existing issues, 30 September 2021.

NOLO in FOCUS: insight into consumer and category perceptions using focus groups. Poster presentation, 18th Australian Wine Industry Technical Conference, June 2022.

AWRI no and low alcohol project overview. Workshop presentation, 18th Australian Wine Industry Technical Conference, 26 June 2022.

Low and no alcohol wine – a category overview. Workshop presentation, 18th Australian Wine Industry Technical Conference, 28 June 2022.

10.Appendix 2: Intellectual property

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

11.Appendix 3: References

Antalick, G., Perello, M.-C., de Revel, G. 2010. Development, validation and application of a specific method for the quantitative determination of wine esters by headspace-solid-phase microextraction-gas chromatography–mass spectrometry. *Food Chem.* 121: 1236-1245.

Espinase Nandorfy, D., Watson, F., Likos, D., Siebert, T., Bindon, K., Kassara, S., Shellie, R., Keast, R., Francis, I.L. 2022. Influence of amino acids, and their interaction with volatiles and polyphenols, on the sensory properties of red wine. *Aust. J. Grape Wine Res.* https://doi.org/10.1111/ajgw.12564

Geffroy, O., Dufourcq, T., Carcenac, D., Siebert, T., Herderich, M., Serrano, E. 2014 Effect of ripeness and viticultural techniques on the rotundone concentration in red wine made from *Vitis vinifera* L. cv. Duras. *Aust. J. Grape Wine Res.* 20: 401-408.

Iland, P., Bruer, N., Edwards, G., Caloghiris, S., Wilkes, E. 2013. *Chemical analysis of grapes and wines: Techniques and concepts* (2nd ed.). Adelaide, South Australia: Patrick Iland Wine Promotions, p. 91.

Pisaniello, L., Watson, F., Siebert, T., Francis, I.L., Hixson, J.L. 2022. The varietal influence of flavour precursors from grape marc on monoterpene and C13-norisoprenoid profiles in wine as determined by Membrane-Assisted Solvent Extraction (MASE) GC-MS. *Molecules*, 27: 2046. https://doi.org/10.3390/molecules27072046

Sarneckis, C., Dambergs, R.G., Jones, P., Mercurio, M., Herderich, M.J., Smith, P. 2006 Quantification of condensed tannins by precipitation with methyl cellulose: development and validation of an optimised tool for grape and wine analysis. *Aust. J. Grape Wine Res.* 12: 39-49.

Siebert, T.E., Wood, C., Elsey, G., Pollnitz, A.P. 2008. Determination of rotundone, the pepper aroma impact compound, in grapes and wine. *J. Agric. Food Chem.* 56: 3745-3748.

Siebert, T.E., Solomon, M.R., Pollnitz, A.P., Jeffery, D.J. 2010. Selective determination of volatile sulfur compounds in wine by gas chromatography with sulfur chemiluminescence detection. *J. Agric. Food Chem.* 58: 9454-9462.

Šuklje, K., Zhang, X., Antalick, G., Clark, A. C., Deloire, A., Schmidtke, L. M. 2016. Berry shriveling significantly alters Shiraz (*Vitis vinifera* L.) grape and wine chemical composition. *J. Ag. Food Chem.* 64: 870-880.

Šuklje, K., Antalick, G., Coetzee, Z., Schmidtke, L. M., Baša Česnik, H., Brandt, J., Deloire, A. 2014. Effect of leaf removal and ultraviolet radiation on the composition and sensory perception of *Vitis vinifera* L. cv. Sauvignon Blanc wine. *Aust. J. Grape Wine Res.* 20: 223-233.

12. Appendix 4: Staff

Dr Wes Pearson, Ms Sheridan Barter, Dr Josh Hixon, Ms Eleanor Bilogrevic, Dr Leigh Francis, Mr John Gledhill

13. Appendix 5: Other supporting material (including raw data, if appropriate)

Not applicable