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Original article for Food Research International

# Sensory profiling and qualities of research Cabernet Sauvignon and Chardonnay wines; quality discrimination depends on greater differences in multiple modalities.

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**Key words:**

Cabernet Sauvignon; Chardonnay; CVA; GPA; wine quality; sorting

**Abstract**

The sensory profiles of Cabernet Sauvignon and Chardonnay research wines were determined and analysed together with wine quality scores of expert judges. Research Cabernet Sauvignon and Chardonnay wines from three and two vintages, respectively were evaluated. Wines of both varieties were produced with grapes harvested from across South Australian wine making regions throughout 2013 - 2016 vintages. Wines within varieties were vinified identically across samples and also across vintages. Wines were profiled in triplicate using descriptive analysis with a panel of trained assessors (n = 9 - 11) and graded for quality in triplicate by winemakers (n = 6 - 9) using a sorting task based on similarity of quality and with the aid of definitions formed by the winemakers prior to sorting. The data sets were analysed using canonical variate analysis (CVA) and multidimensional scaling

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(MDS). The scores from CVA and MDS per variety per vintage were analysed using Generalised Procrustes Analysis (GPA). Differences in Cabernet Sauvignon samples by provenance were determined, where associations with regions by sensory attributes were observed in all vintages. These wines were consistently sorted based on quality by the winemakers, evident from GPA. Chardonnay in comparison were poorly discriminated in both sensory profiles and quality. The combination of descriptive sensory analysis with sorting was complimentary to each other and was able to uncover additional information about the sensory properties of wines when the two methods were used in concert, such as balance and complexity. However the red wine variety had more intrinsic characteristics that lead to better discrimination based on sensory properties and hence quality than the white wine variety.

## 1.0 Introduction

Quality of food and beverages is an important aspect that can heavily influence the purchasing behaviour of consumers. Wine quality broadly encompasses both extrinsic and intrinsic factors (Verdú Jover, Lloréns Montes, & Fuentes Fuentes, 2004) and how these factors are interpreted depends on the level of expertise (Charters & Pettigrew, 2007). Experts such as winemakers have an analytical approach to grading quality of wines based on intrinsic characteristics and are also less prone to halo bias when factors such as price, country of origin, and brand are provided to them, unlike naïve consumers (D'Alessandro & Pecotich, 2013).

The quality of wine is judged primarily for their intrinsic character and the minimum requirement for a sound wine in Australia is the absence of faults (Dunphy & Lockshin, 1998b). Beyond this, quality is graded on holistic aspects of balance, intensity, complexity, as well as "styles" (Dunphy & Lockshin, 1998a), which are intertwined with subjectivity even

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among experts (Lawless, 1984) and as a result the style can be characterised by a wide variety of descriptions (Sauvageot, Urdapilleta, & Peyron, 2006). To account for this in wine shows, grades are allocated through a consensus to discern wines that are worthy of being awarded with medals. Wine qualities are typically judged using the points system out of a maximum of 20 or 100 points and graded on the basis of intrinsic sensory parameters (Dunphy & Lockshin, 1998b; Gawel & Godden, 2008; Jordan, Robinson, & Bulleid, 2015), similar to the Davis scale (Ough & Winton, 1976). This is followed by discussions among judges to determine wines that will be awarded medals.

The expert judges that partake in wine shows are mostly winemakers and critics who have extensive knowledge and experience with tasting wines. The wine experts are also known to be repeatable (Perrin et al., 2007) and as good as a trained descriptive analysis assessors even when experts are required to use descriptive analysis attributes to evaluate wines (Zamora & Guirao, 2004). As reliable as they are, experts have been shown to be reliable at grading quality of commercial red more so than white wines (Gawel & Godden, 2008). An important aspect of the performance of experts, similar with trained descriptive analysis panels, is ideally having standardised training and a minimum of replicate tastings for better confidence in the data (Gawel & Godden, 2008; Lawless, 1984).

