Characterising inter- and intra-regional variation in sensory profiles of Australian Shiraz wines from six regions

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Abstract

Background and Aims: Wines that exhibit regional characters are often the most sought after and the highest valued wines available in the marketplace. This study evaluated the sensory properties that were regionally distinctive for Australian Shiraz wines.

Methods and Results: Sets of wines (22–28 wines) from six prominent Australian Shiraz-producing regions were initially evaluated by groups of local winemakers using a rapid sensory method called Pivot Profile (PP) to obtain maps of their sensory characteristics. Three or four wines from each region were then selected using cluster analysis of the PP data and were evaluated using sensory descriptive analysis. The regional PP assessments provided a sensory fingerprint of the variability of each of the regions studied and identified sensory characteristics that typified the largest groups of wines of each region. The descriptive analysis highlighted sensory characteristics that distinguished the wines from the different regions, including mint, cooked vegetal, viscosity, dark fruit and savoury attributes.

Conclusions: This work has provided detailed quantitative data on the sensory properties associated with each of the regions and demonstrated that there are distinctive, region-specific sensory characteristics.

Significance of the Study: Sensory fingerprints that differentiate one region from another will aid producers and the trade in appreciating what can be expected from different regions; they allow targeting of production decisions to enhance distinctive sensory attributes and will assist in improved communication between marketers and consumers.

Keywords: *descriptive analysis, Pivot Profile, sensory, Shiraz, terroir*

Introduction

The term terroir (from the French word for land, *terre*) is a broad concept that acknowledges the influence of origin or place of agricultural products, and notably wine, which can result in differences distinctive to those of products from other locations (van Leeuwen 2010). While the term is most commonly used in a wine context, it is increasingly applied to other agricultural products such as cheese (Charters et al. 2017). Terroir can be considered the influence of place on the way a product looks, smells and tastes. Distinctive characteristics of a product linked to terroir can be derived from a diverse range of factors related to the physical environment, such as climate, topography, soil and geology, as well as to human intervention, including viticulture and winemaking decisions and regulations.

It could be said that regionality or terroir influences can be found in any agricultural product grown or produced in a particular place. Cultural aspects, however, have often been the most decisive factor as to whether a product has been considered a commodity or a product that becomes a regional champion or industry benchmark. This is partly influenced by economics, where supply and demand over a period of time means that products from a particular region or site become more sought after and command a higher price than those from sites that are considered less desirable (Trubek 2008).

The Appellation d'Origine Contrôlée (AOC) system in France awards food products a designation that defines them as regionally distinguished. Lentils, poultry, cheese, honey and butter are examples of products that have received an AOC designation. Wine, however, has the most comprehensive list of AOCs in France, with more than 300 currently listed (https://www.inao.gouv.fr/). The importance of specific origin in Italian, German and Spanish wine classifications also highlights the acceptance and the commercial and marketing value of denoting the source of sensory differences for these wine-producing countries. The increasing significance of regionality in relatively new wine-producing nations, such as the USA and Australia, indicates that the concept has appeal and value worldwide (Easingwood et al. 2011).

The scale of what are considered to be terroir effects depends on the product, with some wine types relating to a country-wide reputation, such as Australian wine, or on a regional scale, such as Champagne, while for some regions, localised subregional areas can be considered over time to produce distinctive sensory characteristics, most notably in Burgundy (Charters et al. 2017). For wine research studies, investigating at the scale of region has benefit as many wines, especially Australian and other non-European wines, are sold and marketed with information only on region of origin, rather than more specific subregional designations.

The general sensory properties of wines from specific regions can often be described with some degree of agreement among wine professionals, and if the sensory characteristics are apparent repeatedly between seasons, they can

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be considered the result of a regional terroir. Several recent studies have used a 'typicality' approach (Maitre et al. 2010, Cadot et al. 2012) to assess wines, where examples can be rated as more or less 'typical' of the region or appellation by a group of wine experts. While this is a valuable method to gain an insight into what extent a particular wine might be considered typical of the region, it does not consider multiple typical archetypes, which can be found in a set of regional wines. In many regions, there can be traditional or conventional wine styles within a region, as well as developing or more recent styles, as a result of evolution of practices or from a changing climate. Variability among wines from within a specific region or subregion is a critical factor for research studies as composition and resultant sensory properties of wines are well known to vary because of many factors, including between seasons as a result of climatic conditions of the vintage (Pereira et al. 2006, van Leeuwen 2010).

Explaining terroir for wine using scientific means has been a goal of researchers for decades, and the difficulty in doing so is well documented (Trubek 2008, Matthews 2015). Many studies have attempted to quantify regionality from a sensory perspective in commercially produced wine with varied results. The studies of Rankine et al. (1971), Duteau et al. (1981) and Noble et al. (1984) were some of the first to attempt to explain some of the aspects of regionality with regard to sensory assessment and chemical composition. The studies of Guinard and Cliff (1987) and Heymann and Noble (1987) were two investigations of note in a similar time period that began to lay down a blueprint for using sensory descriptive analysis to characterise sensory profiles for varietal wines from different places, in this case American Viticultural Areas (AVAs). Others have since attempted to use this method to characterise regional characters in wines (Fischer et al. 1999, Kontkanen et al. 2004, Vilanova and Soto 2005). Robinson et al. (2012a) examined regionality in a limited number of Australian Cabernet Sauvignon wines produced in 10 geographical indications (GIs) (Wine Australia's regional designation) from one vintage.

One underlying problem with the aforementioned studies is their process for selecting appropriate samples. These studies generally did not elaborate on how the wines were chosen or whether the samples were selected with advice from experts. The major problem with this is the difficulty in knowing that the selected samples are representative of the many wines produced from a particular region (Maitre et al. 2010). In addition, it is well known that one of the challenges in completing sensory descriptive analysis studies is the limited number of wines that can be assessed in one study (Stone et al. 1974, Lawless and Heymann 2010). Accordingly, most studies have included only a small number of wines from different regions, adding to concerns regarding the representativeness of the wines under study. This is especially true when high-volume, commercially produced wines are studied, with variable viticultural and winemaking practices that can obscure region-specific effects (Cadot et al. 2012).

King et al. (2014) published one of the most comprehensive sensory investigations of regionality to date, with the Malbec grape grown in Mendoza, Argentina and in California, USA, and wines produced under standardised conditions. This study included 26 wines from four regions from the province of Mendoza and 15 wines from five different California wine-producing regions.

Table 1. Regions, numbers of wines studied and number of panellists for the regional Pivot Profile sensory assessments.

Region	Number of wines	Number of panellists
Barossa Valley, South Australia	26	9
McLaren Vale, South Australia	28	10
Yarra Valley, Victoria	23	9
Heathcote, Victoria	23	12
Canberra, Australian Capital Territory/New South Wales	22	14
Hunter Valley, New South Wales	23	12

Shiraz is the most widely grown winegrape cultivar in Australia, with significant plantings in every wine-producing region. After France (where it is the third most planted red wine cultivar and often used in blends), Australia has the world's next largest holding of Shiraz vineyards (Robinson et al. 2012b). There have been few studies of the sensory differences related to region of origin for Shiraz. The present investigation builds on the regional differences indicated by the study of Johnson et al. (2013). This has been made possible with the recent development of relatively rapid sensory descriptive procedures (Varela and Ares 2012), with the investigation of larger numbers of wines to assess variability within and between regions becoming a practical option.

The aim of this work was to assess whether there are region-specific sensory differences among commercially produced Shiraz wines sourced from prominent Australian regions, taking into account within-region variability, and to characterise the sensory differences of the wines.

Materials and methods

Wines

The wines studied were all of the Shiraz/Syrah cultivar (no less than 95%) and contained 100% fruit sourced from within the boundaries of the respective region, according to the producers. Wines were all commercially available and sourced through normal commercial channels, with a retail price of between A$15 and 90. Wines were from either the 2015 or 2016 vintages as these were the current vintages for most producers at the time of the sensory assessment. When feasible, wines from a single site/vineyard were preferentially selected over multi-vineyard blends.

Between 22 and 28 wines were selected from each of six regions (Table 1). The regions were selected based on reputation as a premium Shiraz-producing region and on the availability of wines in the marketplace and to include wines from both cooler and warmer climate regions. For four of the six regions, all commercially available wines that met the selection criteria were included in the study. For the two remaining regions (Barossa Valley and McLaren Vale), including all the commercially available wines gave too large a sample size as these two regions have greater production and a larger number of individual wineries and brands (Wine Australia 2019a).