The issue with the word “quality”, despite its frequent use, is that it is a challenging concept to define and measure objectively, due to its ambiguous meaning and its inherent close link with hedonics (Hopfer & Heymann, 2014; Johnson, Hasted, Ristic, & Bastian, 2013). Quality is therefore not a concrete concept. Nevertheless, quality of wine has been determined using expert judges to supplement information from sensory profiles. Key sensory characteristics within a variety appear to be markers for quality. For example, a range of sensory attributes including fruit characteristics, colour, and texture correlate well with high quality Cabernet Sauvignon and Shiraz wines and in general the Australian experts

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considered wines with "*high flavour intensity*" as higher quality (Holt, Francis, Field, Herderich, & Iland, 2008; Lattey, Bramley, & Francis, 2010). Similarly, Rioja and Côtes du Rhone wines that have red fruit characteristics are considered high quality wines by Spanish and French experts (Sáenz-Navajas et al., 2015). This however leaves much to be desired, as there are perhaps other perceptual factors that play an important role in judging wine quality but are difficult to capture, such as balance and complexity that take a broader view of the product above and beyond singular attributes.

The sensory properties of wines are complex and often reported to elicit multiple sensory perceptions (Lattey et al., 2010). Coupled with the large variation in wine styles, a wide range of wines made from a single variety can possess a very diverse set of sensory characteristics (Robinson et al., 2011). These differences in sensory profiles within a varietal wine can segment the consumers into clusters that associate with a specific set of sensory attributes; a group of consumers may like wines with high intensities of fruit characteristics while another may like wines characteristic of coffee, chocolate, and wood in Cabernet Sauvignon (Lattey et al., 2010). All of the attributes that are profiled from a wine can be considered the building blocks of wine quality. In particular with Chardonnay wines, oak characters are an important marker for quality from a winemakers perspective (Gambetta, Bastian, & Jeffery, 2016), but it is unknown whether differences in raw grape materials also result in a range of qualities. This is especially of interest for Cabernet Sauvignon and Chardonnay, as they are among the top three most processed grape varieties for wine in Australia (Winemaker's Federation of Australia, 2017).

As wines are heavily dependent on the raw grape material, differences in the grapes may translate into sensory differences in wines. But, where there are these differences in wines, how their perceived qualities also depends on them is less well understood. The objective of this study was to determine how the sensory profiles of unoaked, research

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Cabernet Sauvignon and Chardonnay wines drive wine experts' evaluation of wine quality. The study was undertaken by descriptive analysis, quality evaluation through sorting, and examining the two data sets together by means of multivariate data analysis.

## 2.0 Materials and Methods

### *2.1 Samples*

Wines were produced from grapes harvested from a range of grape growing regions within the state of South Australia including the; Adelaide Hills (AH), Barossa Valley (BV), Clare Valley (CL), Coonawarra (CWA), Eden Valley (EV), McLaren Vale (McV), Langhorne Creek (LC), Padthaway (PWY), Riverland (RVL), and Wrattonbully (WBY) Geographical Indications (Table 1). Samples were collected from three and two vintages for Cabernet Sauvignon (2013 - 2015) and Chardonnay (2015 – 2016), respectively. A total of 25 samples were harvested per variety per year. Although the study was not intended to characterise provenance, region was nevertheless used to obtain a range of grapes with different characteristics which would, theoretically, carry through into the wines. Grapes were harvested from commercial vineyards and because of this, some samples within a variety were unavailable in some vintages because of commercial reasons. Accordingly, the missing samples were replaced where possible with those from the nearest location within the same region. A comparatively larger number of samples from the Riverland were included in the design for both varieties, because of the relatively large grape growing area of that region (55% and 26% of total crush in South Australia state and nationally, respectively, as of 2017) (Winemaker's Federation of Australia, 2017). Grape bunches were randomly picked from all sections of the canopy and throughout a given vineyard for representative sampling. Cabernet Sauvignon grapes were harvested between 22 – 27 °Brix, while Chardonnay grapes were harvested between 19 – 26 °Brix. These values were as close to usual commercial harvest as

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possible. All wines were vinified identically across both vintages as small scale batch fermentations of 50 Kg as described previously for Cabernet Sauvignon (Niimi, Boss, Jeffery, & Bastian, 2017). Briefly, the grapes were destemmed, crushed and sulphur, in the form of sodium metabisulphite,added prior to fermentation. Ferments were inoculated with the same Saccharomyces cerevisiae yeast (EC1118), and were subjected to malolactic fermentation with *Oenococcus oeni*.

The Chardonnay wines were produced identically across both vintages as small batch fermentations of 50 Kg as described previously for Chardonnay (Niimi, Boss, Jeffery, & Bastian, Accepted). Briefly, grapes were destemmed and pressed before sulphur, in the form of sodium metabisulphite, added  prior to fermentation. The pressed juice, wascold settled and racked off any grape solids. Racked juices were fermented with Saccharomyces cerevisiae yeast until completion (less than 3g/L residual sugar). Wines were not subjected to malolactic fermentation or oak contact and wine pH was not adjusted.

*2.2 Sensory procedures*

All evaluations including descriptive analyses and expert sorting were ethically approved by the University of Adelaide Human Ethics Committee (H-2014-057), prior to the experiments.

*2.2.1 Descriptive analyses*

Descriptive analyses were performed on the wine samples of Cabernet Sauvignon and Chardonnay separately, each at the end of their respective vintage year. Assessors were recruited (n = 9 - 11) based on their interest, availability and previous experience in descriptive analysis panels. The assessors were made up of postgraduate students and staff members of the University of Adelaide. The assessors who participated in the study for 2015 and 2016 vintage Chardonnays, were screened using ISO standards. The training and

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evaluation protocols with attributes list for Cabernet Sauvignon are described previously (Niimi et al., 2017). In brief, training sessions consisted initially of basic taste discrimination, followed by attribute generation and matching each attribute with appropriate reference standards. The attribute list determined for the Chardonnays are shown in Table 2. A preliminary list of reference standards was generated for colour, aroma, flavour, taste, mouthfeel, and aftertaste attributes. The remaining training sessions were devoted to refinement of the list of attributes and the reference standards, and practise evaluations. Chardonnay training were performed using black INAO glasses. Assessors' performances were monitored throughout the training sessions, where each session involved rating of attributes for a selection of wines through mock evaluations. Once performance was consistent, assessors proceeded to evaluate the wines. All wines were evaluated in triplicate.

The assessors were given reference standards at the beginning of every evaluation. All attributes were rated on unstructured 150 pt line scales. Attribute scales with two anchors were indented at 10 % and 90 % with low and high, respectively, and those with three anchors were indented at 10 %, 50 %, and 90 % with low, medium, and high (or the equivalent), respectively. The Cabernet Sauvignon samples were presented in clear XL 5 wineglasses (ISO 3591:1977) labelled with random three digit codes and covered with petri dishes. Chardonnay wines were presented likewise, but in black INAO glasses for the assessment of attributes in mouth. Wines were evaluated in sensory booths at 20 ˚C under fluorescent white light. In a separate booth, assessors evaluated the colour of Chardonnay wines that were presented in clear XL5 wineglasses, covered with petri dishes, and presented under fluorescent white light. Chardonnay wine colour were assessed as yellowness: depth of yellow colour (both 2015 and 2016 vintages), and rose: depth of rose colour (2015 vintage only) using the RHS colour charts (Royal Horticultural Society, London) as reference standards. The order of the Chardonnay wines for colour evaluation were randomised.

Assessors were given inter-stimulus breaks of one minute between each sample and five minutes after every five samples. Filtered water and water crackers were provided as palate cleansers. Data was acquired using Fizz acquisition Ver. 2.47b (Biosystèms, Courternon, France) for Cabernet Sauvignon and RedJade software (RedJade®, Redwood Shores, CA, USA) for Chardonnay.

*2.2.3 Expert sorting*

A panel of winemakers from within South Australia were recruited as experts for sensory evaluation. Cabernet Sauvignon from 2013, 2014, and 2015 vintages were assessed by nine, seven, and seven experts, respectively. Chardonnay from 2015 and 2016 vintages were assessed by seven, and six experts, respectively. The experts were selected based on the criteria of Parr, Heatherbell, and White (2002). Prior to starting the sorting task, the experts were introduced to the task and were informed that the wines had completed both primary and secondary fermentation for Cabernet Sauvignon, primary fermentation only for Chardonnay wines, and no aging in oak for all wines. A discussion was held with the group to define quality levels of wines; premium, high, moderate, and low qualities, labelled as "A, B, C, and D", respectively. An additional quality level "E" for faulty was added in the 2014 and 2016 vintage for Cabernet Sauvignon and Chardonnay, respectively. These definitions were formed generically and broadly so as to provide a framework for the winemakers to categorise the wines into quality groups, whilst allowing freedom for their individual opinions to be incorporated during the sorting step (Table 3).