Therefore, for wines from these two regions, a preliminary sensory assessment was conducted in order to select wines that represented the diversity of wine styles within each region. Wines that were similar, and those with off-flavours, were excluded. This preliminary tasting was judged by experienced wine-tasting professionals from the technical quality panel at The Australian Wine Research Institute (AWRI). This panel convenes weekly to taste wines as a preliminary sensory evaluation of both industry and research wines. Panellists have from 3 to 15 years' experience on the panel. The final selection of wines for these two regions was then made considering geographical factors, such as differences in location across the region and altitude, winemaking influences and a spread of retail prices, and with consultation from local winemakers. The regional Pivot (reference) wines were selected from the regional groups of wines. The selection was based on being of sound quality and considered by the authors to have subtle, balanced regional characteristics.

Pivot Profile

For this study, a relatively large number of wines from each of the six selected regions (Table 1) was initially characterised using a rapid sensory methodology, namely, Pivot Profile (PP) (Thuillier et al. 2015). The purpose of these assessments was: first, to allow an understanding of sensory differences within each region and of the extent of variability and second, to provide data that could be used to select examples of wines from each region that encompass the range of sensory properties to be used in a sensory descriptive analysis study to allow direct comparisons of sensory profiles across regions.

Judges for the PP evaluation of the wines from each region were experienced wine industry professionals from the respective regions, with no less than 3 years of professional winemaking experience, recruited through local wine organisations and personal communication. No training was given, and none of the tasters had previously used the method. No compensation was offered to the panellists. The tastings were held within each region between May and August 2017 at either a municipal hall or at a winery that had a suitable tasting area.

Between 9 and 14 panellists completed the assessments (Table 1). Wines (50 mL) were presented in randomised order in ISO tasting glasses marked with three-digit codes. The Pivot wine was chosen by the authors from the regional sample sets as a wine representative of the region but not having any strong, distinguishing characters. Panellists received 100 mL of the Pivot wine, and more was available if requested during the tasting. Water was provided to all panellists as a palate refresher. Panellists were given 60 min to complete the tasting. Data were collected on A4 ballots with spaces for writing *more* or *less* than the Pivot for appearance, aroma and palate attributes (Figure S1). Overall, 145 wines were characterised by the PP method, with 22 assessed using both PP and descriptive analysis. Lemmatisation was completed by one individual to maintain consistency in the assessment of the ballots of the panellists in grouping-like terms. Initially, ballots were transposed into a spreadsheet by sample, and then, attributes were lemmatised under one general attribute name, that is, the terms tannin, tannic, drying and astringent were all grouped under the term tannin. Once grouping was complete, a frequency table was produced for all samples and attributes.

Descriptive analysis

Upon completion of the PP regional tastings 22 wines were selected for a sensory quantitative descriptive analysis study (Table 2).

A panel of 12 assessors (one male) was convened for this study, all of whom were part of the AWRI-trained external descriptive analysis panel with at least 2 years of wine descriptive analysis experience. Panellists ranged in age from 28 to 69 years, with an average age of 51 years (SD = 10.9). The panel runs approximately 45 weeks of the year with sessions held three times per week. Details of the

Table 2. Details of the wines selected from the sensory descriptive analysis study: codes, origin, vintage, price, alcohol concentration and regional growing degree days (GDD).

Region	Wine code	Subregion	Vintage	Price (A$)	Alcohol (% v/v)	Single vineyard?	Growing degree days (Region)†
Barossa Valley	BV1	Rowland Flat	2016	30	14.0	Y	1836
	BV2	Krondorf	2015	35	14.0	Y	1836
	BV3	Eden Valley	2015	70	14.9	N	1836
	BV4	Eden Valley	2015	35	14.7	Y	1836
McLaren Vale	MV1	Seaview	2015	28	14.9	Y	1829
	MV2	McLaren Vale	2015	28	14.2	Y	1829
	MV3	McLaren Flat	2016	25	14.6	Y	1829
	MV4	Blewitt Springs	2016	29	14.3	Y	1829
Heathcote	HC1	Mount Ida	2015	78	15.9	Y	1735
	HC2	Redesdale/Mia Mia	2015	30	14.1	Y	1735
	HC3	East Mount Camel	2016	30	14.4	Y	1735
Hunter Valley	HV1	Hermitage Road	2016	35	13.7	Y	2115
	HV2	Polkolbin	2016	65	13.8	Y	2115
	HV3	Polkolbin	2015	50	13.7	Y	2115
Canberra	CB1	Murrumbateman	2016	27	14.3	Y	1410
	CB2	Murrumbateman	2016	36	13.9	N	1410
	CB3	Lake George	2015	45	14.6	Y	1410
	CB4	Majura Valley	2015	34	14.0	Y	1410
Yarra Valley	YV1	Coldstream	2015	92	13.0	Y	1301
	YV2	Healesville	2015	35	14.2	Y	1301
	YV3	Gembrook	2015	40	13.7	Y	1301
	YV4	Dixons Creek	2015	52	14.0	Y	1301

†Growing degree day data from Wine Australia (2019b).

protocols and training for the descriptive analysis can be found in Siebert et al. (2018). Panellists undertook three 2h sessions in order to develop a list of consensus attributes appropriate for assessing the samples. A fourth 2h training session was then completed as a practice session with the list of consensus attributes in order to assess the effectiveness of the list. The finalised attribute list included three appearance terms, 19 aroma terms (18 defined and 'other') and 17 palate terms (16 defined and 'other'). These attributes, definitions/synonyms and reference standards are shown in Table 3. Reference standards were presented in wine (2017 Shiraz 2 L bag-in-box) unless otherwise noted.

All 22 wines were presented to assessors twice in a modified Williams Latin Square incomplete random block design generated by Fizz sensory acquisition software (version 2.51, Biosystèmes, Couternon, France). The 22 wines were split into eight blocks: seven blocks of three wines and one block of one wine. Panellists assessed five blocks per session. Formal assessment took place during four sessions over 4 days.

Panel performance was assessed using Fizz and R (The R Foundation for Statistical Computing Platform 2017) with the FactomineR (Lê et al. 2008) package, as described in Analyzing sensory data with R (Lê and Worch 2014). The performance assessment included ANOVA for the effect of judge, wine and presentation replicate and their interactions, degree of agreement with the panel mean, degree of discrimination across samples and the residual SD of each judge by attribute.

Data analysis

Pivot Profile data were prepared and standardised to positive values (Pearson et al. 2020). The data were then analysed using Correspondence Analysis (CA) (XLSTAT, Version 19.6, Addinsoft, Boston, MA, USA) to give a biplot of the wines and the relative frequency of the attributes. Analysis was initially undertaken for appearance, aroma and palate terms individually, and then, another CA analysis was completed for all of the most frequently used attributes ($SD > 1.0$) together. Agglomerative hierarchical clustering (AHC) using Ward's method was then applied to the raw data matrix to separate the wines into clusters to allow wines that best represented the regional diversity to be included in the descriptive analysis study. Four wines were selected from each of the following regions: Barossa Valley, Canberra, McLaren Vale and the Yarra Valley, together with three wines each from Heathcote and the Hunter Valley.

For descriptive analysis data, ANOVA was carried out using Minitab (Minitab, Sydney, NSW, Australia). The effects of wine, region, judge, presentation replicate and their two-way interactions were evaluated, with judge as a random effect. Fisher's least significant difference was then completed as a post-hoc test used for pairwise comparisons. Principal component analysis (PCA) was conducted on the mean values of the $P < 0.05$ and $P < 0.1$ attributes by wine averaged over panellists and replicates, using the correlation matrix. Any possible trends were highlighted by including $P < 0.1$ attributes. A Partial Least Squares Discriminant Analysis (PLS-DA) for the effect of region was completed on the significant and nearly significant standardised descriptive analysis means as X-data (The Unscrambler, Version 10.5, Camo Software, Oslo, Norway), with each region indicated as individual dummy variables (0 or 1, Y-data). Following full leave-one-out cross validation and inspection of the residual validation variance of the models, together with the cross-validated coefficient of determination (R^2 validation, also known as Q^2), a three-factor solution was considered optimal, ensuring avoidance of over-fitting the data. Regression coefficients for the sensory attributes that were greater than 0.01 for positive regression coefficients and lower than −0.01 for negative regression coefficients were considered potential contributors to the models.

Chemical analyses

The chemical composition of all wines included in the descriptive analysis study (Table S1) was determined in a single replicate analysis by The AWRI Commercial Services. Titratable acidity (pH 8.2), pH, volatile acidity (VA), residual sugar (glucose + fructose), specific gravity and alcohol were measured using FTIR WineScan (FOSS, Hillerød, Denmark).

Results and discussion

Regional Pivot Profile evaluations

The PP results for each region are shown in Figure 1. The data for each region are presented as a CA biplot to show the sensory differences among the wines and the descriptors that are related to the separation. The maps show which wines were associated with specific attributes compared to other wines. The biplots also show the proportion of 'inertia' that can be considered to be related to proportion of variability in the data, with most maps having a value of approximately 40%. This allows assessment of the strongest patterns in the frequency data. Any attributes less than 0.05 from the origin on both axes in Figure 1 were deleted as these attributes play a less meaningful role in defining the sensory character of the dimensions. Any further patterns noted below were also identified through inspection of the frequency tables. The data were subjected to cluster analysis, and wines from the same cluster were represented by the same colour in the biplots in Figure 1 and can be considered similar in sensory properties.