Upon forming the agreed definitions, experts were instructed to taste wines from left to right, write comments on each wine, and using the definitions, sort samples based on similarity of quality. Sorting was undertaken as if the samples were being allocated to different quality levels in an industrial setting, thus the wines were assessed for their entirety. The winemakers were randomly presented with 24 to 25 wines at a time on individual table

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surfaces to allow space for sorting. Each sample (30 mL) was served in clear XL5 glasses, labelled with random three digit codes and covered with petri dishes. Samples were tasted at 20 ˚C and under natural lighting. Samples were expectorated into spittoons. Experts were provided with ballots to write comments in order to assist in sorting each wine. Each expert consolidated the sample codes belonging to each quality level and wrote three important descriptions that characterised each quality using their own terms. After tasting the 25 wines, a 30 min break was given. The entire process was performed within one day and in triplicate. The experts were not made aware that the wines were evaluated in replication. The quality grading was performed within 6 months of completing the descriptive analyses of the respective vintages per variety, in order to capture data on the wines with minimal changes since their sensory profiling, as practical.

*2.3 Data analysis*

Descriptive analysis data were analysed with univariate analysis of variance (ANOVA) using SPSS statistics Ver. 20 (SPSS Inc. Chicago, IL, USA). Sensory attributes were analysed as the dependent variables, samples and replicates, taken as independent factors, and assessors as a random factor. Assessor × replicate interactions were also analysed for each attribute with 2-way ANOVA. For each significantly different sensory attribute ($\alpha$ = 5%), assessor variation was removed by centring the means prior to canonical variate analysis (CVA). Means were centred by subtracting assessor means per attribute per sample from the overall sample mean per attribute, leaving the residuals as variables for CVA. CVA was used to determine the relationship of the samples through estimations in significant differences (Heymann & Noble, 1989) and was run using XLStat ver. 2015 1.01 (Addinsoft SARI, Paris, France).

Sorting data from the experts, in triplicate for each vintage, were collated in a similarity matrix where both the header rows and columns were samples. For each sample

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pair a value of either 1 (sorted together) or 0 (not sorted together) was assigned between a row and a column. The sums were calculated to obtain the similarity matrix for the entire panel of experts across triplicates. Pairs of samples with high values therefore, indicated stronger similarity in quality. The similarity matrix was analysed with multidimensional scaling (MDS) using PROXSCAL, which scaled data with proximity based on similarity using SPSS statistics Ver. 20. Proximities were transformed as ordinal data and analysed up to a maximum of three dimensions. The resulting configurations generated were plotted to represent the sample distributions relative to each other. The descriptions provided by the wine makers and the frequency thereof were taken into account for data interpretation. As quality group was categorical but also continuous by level, arbitrary values were assigned as A = 4, B = 3, C = 2, D = 1, and E = 0 where required, which was used to interpret differences in wine quality projected on the MDS matrix. Experts' repeatability were checked by taking the arbitrary quality values and analysed using univariate ANOVA, where sample and replicates were taken as fixed factors, expert as random factor, and grades as the dependent variable. Expert by replicate interaction was also checked using 2-way ANOVA.

To compare the projections of scores by the DA sensory panellists and the wine experts, the scores from CVA and MDS analyses up to three canonical variates (CVs) and dimensions, respectively, were analysed further using Generalised Procrustes Analysis (GPA) using XLStat ver. 2015 1.01. GPA was performed on each variety per vintage separately to determine the similarity in projection of scores from the CVA and MDS. Scores on the first 3 CVs and first 3 MDS dimensions were used for the analysis, hence these CVs/dimensions became the loadings of the GPA.

## 3.0 Results and discussion

### *3.1 Descriptive analyses of the Cabernet Sauvignon and Chardonnay wines*

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To determine the differences in sensory properties of 25 Cabernet Sauvignon wines, samples were profiled using descriptive analysis. Significantly different ($p < 0.05$) attributes from colour, aroma, taste, mouthfeel, and aftertaste categories were revealed for each vintage; 19, 31, and 23 attributes for 2013, 2014, and 2015 vintages, respectively. Significant assessor □ replicate interactions were detected for some of the attributes throughout all vintages and varieties. However none of the attributes were removed for further analysis as the variation across replicates for most assessors were within 10% of the scale. The significantly different attributes were analysed using CVA. The first three CVs were significant ($p < 0.001$) according to Bartlett's test, indicating differences among the samples on the matrix in three dimensions. The first three canonical variates (CVs) of 2013, 2014, and 2015 vintage sensory profiles accounted for 85.2 %, 86.4 %, and 81.5 % of the explained variance, however for brevity the first 2 CVs are shown (Fig. 1a-c). CWA5 was an outlier that influenced the CVA model in the 2014 vintage, possibly due to a taint, and was subsequently removed from the analysis.

Attributes that consistently discriminated the Cabernet Sauvignon samples were the colour attributes hue and depth, for which the majority of the RVL samples were more ruby than purple with less depth compared to samples from other regions (Fig. 1a-c). Dark fruit aroma and flavour, and mouthfeel of body and astringency were additional attributes that discriminated samples on CV1, which were comparatively intense in samples CWA2 and CL1 and 2 (Fig. 1a-c). Conversely, RVL samples were consistently projected in the opposite direction, indicating their low intensities of the above mentioned attributes. For 2014 and 2015 vintages, the RVL samples were significantly more intense in red fruit and confectionery attributes. Samples were mostly separated on the CVA matrix based on the region from which the grapes were sourced, although the CL, CWA, WBY, McV, and LC regions were not strongly discriminated amongst each other. Differences within-region were

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observed in samples obtained from CWA, LC, and RVL as the confidence ellipses for the samples from these regions did not always overlap. These differences suggest that disparate sensory characteristics can be inherent in wines produced from grapes that were grown within regions. Green flavour and aromas were not discriminated on the first two CVs of the 2015 vintage, however were projected strongly on CV3 along with the sample EV2 (data not shown). Green flavour characteristics are known to be an integral part of the Cabernet Sauvignon variety. Further discussion on this matter with regards to quality will be made in section 3.3. Cabernet Sauvignon wines from Australia are known to differ in the sensory characteristics from one another (Robinson et al., 2011; Robinson et al., 2012), but in this case even in wines that have completed only primary and secondary fermentations.

Chardonnay wines were evaluated and significantly different attributes were analysed with CVA. Bartlett's test showed that up to the first five and four CVs were significant ($p < 0.05$) for the 2015 and 2016 vintages, respectively; explained variance of 76.6 % and 84.7 % for 2015 and 2016 vintages, respectively. For brevity, matrices with only the first two CVs are presented (Fig. 2). The 2015 vintage showed sample discrimination based on more sensory attributes than in 2016. Sample discrimination by attribute was comparatively less consistent than Cabernet Sauvignon. Only a few attributes were projected consistently with scores to discriminate samples across vintages: sour taste for CWA1; tropical/peach flavour and aromas for RVL3 and 5; and WBY1 with medicinal characteristics. Colour discriminated samples across vintages, however the samples that were intense in yellowness were not consistent. The RVL3, 5, 7, and RB1 samples were faint rose in colour in the 2015 vintage. This rose colour (pinking) is caused by anthocyanins and their polymeric forms within the white wines, which can arise from reductive wine making or from depletion of free sulfur dioxide by excessive oxygen in finished wines (Andrea-Silva et al., 2014; Singleton, Trousdale, & Zaya, 1979). Given that the wines were produced identically, it is more likely

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pinking may have occurred during bottling. It is possible to remove the pink colouration with fining such as polyvinyl polypyrrolidone (Lamuela-Raventó, Huix-Blanquera, & Waterhouse, 2001), however this was not performed in the wines as there was the risk of excessive flavour removal from this process. Some of the attributes tended to be correlated with each other, for example sweetness with tropical fruits and astringency with sourness. Acids at high levels are known to elicit astringency (Corrigan Thomas & Lawless, 1995), however, the concurrent perception of fruit flavours with sweetness may stem from learned association and be independent of the presence of stimulus (Djordjevic, Zatorre, & Jones-Gotman, 2004), particularly as all the wines used in the current study were dry (< 2g/L residual sugar, data not shown).