Direct comparisons between the individual regional PP evaluations require some caution, bearing in mind different groups of expert winemakers were used for each set. A previous study (Pearson et al. 2020), however, showed that the sample configurations from the sensory map of Shiraz PPs conducted by two different panels, one including international sommeliers and one using Australian winemakers, were similar. In addition, the attributes used to describe the wines were also largely the same. Thus, considering that all assessors were Australian professional winemakers with similar backgrounds who have experience across Australian wine styles and types, it is informative to compare differences among the wines from each region from the PPs generated.

The Barossa Valley biplot shows that wines along Factor 1 (F1) were separated based on fruit-related attributes versus jammy/savoury attributes. Interestingly, there were no colour attributes distinguishing the wines. Fruit aroma (A) and Dark fruit A were most associated with wines in the far right of Figure 1a, with other fruit-related attributes, such as Dark fruit Palate (P) and Red fruit P, also associated with these wines. Oak attributes such as Oak A, Smoke A and Spice P, as well as Herbal P, Soft P, Body P, were also used as descriptors for the wines to the right of Figure 1a. Wines at the far left of Figure 1a were most strongly related to the attributes Mint A, Reduced A, Savoury A and Jammy

Table 3. Sensory attributes, definitions and reference standards.

Attribute	Definition/synonyms	Reference standard composition
Appearance		
Opacity	The degree to which light is not allowed to pass through a sample	
Purple tinge	The degree of purple hue in the sample	
Brown tinge	The degree of brown hue in the sample	
Aroma		
Overall fruit	Intensity of the fruit aromas in the sample	
Dark fruit	Intensity of the aroma of dark fruits and berries: blackberries, plums, cherries, blueberries, blackcurrants	3 Frozen blueberries, 1 frozen blackberry (Sara Lee brand)
Red fruit	Intensity of the aroma of red fruits and berries: raspberries, strawberries and cranberries	3 Frozen raspberries (Sara Lee brand)
Dried fruit	Intensity of the aroma of dried fruit, cooked fruit, jam, prunes, dates	1 Dried prune, 1 dried fig (Coles brand)
Confection	Intensity of the aroma of confectionery, lollies	3 Raspberry lollies, no wine (Allen's brand)
Floral	Intensity of the aroma of flowers: violets, rose and blossoms	80 μL of 100 mg/L Linalool, 10 μL of 200 mg/L 2-phenyl ethanol
Vanilla/ Chocolate	Intensity of the aroma of vanilla, chocolate and dark chocolate	1/8 tsp Vanilla paste (Queen brand)
Spice	Intensity of the aroma of spices: cinnamon, nutmeg, cloves, sweet spice, mixed spice	50 mg Each mixed spice, nutmeg, cinnamon and 1 clove (Masterfoods brand)
Pepper	Intensity of the aroma of black pepper, white pepper, peppercorns	3 Grinds fresh black pepper (Saxa brand)
Woody	Intensity of the aroma of wood, oak, cedar, smoky oak	1 tsp French oak chips
Stalky	Intensity of the aroma of green stalks, dried herbs	2 Pieces tomato stalk, no wine
Mint	Intensity of the aroma of mint, eucalypt	1 Fresh mint leaf, no wine
Coffee	Intensity of the aroma of coffee, mocha	3 Coffee beans, crushed
Earthy	Intensity of the aroma of dust, dry earth, wet earth, beetroot, mud and compost	30 μL of 1 mg/L Geosmin
Cooked vegetable	Intensity of the aroma of cooked vegetables, cooked vegetable water, drains	2 tsp Liquid from canned mixed vegetables (Edgell brand)
Drain	Intensity of the aroma of drain, cooked egg	¼ tsp Ash
Beef stock	Intensity of the aroma of beef stock, vegemite, soy sauce, green and black olives	1 Beef bouillon cube (OXO brand)
Pungent	Intensity of the aroma and effect of alcohol	4 mL Ethanol (SVR, Tarac Technologies, Nuriootpa, SA, Australia)
Palate		
Overall fruit	Intensity of fruit flavours in the sample	
Dark fruit	Intensity of the flavour of various dark fruits: blackberries, plums, cherries, blackcurrants and blueberries	
Red fruit	Intensity of the flavour of red fruits and berries: raspberries, strawberries, cranberries	
Woody	Intensity of the flavour of wood, oak, vanilla, including after expectoration	
Earthy	Intensity of the flavour of earth, beetroot, including after expectoration	
Pepper	The intensity of the flavour of peppercorns including after expectoration	
Stalky	Intensity of the flavour of green stalks, capsicum, fresh green beans and other green vegetables including aftertaste	
Mint	Intensity of the flavour of mint, eucalypt, including aftertaste	
Umami	Intensity of umami taste, including aftertaste	2.5 g/L Monosodium glutamate in water (G Fresh brand)
Sweet	Intensity of sweet taste, including aftertaste	8 g/L White sugar in water
Viscosity	The perception of the body, weight or thickness of the wine in the mouth; Low = watery, thin mouth feel, High = oily, thick mouth feel	1.5 g/L Carboxymethylcellulose sodium salt (Sigma-Aldrich, St Louis, MO, USA) in water
Acid	Intensity of acid taste in the mouth including aftertaste	2 g/L L-(+)-Tartaric acid (Chem-Supply, Gilman, SA, Australia) in water
Hotness	The intensity of alcohol heat perceived in the mouth, after expectoration and the associated burning sensation; Low = warm, High = hot, burning	8% Food-grade alcohol (Tarac Technologies) in water
Astringency	The drying and mouth-puckering sensation in the mouth; Low = coating teeth, Medium = mouth coating and drying, High = puckering, lasting astringency	0.43 g/L Alum sulfate (Ajax Finechem-Supply, Cheltenham, Vic., Australia) in water
Bitter	The intensity of bitter taste perceived in the mouth, or after expectoration	0.15 g/L Quinine sulfate (Sigma-Aldrich) in water
Fruit AT	The lingering fruit flavour perceived in the mouth after expectorating	