*3.2 Sorting by experts of the Cabernet Sauvignon and Chardonnay wines*

A panel of experts sorted the 25 wines into groups of similar qualities. Four to five levels of quality that spanned categories from premium down to low/faulty were defined based on group consensus (Table 3). These definitions served as the framework for the grading of wines. The individual sorting data were analysed using MDS (Fig. 3a-c). Consistent discrimination of the majority of RVL samples from the remaining samples on dimension 1 was seen for Cabernet Sauvignon in all three vintages. The majority of RVL samples were often described with poor colour, texture and varietal definition, simple, and possessing red fruit, green and acidic characters, leading them to be judged with a comparatively lower quality. The exceptions were RVL 3 and 7, which were regarded as being higher in quality, relative to the other RVL samples, and this was evident in the 2013 and 2015 vintages. The samples from remaining regions were considered to have more body, tannin structure (texture), dark fruit flavour, varietal characteristics, balance and complexity; characteristics that were judged as higher quality. Samples from other regions however were also considered lower in quality depending on the vintage; CWA3, EV1, and EV2 in 2013,

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BV2 and McV1 in 2014, and BV1 and BV2 in 2015. The second dimension showed specific characters that could be discerned within lower quality and higher quality wines in 2013 and 2015 (Fig. 3a and 3c). In 2014 however, there appeared to be a continuum of quality along dimension 2 as well as dimension 1, where samples projected on positive dimension 2 were moderate in quality in comparison to the lower left (higher quality) and lower right (lower quality) areas of the MDS plot (Fig. 3b).

The Chardonnay wines were poorly discriminated overall by the sorting task, compared to Cabernet Sauvignon wines. The range of quality scores given by winemakers were comparatively narrower than the range of Cabernet Sauvignon quality scores. Four and five different categories of quality were defined by the winemakers for the 2015 and 2016 vintages, respectively. Yet, only an average of two categories were used when assessing Chardonnay wines of each vintage and most of the wines were low quality. In 2015, samples on positive dimension 1 were characteristic of simple flavours while on the negative end, samples were of peach and melon (Fig. 3d-e). Dimension 2 separated acidic wines from those that were green. The 2016 samples again showed discrimination by tropical fruits and peach along dimension 1, similar to 2015 vintage samples, as well as low acid. Samples were discriminated on positive dimension 1 by lack of fruit characteristics. Dimension 2 discriminated samples based on simple yet persistent flavour characteristics, in particular on negative dimension 2.

Commonly used descriptions by the experts that are often difficult to interpret, were “balanced”, “varietal expression”, and “complexity”. These descriptions, are also difficult to measure objectively, given their tendency to be a holistic attribution of multiple components and the meanings being individually subjective (Green, Parr, Breitmeyer, Valentin, & Sherlock, 2011; Parr, Mouret, Blackmore, Pelquest-Hunt, & Urdapilleta, 2011). However, it is often these particular descriptions that are used in concert that determine the degree of

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wine quality. Complexity can relate to a large number of perceived sensory characteristics (Charters & Pettigrew, 2007) and indeed this appears to be the case in the current study, where wines that were considered complex were typically associated with more sensory attributes as seen for Cabernet Sauvignon. Varietal expression, similar to complexity, may be a combination of factors that are unique to the varietal grape. For Cabernet Sauvignon, this may include the distinctive "green" characters and the diverse descriptions of "tannins" and "structure". Interestingly, despite the experts using "varietal definition" as part of high quality Chardonnay wines, experts were not able to discriminate the quality of the Chardonnay wines using varietal definition in both 2015 and 2016 vintages. The concept of varietal definition for Chardonnay either may not have been present in the wines or may not be grape and fermentation derived, but rather by other external winemaking inputs such as oak.

In an attempt to account for "cellar palate bias" (Dunphy & Lockshin, 1998a), definitions were developed for quality grades across the vintages for both varieties. Interestingly, the experts were employees of different companies who are competitors of each other, and personnel differed between vintages, yet their use of descriptions was generally similar. Expert judges have been reported to lack consistency despite their ability to describe, in particular, high quality wines (Hopfer & Heymann, 2014) and they also vary widely in their descriptions when given the opportunity for free-description (Sauvageot et al., 2006). From a grading perspective, experts as a group were repeatable, as replicate was not significantly different in quality grades of Cabernet Sauvignon or Chardonnay in all vintages in the current study. Further 2-way expert by replicate interactions were not detected, indicating that each expert repeatedly gave similar scores for each replicate assessment. The initial definition of quality levels in the current study may have assisted in their repeatability. Setting definitions for quality grading coupled with the sorting task thus served as a mini-training task, analogous to the process for free choice profiling (Williams & Langron, 1984).

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The extremes in quality grades in particular were consistent for the Cabernet Sauvignon wines, however the grading of moderate quality groups were variable, particularly for the 2014 vintage. It was also the case that there were idiosyncratic use of words sparingly by each expert, for example “layered”, “hollow”, and “developed”, which suggest a temporal aspect but are difficult to interpret with the current data. This is a limitation of sorting and hence a compromise of the method (Valentin, Chollet, Lelièvre, & Abdi, 2012). Data interpretation of MDS to some extent thus becomes somewhat arbitrary to the analyst.

*3.1.3 Descriptive analysis vs sorting*

To determine the similarity of the configuration of samples from descriptive analysis versus sorting, the scores from the CVA and MDS were analysed with GPA. The advantage of GPA is it’s iterative process of rotation, translation, and transformation of the projections to find the closest match between configurations (Dijksterhuis, 1996), in this case the scores between MDS and CVA. Procrustean fitting of configurations can be used to its advantage, where it can show similarities in scores and loadings projections between multivariate analysis methods such as those from CVA and principal components analysis (Peltier, Visalli, & Schlich, 2015). The analysis of the Cabernet Sauvignon scores from CVA and MDS overall were similar, where dimension 1 explained most of the variance for all vintages, with a minimum of 68 % (Fig. 4). The directionality of the first and second dimensions/CVs were plotted on the first and second dimensions of the GPA, respectively. Although in some vintages, the projection of the second CV and dimension were in opposite directions, they were nevertheless on the same plane. Thus, angular differences by visual inspection based on deviations from orthogonal directions between the first and second CV/dimension were used to qualify similarities in configurations, rather than absolute angles.

Overall the Cabernet Sauvignon wines were being similarly discriminated by the descriptive analysis panel and experts. It also confirmed that overall, the more intense

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sensory characteristics of depth of colour, flavour intensity, dark fruit, body and astringency resulted in a comparatively higher perceived quality (Lattey et al., 2010). Conversely, samples with less intense sensory attributes were considered lower quality by the winemakers. Particularly wines from WBY and CWA shared common mouthfeel descriptions between the descriptive analysis and the experts with astringency and "structure/tannins", respectively. These wines were perceived to be higher in quality than the other wines, which corroborates with literature, where there is a direct relationship between tannin concentration and perceived wine quality score until an optimum is reached (Smith, Mercurio, Dambergs, Francis, & Herderich, 2007). Intensely astringent wines are considered higher quality, as experts consider this as an indicator of prolonged stability and longevity of mouthfeel with time, thus potential to age (Jaffré, Valentin, Dacremont, & Peyron, 2009; Langlois, Ballester, Campo, Dacremont, & Peyron, 2010). That the colour of wines related well with the quality was of no surprise, given the well-known strong correlation of colour with quality and also liking (Parpinello, Versari, Chinnici, & Galassi, 2009; Somers & Evans, 1974).

Green/vegetal character is typical of Cabernet Sauvignon or Merlot and is the result of a combination of compounds including methoxypyrazines (Preston et al., 2008) and C6 compounds (Mendez-Costabel et al., 2013). Discrimination of green aroma and flavour attributes differed between the panels, specifically in 2013. The descriptive analysis panel did not discriminate in green characters by wine samples unlike the experts. This also appeared to be the case in 2014, however the green characteristic was most likely regarded as a part of "varietal characteristics". In 2015, the green characteristic detected by the experts were most likely regarded as excessive, which reflected the qualities of some of the samples. EV2 of the 2015 vintage was highly green and consequently considered unbalanced by the winemakers. Clearly the green character of Cabernet Sauvignon also drives quality in wines, where balance thereof is important; too little or too much results in poorer quality. The unique green

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flavour/aroma character of Cabernet Sauvignon in excessive levels is an undesirable trait to consumers (Jiang, Niimi, Ristic, & Bastian, 2016), though their liking can be dependent on segments of consumers (Bindon et al., 2014). Further work into ascertaining the prerequisites required for a "balanced" wine would be of immense benefit, particularly as the judgement of balance in a complex matrix such as wine is rather poorly understood.