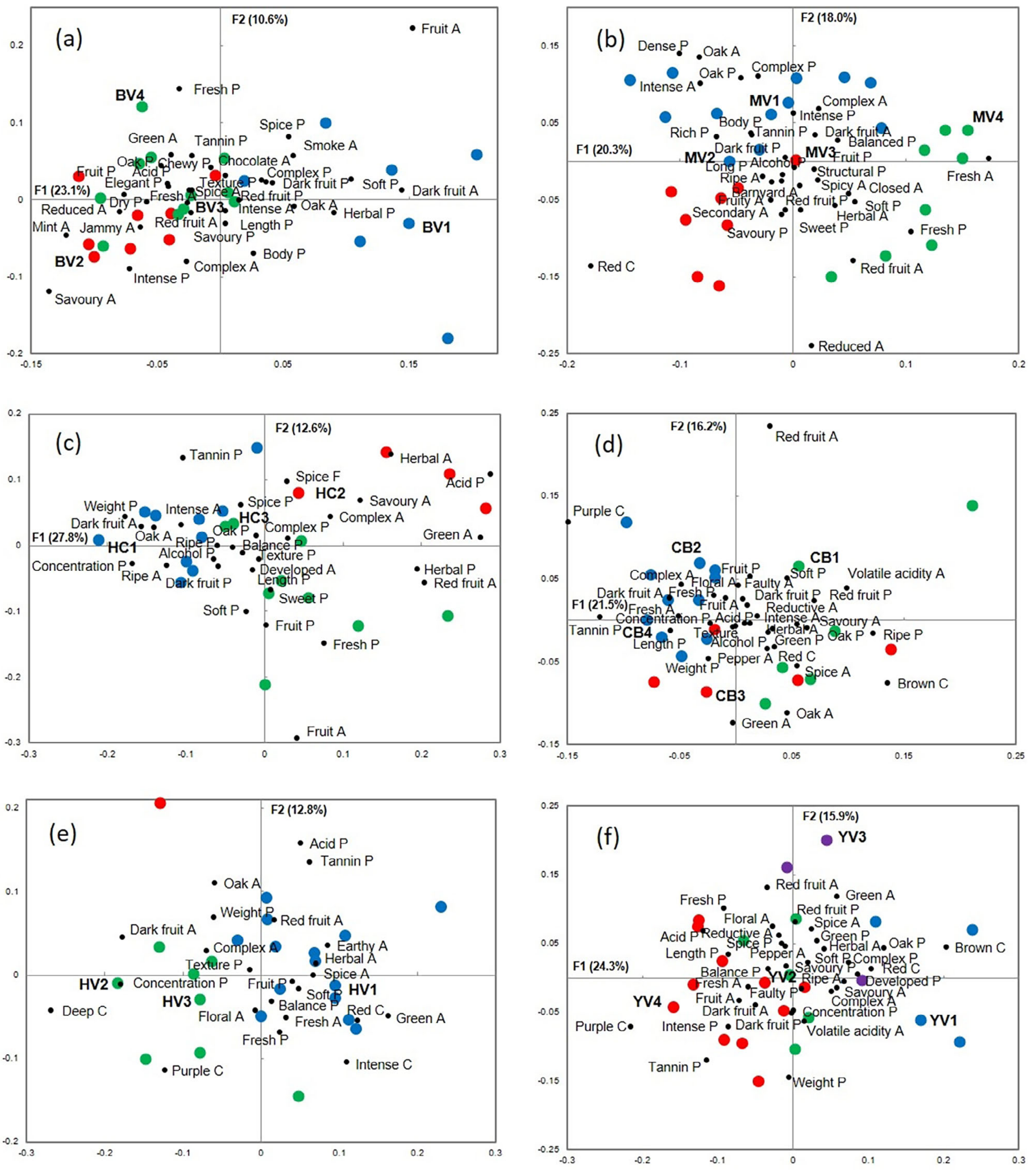

Figure 1. Correspondence analysis map for Pivot Profile sensory data for wines from (a) Barossa Valley (BV), (b) McLaren Vale (MV), (c) Heathcote (HC), (d) Canberra (CB), (e) Hunter Valley (HV) and (f) Yarra Valley (YV). Clusters *are denoted for each region by colour. Samples marked with a code were selected for the multi-regional descriptive analysis. The letter C after an attribute denotes colour; A, aroma; and P, palate.*

A. Along Factor 2 (F2), the attributes Fruit A, Tannin P, Green A and Fresh P are opposed to the attributes Body P, Complex A and Intense P.

From the cluster analysis applied to the data set, three clusters were identified (Figure 1a). Cluster 1 consisted of seven wines, and these wines were most associated with the attributes Mint A, Reduced A, Savoury P, Intense P, Complex P, Jammy A, Dry P and Fruit P. The largest Cluster 2 consisted of 11 wines, associated with Fresh A/P, Green A, Tannin P, Chewy P, Oak P, Acid P, Fruit P, Elegant P, Spice A, Texture P, Length P and Savoury P. Along Factor 3 (F3), this cluster was also associated with Length P, Fresh P, Oak A/P and Mint A. Cluster 3 contained eight wines, associated with Dark fruit A and P, Soft P, Spice A/P, Fruit A, Herbal P, Red fruit P, Chocolate A, Smoke A, Oak A and Complex P. Overall, the Barossa wines can be broadly summarised as falling into three categories: softer, lower tannin wines with high intensity of dark fruit flavour and some oak flavour; wines with jammy characters with mint, savoury or sulfidic characters; and higher tannin, fresh wines with some green notes.

The McLaren Vale biplot (Figure 1b) shows that Fresh A/P, Purple C and Red fruit A are opposed to Red C, Dense P, Intense A, Oak A/P and Rich P along F1. Wines plotted to the upper half of Figure 1b were associated with Oak A/P, Dense P, Complex P and Intense A attributes. Factor 3 (not shown) separated the wines based on the terms Fruit A and Tannin P. Compared to the Barossa results, attributes such as jammy, mint, green or smoky were not used for the McLaren Vale wines, while colour terms and others such as sweet, structural, closed, barnyard and secondary were applied, which did not have direct equivalents for the Barossa Valley wine set.

Three clusters were identified, with the largest Cluster 1 including 12 wines spread over the top two quadrants (Figure 1b), having associations with the attributes Dense P, Oak A/P, Complex A/P, Body P, Tannin P, Intense A and Rich P. Cluster 2 wines were located in the bottom left quadrant, with these wines described as higher in Red C and were less frequently described by the attributes Red fruit A and Fresh A/P. Cluster 3 samples are all located in the upper right quadrants. The wines in this cluster had a strong association with the attributes related to Fresh A/P and Red fruit A. Overall, the McLaren Vale wines tended to be defined by differences in colour and freshness/red fruit on the aroma and palate, relative to those wines with red colour, greater fruit intensity, tannin, body, complexity and oak character.

For the Heathcote biplot (Figure 1c), the major separation of the wines along F1 related to the attributes Dark fruit A/P, Oak A/P, Weight P, Concentration P and Ripe A/P, associated with those wines to the left of Figure 1c, as opposed to Red fruit A, Herbal A/P, Green A and Acid P. Factor 3 (not shown) separated the wines by the attributes Developed A, Ripe A/P and Tannin P. Factor 4 (F4, not shown) separated the wines by the attributes Oak A and Texture P.

Of the three clusters found, the largest Cluster 1 consisted of 10 wines, which were located to the left of Figure 1c. These wines were associated with the terms Purple C, Weight P, Dark fruit A/P, Oak A/P, Intense P, Ripe A/P, Concentration P, Alcohol P, Spice A/P and Tannin P. Cluster 2 consisted of only four wines, associated with the attributes Savoury A, Complex P, Green A, Acid P, Herbal A and Spice P. Cluster 3, with nine wines, was most associated with Soft P, Fruit A/P and Red fruit A. Overall, the Heathcote wines were separated in a similar manner to the previous warmer climate regions, with major differences in freshness/red fruit comparative to those wines with deeper colour, high fruit intensity, tannin, body, complexity and oak. The high usage, however, of the terms Herbal A/P and Green A for several wines is different from the Barossa and McLaren Vale characterisations, and many wines were clearly associated with the descriptors ripe and dark fruit.

The Canberra wines are shown in Figure 1d, with the separation along F1 influenced primarily by Purple C, Tannin P and Dark fruit A (negatively loaded on F1) as opposed to Brown C and Ripe P and, to a lesser extent, Red fruit A/P. Interestingly, the term Ripe is associated with the terms Red fruit A/P in this region, but in the other regions, Ripe tended to be associated with Dark fruit A/P. The terms Purple C and Brown C are also important to the separation of the wines.

The largest of the three identified clusters, Cluster 1, consisted of 11 wines that were related to the attributes Purple C, Dark fruit A/P, Tannin P, Fresh A/P, Length P, Complex A, Floral A and Fruit A/P. Along F3, the attribute Green A was also associated with this cluster. Cluster 2 contained six wines, and they were associated with the terms Red fruit A/P, Savoury A, Oak A/P, Spice A, Pepper A and Green A/P. While F1 and 2 do not clearly differentiate Clusters 2 and 3, they were separated more effectively along F3. Cluster 2 wines were associated with the terms Pepper A, Green A, Floral A, Herbal A and Spice A. Factor 3 also associated these wines with the term Brown C. Cluster 3 had five wines and was related to the attributes Weight P, Spice A and Red and Brown C by F1 and 2. Along F3, wines in this cluster were also related to the term Ripe P and were described less frequently by Pepper A, Green A, Herbal A and Floral A. Overall, Cluster 1 can be summarised as having dark fruit, purple colour and tannin attributes, while Cluster 2 wines were fresh, peppery, green and herbal. Cluster 3 wines were oak influenced and ripe.

The Hunter Valley biplot (Figure 1e) shows the wines from this region separated along F1 by the terms Deep C, Dark fruit A, Concentration P and Purple C on the left side of Figure 1e and Green A, Intense C, Red C, Herbal A, Spice A, Earthy A and Tannin P. Factor 3 (not shown) separated the attributes Dark fruit A, Green A and Complex A from Tannin P, Intense C, Deep C and Oak A. Factor 4 (not shown) separated Dark fruit A from Red fruit A and Fruit P, as well as Acid P, Intense C and Fresh P from Soft P, Earthy A and Texture P.

There were three clusters obtained for the Hunter Valley wines, although one cluster had only one wine, which can be considered an outlier, meaning the variation in sensory properties for Hunter Valley Shiraz can be considered lower than the other regions studied, with only two major clusters. Cluster 1 consisted of nine wines, and they were associated with the terms Deep and Purple C, Concentration P, Dark fruit A, Complex A, Texture P and Floral A. Along F3, there were associations for wines of this cluster with the terms Green A, Intense C and Tannin P and, along F4, Acid P and Fresh P. The larger Cluster 2 consisted of 13 wines and had associations with the terms Weight P, Oak A, Acid P, Tannin P, Earthy A, Red fruit A, Herbal A, Spice A, Green A, Red C and Balance P. Along F4, there was also an association with Dark fruit A. The one wine in Cluster 3 was strongly associated with Oak A, Acid P and Tannin P. Overall, for the Hunter Valley region, separation of wines tended be based on dark fruit, concentrated wines with deep and purple colour and wines with higher acid and tannin, with earthy, herbal and red fruit characters.

The Yarra Valley biplot (Figure 1f) shows broad separation of the wines along both F1 and F2. Wines to the left of Figure 1f were associated with the attributes Purple C, Tannin P, Acid P, Fruit A, Intensity P, Length P and Fresh A, while wines to the right were described by the attributes Brown C, Oak A/P, Developed A, Complex A/P, Green A/P, Herbal A and Savoury A. Factor 2 separated the wines by the attributes Weight P, Tannin P, Purple C and Intense P, which are contrary to Red Fruit A/P, Green A, Floral A and Fresh P.

For this region, four clusters were identified. The largest Cluster 1 consisted of 11 wines, where almost all were located in the left of Figure 1f, associated with the terms Purple C, Tannin P, Fruit A/P, Intense P, Dark fruit A/P, Fresh P, Ripe A and Complex P. Cluster 2 had five wines, associated with the terms Fresh P, Floral A, Pepper A, Savoury P, Soft P, Complex P, Green A and Herbal A. These wines were intermediate in those attributes along F1, and F3 highlighted the associations with some less-desirable attributes, such as Faulty A, Volatile acidity A and Reductive A. The wines in this cluster were also less frequently described by the attributes Length P, Balance P, Complex P and Fruit A. Cluster 3 had only three wines and was

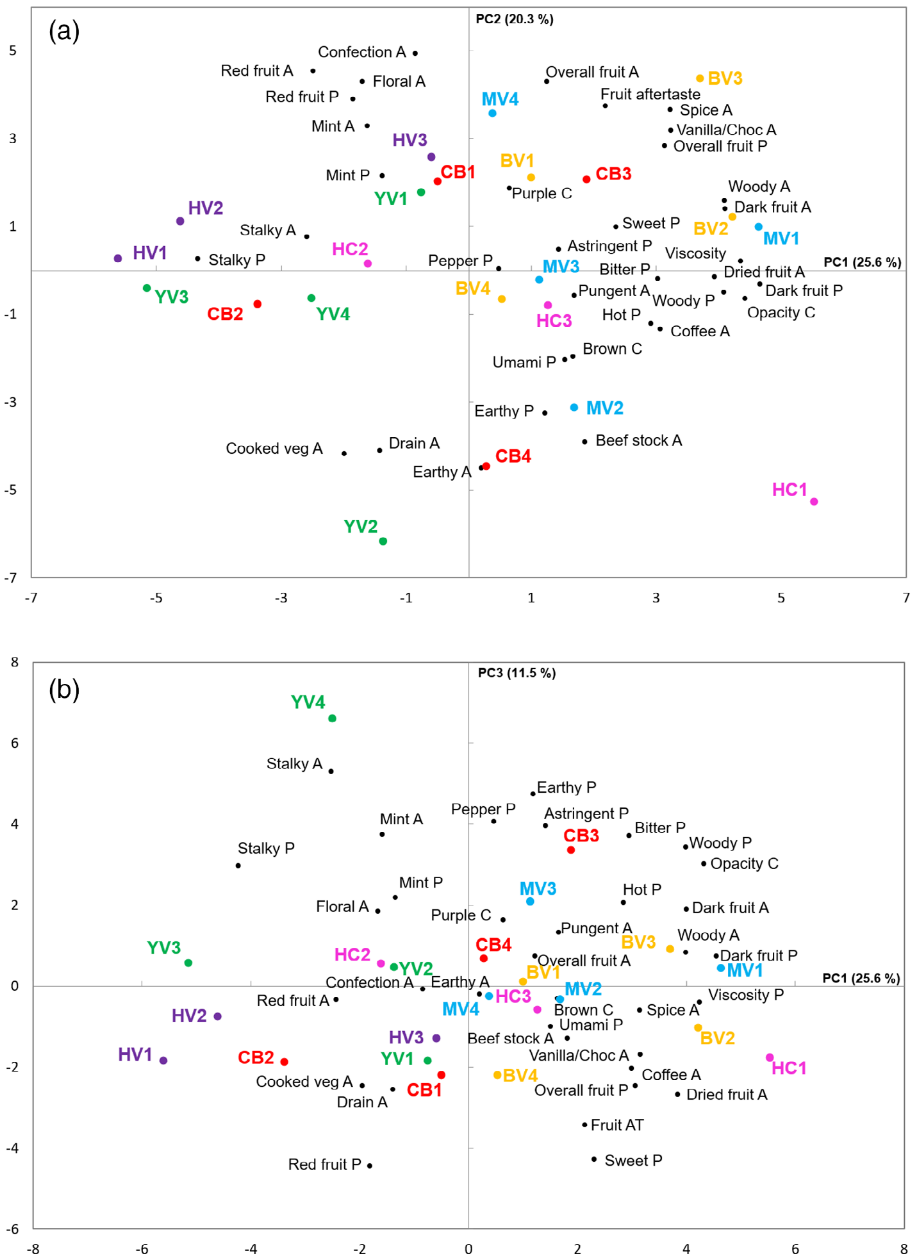

Figure 2. Biplot of principal components (a) PC1 and PC2 and (b) PC1 and PC3 for the sensory descriptive analysis mean attribute scores (n = 12 panellists × 2 replicates) for the 22 wines. Vectors for the sensory attributes and points for the wines are shown, with the wines coded based on region, where Barossa Valley (BV); McLaren Vale (MV); Heathcote (HC); Yarra Valley (YV); Hunter Valley (HV) and Canberra (CB). The letter C after an attribute denotes colour; A, aroma; and P, palate.

generally associated with the terms Red fruit A/P, Green A/P, Complex P, Red C and Developed A. Cluster 4 had four wines, and these wines were associated with the terms Brown C, Oak A/P, Red C, Savoury A and Developed P along F1 and 2. The sensory characteristics of the Yarra Valley wines can be considered to have higher variability than those of other regions and range from high tannin, high purple colour, concentrated and fruit driven (Cluster 1) to similar but slightly faulty wines (Cluster 2), to red fruit, green and spicy wines (Cluster 3), to oak driven, brown colour, developed and complex wines (Cluster 4).

Overall, these PP sensory assessments highlighted the range and variability of sensory properties within each region. It has also provided firm indications of the characteristics responsible for regional differences, despite a range of sensory properties represented within each region. The identification of specific styles that might be considered 'typical' is difficult. One possible approach is to examine the largest cluster from each region and assign it as 'regionally typical'. If we assume that each region will have some wines that would be considered outliers from a sensory perspective, resulting from major differences in the production of the wine, it will lie outside the largest cluster. Therefore, examining the sensory characteristics associated with the largest cluster can yield a general profile of what might be typical for the region. This is particularly relevant when examining the biplots of the Canberra and Yarra Valley regions, where there was one cluster that was much larger than the others, and to a lesser extent McLaren Vale, Hunter Valley and Barossa Valley.

Descriptive analysis

To compare wines from the regions in more detail, a subset of three or four wines from each region was carefully selected for study by sensory descriptive analysis (selected samples marked in bold typeface in Figure 1a–f). Cluster analysis on the PP data for each region allowed for a choice of wines that can be considered representative of the different sensory profiles found for that region. This approach provides a transparent means of truly evaluating whether wines from different regions may be distinctive. The selection of wines was made through choosing the wine from the cluster analysis that closely matched the centroid of the cluster, although in four regions, two wines were selected from the same cluster (i.e. Barossa Valley, Canberra, McLaren Vale, Hunter Valley), where the cluster contained a relatively large number of wines, and there was a wide spread of wines across the cluster. The selection also attempted to avoid wines sourced from multiple vineyards.

From the sensory descriptive analysis study, the ANOVA showed that all attributes were significantly different among wines ($P < 0.05$) except for Pepper A and Acid P (Table S2). The attributes Coffee A and Overall fruit A were significant ($P < 0.1$); however, they were not significant by region. The terms Confection A, Mint A and Umami P were the only other attributes not significant by region while being significant at $P < 0.05$ across all samples. The lack of significance of these attributes does not mean they are not important as the method for the selection of samples to represent a region inherently could lead to some typical and non-typical characteristics in the wines. Pepper A and Acid P were not included in further analysis, while the significant $P < 0.1$ attributes were included. Attribute mean values from the sensory descriptive analysis are displayed in Table S3, and regional means for the sensory attributes are displayed in Table S4.

Figure 2 shows the PCA biplots of PC1 and PC2 and also PC1 and PC3. The first two PCs account for 45.9% of the variance, with PC3 explaining a further 11.5% and PC4 (not shown) explaining 8.4%, indicating that the sample set was relatively complex, with several uncorrelated sensory attributes. Separation along PC1 was most strongly influenced by the attributes Woody A and P, Dark fruit A and P, Opacity C, Dried fruit A and Viscosity P, together with Spice A and Vanilla/Chocolate A, which were highly positively loaded along PC1, with Stalky A and P strongly negatively loaded along PC1. Wines situated in the upper half of Figure 2a were rated higher in Confection A, Floral A, Red fruit A and P, as well as Overall fruit A and AT, while those in the lower half of Figure 2a were rated higher in Cooked veg A, Drain A, Earthy A and Beef stock A. The separation along PC3 related to the terms Stalky A and Earthy P, together with Pepper P and Astringent P, with wines plotted to the lower half of Figure 2b rated lower in these attributes and higher in Red fruit P, Fruit AT and Sweet P. PC4 explained variation of Purple C and Brown C.

The separation of the wines revealed a general trend of wines from the cooler regions plotted to the left, while wines from warmer regions such as McLaren Vale, Barossa Valley and Heathcote were to the right, being higher in opacity (colour intensity), viscosity, dark fruit, dried fruit and oak related attributes. These wines were also generally higher in hot, bitter and coffee attributes. Also situated to the left were wines from the Hunter Valley, which has the highest growing degree days (GDD) value of the regions studied and would be considered a warm region. The two vintages studied (2015 and 2016), however, were both wet vintages (Bureau of Meteorology 2020), which likely would have led to early harvests.

The four Barossa Valley wines were grouped quite closely together, indicating a similar sensory profile, namely, being high in Opacity C, Dark fruit A/P, Viscosity P, Woody A/P, Dried fruit A, Overall fruit A/P and Fruit AT and rated low in Stalky A/P and intermediate in Red fruit A/P, Floral A and Confection A. All four Barossa Valley wines also had relatively high scores for Sweet P.

Three of the McLaren Vale wines were also grouped reasonably tightly with similar sensory properties to those of the Barossa Valley wines. The position of MV2 was more influenced by Earthy A/P and Beef stock A attributes.

The three wines originating from the Heathcote region were widely separated mainly along PC1, with the wine HC1 showing a high mean score for the attributes Opacity C, Dark fruit A/P and Dried fruit A, as well as Coffee A, Beef stock A, Umami P and Hot P, with particularly low scores for the attributes Red fruit A/P, Confection A, Floral A and Stalky A/P. The HC2 wine had higher ratings for Red fruit A/P and Stalky A/P.

The four wines from the Canberra region were also widely dispersed across Figure 2. Interestingly, the two wines situated to the left were from the same subregion (Murrumbateman), with the other two wines from different subregions (Lake George and Majura Valley). The two Murrumbateman wines were both rated highly for the attributes Red fruit A/P and Stalky A/P and low for the attributes positively loaded on PC1, with the CB2 wine notably high in Stalky A/P. The Lake George Canberra wine CB3 was unusually complex, being rated highly for the attributes Brown C, Floral A, Dried fruit A, Opacity C, Viscosity P, Overall fruit A/P, Dark fruit A/P, Spice A, Woody A, Bitter P, Mint A/P and Pepper P. The Majura Valley wine CB4 was rated highly for the attributes Earthy A/P, Cooked veg A, Drain A, Beef stock A, Woody P and Pepper P.

The four Yarra Valley wines were separated in Figure 2 by a similar distance to the Canberra wines, with all wines situated to the left of the figure, indicating low ratings for the attributes heavily positively loaded along PC1 and high ratings for the Stalky A/P attributes. The wine YV1 was located close to the origin, which indicates intermediate ratings. Trends among the Yarra Valley wines include high scores for Stalky A/P for three of the four wines and Mint A/P, Red fruit A/P, Floral A and Pepper P for two of the four wines. Three of the four wines also scored low for the attributes Astringency P and Dried fruit A.

The three Hunter Valley wines were all scored highly for the attributes Red fruit A/P; moderately high for Stalky P and Mint A/P; and low for the attributes Dark fruit A/P, Viscosity P, Pepper P and Woody A/P. Of all the regions, the Hunter Valley wines showed the most similarities between the wines studied.

The PCA did not clearly distinguish regions, with no regions being clearly separated and a strong degree of overlap between some regions. This is most probably a result of the selection process from the initial PP assessments. Wines were purposefully selected from each cluster to represent the diversity of all the main characters in each region. Therefore, the wines were deliberately selected to be as varied as possible but still representative of Shiraz from a particular region.

While the selection process considered the different sensory profiles, it is acknowledged that some clusters had a much smaller number of wines and so may be considered less typical of the region or from a minority group. This was most clear for the Yarra Valley wines, where YV3 was selected from a set of only three similar wines, while for the Canberra region, CB3 was one of five wines. Identifying the wines that can be considered representing the majority of the wines, that is, those from the largest clusters, the effect of region becomes more obvious. This is evident in Figure 2, where the majority of the most 'typical' wines (BV3/4, MV1, HC1, CB2/4, YV4, HV1) are well spread across the biplots, showing clearly distinct sensory properties.

To specifically pinpoint individual attributes that discriminate between regions, a PLS-DA was conducted. A three-factor solution was selected based on residual validation variance (minima 0.152), and the results are shown in Figure 3.

The HV wines were well discriminated from the other regions (R^2 calibration for the model 0.61, R^2 validation 0.21), with Purple C positively related to the discrimination, and the relative absence of Brown C, Dark fruit A, Pepper P, Woody P, Bitter P and Hot P, as well as most other attributes (as indicated by the negative regression coefficients), being important to classify wines from this region from those of the other five regions. Wines from Canberra were also moderately well discriminated (R^2 calibration 0.43, R^2 validation 0.03), with Figure 3f showing that higher Brown C, Stalky A, Pepper P, Mint P, Bitter P and lower Purple C contributed the most in separating Canberra wines from the other regions. Yarra Valley wines were predicted to a similar degree (R^2 calibration 0.39, R^2 validation 0.03), with the most positively related attributes being Brown C, Stalky A/P, Pepper P and Cooked veg A and the most negatively related being Purple C, Vanilla/Choc A, Spice A, Sweet P, Viscosity P, Astringent P and Fruit AT. The Barossa Valley classification was less clear (R^2 calibration 0.29, R^2 validation 0.02), with two Barossa wines not predicted well by the model (BV1 and BV4). The strongest positively related attributes for the Barossa classification were Vanilla/Choc A, Spice A, Woody A, Overall fruit P, Sweet P, Viscosity P and Fruit AT, with the negatively associated attributes being Cooked veg A, Beef stock A, Earthy P and Stalky P. McLaren Vale wines were classified poorly (R^2 calibration 0.20, R^2 validation not calculable). The attributes Opacity C, Purple C, Vanilla/Choc A and Astringent P were positively associated with the MV discrimination, while negative attributes included Brown C, Stalky A/P and Mint P. Finally, the Heathcote region was predicted slightly poorer than that of Barossa Valley (R^2 calibration 0.25, R^2 validation not calculable), with only one wine well classified (HC1), although no wines from other regions were misclassified as Heathcote. Opacity C and Purple C, Beef stock A, Earthy P, Umami P and Astringent P were positively associated with Heathcote regional discrimination, while Red fruit A/P, Floral A, Stalky A and Mint P were most strongly negatively related. As a second step in the analysis, the PLS-DA model was then used to predict each wine's region based on its sensory characteristics. Using this model, only CB2 and HC2 were misclassified (both as Yarra Valley wines). These results from the PLS-DA provide some reinforcing evidence regarding the key sensory attributes and their relative contributions that were distinctive for each region's wines, with several attributes found to be unique for a specific region: with Mint P for Canberra; Cooked veg A for Yarra Valley; Overall fruit P, Sweet P and Viscosity P for Barossa Valley; and Beef stock A, Earthy P, Umami P for Heathcote. McLaren Vale did not have a unique positive or negative attribute, while the Hunter Valley region's model included the negatively associated distinctive attribute Dark fruit A. The PLS-DA models, as noted above, were not highly robust, and a larger number of wines from each region would be required to be characterised to allow reliable predictive ability for unknown samples, with higher R^2 validation values.

The descriptive panel described some interesting attributes that were linked to the region of origin. The term Beef stock A was rated high in wines from Heathcote but was also noted in some Canberra and Yarra Valley wines. The Heathcote mean (Table S4) for this attribute, however, is nearly double that of the next highest regional mean. The origin of this attribute is unclear. Mint as an attribute is better understood, often used synonymously with the term eucalypt (Robinson et al. 2011, 2012a), which can be associated with Australian red wines in a global context. The origin of these sensory characters can often be attributed to nearby eucalypt trees (Capone et al. 2012). In the present study, this attribute was moderately associated with Canberra wines. In the PP tastings, the term earthy was used only by the winemakers assessing Hunter Valley wines and was associated with herbal and green terms; however, it was used by the DA panel to describe several other wines, and the earthy aroma was correlated with sulfide-related terms Drain A and Cooked veg A. The attribute Pepper has often been associated with Australian Shiraz from cooler regions (Parker et al. 2007, Siebert et al. 2008). Two of the four wines from both the Canberra and Yarra Valley regions had higher scores for this attribute, which might be expected as they would be considered the cooler of the regions included in the study. The term Coffee A was found to be significant across all wines, $P < 0.1$; however, upon examination of the mean scores, the five highest scoring wines came from five different regions. Regarding the 'green' attributes indicated by winemakers in the PP assessment of each region's wines, the DA results provided evidence that the wines of some regions were more likely to have a 'stalky' green character, while others were described as cooked veg. 'Cooked veg' has been previously linked to the sulfur compound dimethyl sulfide, which may be in turn related to nitrogen management in both the vineyard and winery through urea or diammonium phosphate use (Ugliano et al. 2008). In contrast, stalky has been recently linked to the concentration of 3-isobutyl-2-methoxypyrazine in Shiraz wines made with rachis included in the fermentation (Capone et al. 2018), for example, in whole bunch fermentation. The volatile and non-volatile compounds that relate to the sensory properties found in this study will be reported in a separate publication.

The effects of winemaking decisions must be considered when discussing regionality. There are some production decisions in Australia that may be considered 'cultural', meaning the technique has a history of usage in the region and is found in many wines produced therein. An example of this is the inclusion of small amounts of Viognier in Shiraz wines produced in Canberra. Another example would be the inclusion of whole bunches in Shiraz ferments in the Yarra Valley, a technique that is more traditionally associated with wines made from the Pinot Noir grape in that region. Harvest ripeness or the use of a large proportion of new oak barrels are also good examples of these cultural

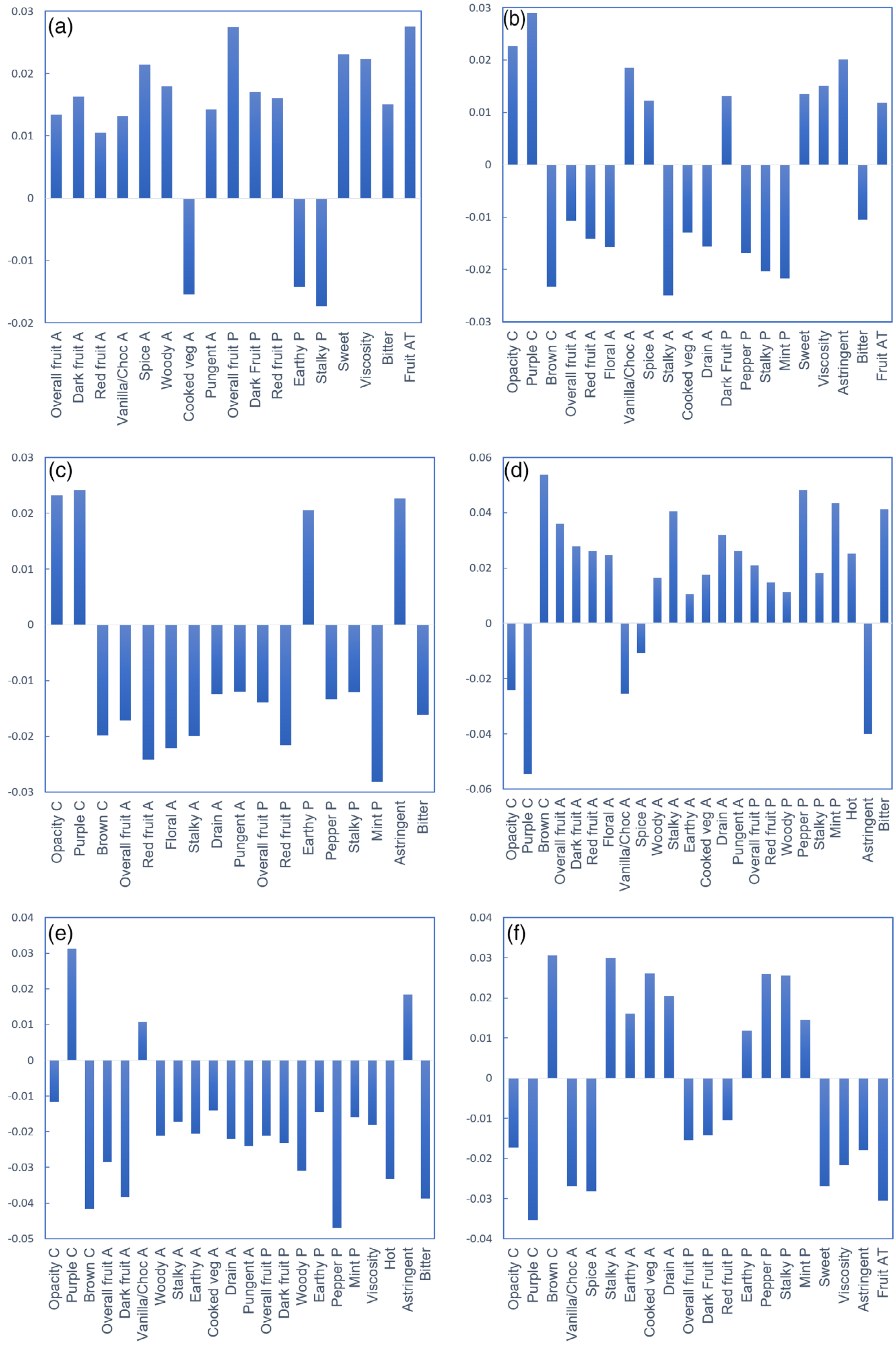

Figure 3. Regression coefficients from a three-factor partial least squares discriminant analysis model generated to relate sensory attributes to regional discrimination for (a) Barossa Valley, (b) McLaren Vale, (c) Heathcote, (d) Canberra, (e) Hunter Valley and (f) Yarra Valley. Only attributes with regression coefficients greater than +0.01 or less than −0.01 are shown.

influences. From both the PP and the DA data, warmer regions in the study tended to have less variable sensory properties than the cooler climate regions. Whether this is related to grapes harvested at a lower ripeness level being more sensitive to the effects of site or simply greater variability in climate requires further investigation. Using the Heathcote wines as an example, there were two wines with similar alcohol concentration [14.1 and 14.4% v/v (Table S2)] and one wine (HC1) with a high alcohol concentration (15.9% v/v). The two wines with similar alcohol concentration were grouped closely together in the DA biplot, with the high alcohol wine located far away from the other two wines. King et al. (2013) showed how perception of sensory attributes changed with alcohol concentration, so in this instance, it is the perhaps the winemaker's decision to harvest at a higher sugar concentration that is influencing some of this wine's sensory characteristics and not the site or region where the grapes were grown. Comparing the results of the present study with the findings of a similar investigation of Shiraz wines by Johnson et al. (2013), there are some similarities, with the earlier study also indicating McLaren Vale wines were higher in astringency; a Heathcote wine was high in savoury; Barossa Valley wines were high in dark fruit attributes and lower in astringency; Canberra wines were quite variable; and Hunter Valley wines were relatively low in many attributes. The results of the current study reinforce and expand on the results of the earlier work.

As with earlier regional studies involving commercial wines, the limitations of this study include an inability to disentangle site-specific effects from viticultural and winemaking practices. Thus, some differences observed are likely to be because of winemaking practices, as discussed above, while others can relate to viticultural practices, such as the use of rootstocks, clone, vine density, cover crops, the use of mulch, irrigation decisions, fruit exposure and crop level, among others. Thus, the regional differences indicated encompass the term terroir in its broadest sense, involving the physical environment in which the vines grow and the management practices because of human factors.

The sensory attributes that were highlighted as distinctive can provide winemakers and viticulturists with targets for production decisions to attempt to potentially optimise these attributes. It should be noted that segments of consumers will react strongly to some attributes, such as astringency, sulfidic flavours or green characters (Francis and Williamson 2015), so a degree of caution would be recommended.

Conclusion

This study provides a detailed insight into the range of sensory differences found in Australian Shiraz wines that relate to the region of origin. The approach of utilising PP assessments of 145 wines provided a robust means of selecting the wines for the DA comparative study, as well as assessing the extent of variability of sensory properties within each of the regions studied.

While there was a degree of overlap in sensory properties of wines from the different regions, the study showed that there were region-specific variations among the wines, with certain attributes identified that can be considered distinctive for some regions, while for others, it is the overall pattern of multiple sensory properties that makes those wines unique.

The study has shown the flavour diversity of Australian Shiraz wines and the extent to which differences in sensory properties can be ascribed to region of origin. The insights from this work will assist winemakers, marketers, wine trade and consumers to understand which sensory attributes can be expected from a wine sourced from the regions studied. The work will provide sensory attribute targets for individual producers to optimise so as to align with regional styles if desired. The approach followed using the PP method combined with DA can be applied in other wine regions and countries and also with other products to simplify the collection of complex sensory data.

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References

Bureau of Meteorology (2020) Bureau of Meteorology website (Australian Government: Canberra, ACT, Australia) http://www.bom.gov.au/climate/current/month/nsw/archive/201601.summary.shtml#recordsRainTtlHigh, http://www.bom.gov.au/climate/current/month/nsw/archive/201501.summary.shtml [accessed 19/11/2019]

Cadot, Y., Caillé, S., Thiollet-Scholtus, M., Samson, A., Barbeau, G. and Cheynier, V. (2012) Characterisation of typicality for wines related to terroir by conceptual and by perceptual representations. An application to red wines from the Loire Valley. Food Quality and Preference **24**, 48–58.

Capone, D.L., Jeffery, D.W. and Sefton, M.A. (2012) Vineyard and fermentation studies to elucidate the origin of 1,8-cineole in Australian red wine. Journal of Agricultural and Food Chemistry **60**, 2281–2287.

Capone, D.L., Pearson, W., Bindon, K., Kassara, S., Solomon, M., Bey, L., Francis, I.L., Herderich, M.J. and Johnson, D. (2018) What makes a red wine green? Wine and Viticulture Journal **33** (**2**), 32–35.

Charters, S., Spielmann, N. and Babin, B.J. (2017) The nature and value of terroir products. European Journal of Marketing **51**, 748–771.

Duteau, J., Guilloux-Benatier, M. and Seguin, G. (1981) Influence des factuers naturels sur la maturation du raisin, en 1979, a Pomerol et Saint Emilion. Journal International des Sciences de la Vigne et du Vin **15**, 1–27.

Easingwood, C., Lockshin, L. and Spawton, A. (2011) The drivers of wine regionality. Journal of Wine Research **22**, 19–33.

Francis, I.L. and Williamson, P.O. (2015) Application of consumer sensory science in wine research. Australian Journal of Grape and Wine Research **21**, 554–567.

Fischer, U., Roth, D. and Christmann, M. (1999) The impact of geographic origin, vintage and wine estate on sensory properties of *Vitis vinifera* cv. Riesling wines. Food Quality and Preference **10**, 281–288.

Guinard, J.X. and Cliff, M. (1987) Descriptive analysis of Pinot Noir wines from Carneros, Napa, and Sonoma. American Journal of Enology and Viticulture **38**, 211–215.

Heymann, A.C. and Noble, A.C. (1987) Descriptive analysis of commercial Cabernet Sauvignon wines from California. American Journal of Enology and Viticulture **38**, 41–44.

Johnson, T.E., Hasted, A., Ristic, R. and Bastian, S.E.P. (2013) Multidimensional scaling (MDS), cluster and descriptive analyses provide preliminary insights into Australian Shiraz wine regional characteristics. Food Quality and Preference **29**, 174–185.

King, E.S., Dunn, R.L. and Heymann, H. (2013) The influence of alcohol on the sensory perception of red wines. Food Quality and Preference **28**, 235–243.

King, E.S., Stoumen, M., Buscema, F., Hjelmeland, A.K., Ebeler, S. E., Heymann, H. and Boulton, R.B. (2014) Regional sensory and chemical characteristics of Malbec wines from Mendoza and California. Food Chemistry **143**, 256–267.

Kontkanen, D., Reynolds, A.G., Cliff, M.A. and King, M. (2004) Canadian terroir: sensory characterization of Bordeaux-style red wine varieties in the Niagara Peninsula. Food Research International **38**, 417–425.

Lawless, H.T. and Heymann, H. (2010) Sensory evaluation of food. Principles and practices, 2d ed. (Springer: New York, NY, USA).

Lê, S., Josse, J. and Husson, F. (2008) FactoMineR: an R package for multivariate analysis. Journal of Statistical Software **25** (**1**), 1–18.

Lê, S. and Worch, T. (2014) Analyzing sensory data in R (CRC Press: Boca Raton, FL, USA).

Maitre, I., Symoneaux, R., Jourjon, F. and Mehinagic, E. (2010) Sensory typicality of wines: how scientists have recently dealt with this subject. Food Quality and Preference **21**, 726–731.

Matthews, M. (2015) Terroir and other myths of winegrowing (University of California Press: Oakland, CA, USA).

Noble, A.C., Williams, A.A. and Langron, S.P. (1984) Descriptive analysis and quality ratings of 1976 wines from four Bordeaux communes. Journal of the Science of Food and Agriculture **35**, 88–98.

Parker, M., Pollnitz, A.P., Cozzolino, D., Francis, I.L. and Herderich, M.J. (2007) Identification and quantification of a marker compound for 'pepper' aroma and flavor in shiraz grape berries by combination of chemometrics and gas chromatography –mass spectrometry. Journal of Agricultural and Food Chemistry **55**, 5948–5955.

Pearson, W., Schmidtke, L.M., Francis, I.L. and Blackman, J. (2020) An investigation of the Pivot© Profile sensory analysis method using wine experts: comparison with descriptive analysis and results from two expert panels. Food Quality and Preference **83** (**2020**), 103858.

Pereira, G.E., Gaudillere, J.P., van Leeuwen, C., Hilbert, G., Maucourt, M., Deborde, C., Moing, A. and Rolin, D. (2006) ^{1}H NMR metabolite fingerprints of grape berry: comparison of vintage and soil effects in Bordeaux grapevine growing areas. Analytica Chimica Acta **563**, 346–352.

Rankine, B.C., Fornachon, J.C.M., Boehm, E.W. and Cellier, K.M. (1971) Influence of grape variety, climate, and soil on grape composition and on the composition and quality of table wines. Vitis **10**, 33–50.

Robinson, A., Adams, D., Boss, P., Heymann, H., Solomon, P. and Trengove, R. (2011) The relationship between sensory attributes and wine composition for Australian Cabernet Sauvignon wines. Australian Journal of Grape and Wine Research **17**, 327–340.

Robinson, A.L., Adams, D.O., Boss, P.K., Heymann, H., Solomon, P. S. and Tengrove, R.D. (2012a) Influence of geographic origin on the sensory characteristics and wine composition of *Vitis vinifera* cv. Cabernet Sauvignon wines from Australia. American Journal of Enology and Viticulture **63**, 467–476.

Robinson, J., Harding, J. and Vouillamoz, J. (2012b) Wine grapes (Harper Collins: New York, NY, USA).

Siebert, T.E., Wood, C., Elsey, G.M. and Pollnitz, A.P. (2008) Determination of rotundone, the pepper aroma impact compound, in grapes and wine. Journal of Agricultural and Food Chemistry **56**, 3745–3748.

Siebert, T.E., Barker, A., Pearson, W., Barter, S.R., de Barros Lopes, M.A., Darriet, P., Herderich, M.J. and Francis, I.L. (2018) Volatile compounds related to 'stone fruit' aroma attributes in Viognier and Chardonnay wines. Journal of Agricultural and Food Chemistry **66**, 2838–2850.

Stone, H., Sidel, J., Oliver, S., Woolsey, A. and Singleton, R.C. (1974) Sensory evaluation by quantitative descriptive analysis. Food Technology **8**(**11**), 24–32.

Thuillier, B., Valentin, D., Marchal, R. and Dacremont, C. (2015) Pivot© Profile: a new descriptive method based on free description. Food Quality and Preference **42**, 66–77.

Trubek, A.B. (2008) The taste of place: a cultural journey into terroir (University of California Press: Berkley, CA, USA).

Ugliano, M., Siebert, T., Mercurio, M., Capone, D. and Henschke, P. A. (2008) Volatile and color composition of young and model-aged shiraz wines as affected by diammonium phosphate supplementation before alcoholic fermentation. Journal of Agricultural and Food Chemistry **56**, 9175–9182.

van Leeuwen, C. (2010) Terroir: the effect of the physical environment on vine growth, grape ripening and wine sensory attributes. Reynolds, A.G., ed. Managing wine quality: viticulture and wine quality (Woodhead Publishing: Cambridge, England) pp. 273–315.

Varela, P. and Ares, G. (2012) Sensory profiling, the blurred line between sensory and consumer science. A review of novel methods for product characterisation. Food Research International **48**, 893–908.

Vilanova, M. and Soto, B. (2005) The impact of geographic origin on sensory properties of *Vitis vinifera* cv. Mencia. Journal of Sensory Studies **20**, 503–511.

Wine Australia (2019a) Wine Australia website (Wine Australia: Adelaide, SA, Australia) https://www.wineaustralia.com/market-insights/regional-snapshots [accessed 8/10/2019]

Wine Australia (2019b) Wine Australia website (Wine Australia: Adelaide, SA, Australia) https://www.wineaustralia.com/market-insights/regional-snapshots [accessed 6/12/2019]

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Figure S1. An example of the Pivot Profile assessment ballot used.

Table S1. Chemical composition of the wines used for descriptive analysis.

Table S2. ANOVA *P*-values for all attributes.

Table S3. The mean descriptive analysis sensory attributes values for the wines.

Table S4. Regional means for all sensory attributes.