Of note are the RVL 3 and 7 wines from 2013 and 2015 vintages that differed between their sensory profiles and quality relative to other wines with the same provenance. The two samples were not discriminated by any of the significantly different attributes in the descriptive analysis. Yet, these samples were considered higher quality than their counterparts from the same region; RVL 3 and 7 wines were described as "simple", but were also "balanced" and demonstrated "varietal definition" (Fig. 3). These two samples demonstrated that high flavour intensity was not necessary for the wines to be perceived high in quality, unlike that suggested previously (Lattey et al., 2010). The descriptive analyses and sorting tasks in this instance were complementary methods in uncovering additional information driving wine quality.

The scores of the Chardonnay samples on the contrary were poorly discriminated. Many of the scores not only overlapped each other, but also there was a general lack of agreement between the CVA and MDS scores. The loadings did not show a clear discrimination of dimensions/CVs along GPA dimension 1 and 2 (Fig. 5.) in contrast to Cabernet Sauvignon. There was also a lack of consistency in sample discrimination between vintages, which complicates data interpretation. Lack of consistent discrimination may have been from a lack of clear sensory differences between the samples, which may have resulted in the projection of noise.

The consistent discrimination of Cabernet Sauvignon quality but not Chardonnay wines corroborated with previous results (Gawel & Godden, 2008). Chardonnay wines do not

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have as many sensory cues for an assessor to discriminate wines sensorially and subsequently their quality. The major factors for discriminability most likely relate to colour and texture differences, where they clearly discriminated Cabernet Sauvignon but not Chardonnay, as discussed previously (Gawel & Godden, 2008). Polyphenolic compounds are responsible for pigment and astringency in wine, both of which Chardonnay wines do not possess in great quantities. This signifies the relative importance of colour and texture in wine and the assessors' reliance thereof for perceptual discrimination and without these sensory properties, even experts had difficulty discriminating Chardonnay research wines. Most likely other sensory properties that may arise from additional wine making processes are likely to contribute to an improved quality discrimination of Chardonnay, such as oak flavour (Gambetta et al., 2016). The implications of this is that Chardonnay quality is not dependent on the raw material at least with wines fermented with primary alcoholic fermentation only. This has huge implications on the pricing structure of Chardonnay grapes throughout South Australia, where price per tonne can vary widely (Winemaker's Federation of Australia, 2017). Further investigations are required to confirm this lack of sensory and quality discrimination of Chardonnay and if additional winemaking variables other than primary fermentation might influence this discrimination.

It is possible that this lack of discrimination in sensory characteristics and subsequently the quality is specific to the Chardonnay variety. Anecdotally, Chardonnay has been described as a neutral wine variety that requires winemakers' interventions to produce wines with a point of difference (Clarke & Rand, 2001). Other white varieties with unique and distinctive sensory characteristics may vary more; varieties such as Riesling, Sauvignon Blanc, and Gewürtztraminer for example, may result in better discrimination across samples, within variety. Each of these varieties are known for their unique sensory attributes such as kerosene in Riesling (Sacks et al., 2012), tropical and citrus fruits in Sauvignon Blanc

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(Tominaga, Furrer, Henry, & Dubourdieu, 1998), and floral or perfume features in Gewürtztraminer (Girard, Fukumoto, Mazza, Delaquis, & Ewert, 2002). It would be interesting to test if perceived quality differences by variations in the raw grape material would be easier to determine in these aromatic white varieties than Chardonnay.

**4.0 Conclusions**

Sorting and descriptive analysis provided complementary results for Cabernet Sauvignon wines as shown by the GPA. Sorting is a quick way to qualitatively group wines with similar qualities based on sensory characteristics and quality drivers. Each method provided additional information that could not be interpreted when data was collected using only one method. Cabernet Sauvignon can be discriminated on sensory properties and wine quality better than Chardonnay wines, most likely because of the range in colour and textural sensory properties within the Cabernet Sauvignon variety. Chardonnay wines are a difficult variety to discriminate in both sensory perception and by quality without additional wine processing interventions, suggesting that wide variation in sensory profiles of Chardonnay are not as dependent on the starting grape materials compared to Cabernet Sauvignon. Future work to determine the oenological practices that may alter Chardonnay wine quality would assist in understanding sensory drivers of quality in this variety.

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**Figure captions**

**Fig 1.** CVA plots of Cabernet Sauvignon sensory profiles for a) 2013, b) 2014, and c) 2015 vintages. Scores and loadings plots for each vintage are displayed as i) and ii), respectively. Attribute categories denote for the following: C_ = colour, A_ = aroma, F_ = flavour, T_ = taste, and MF_ = mouthfeel.

**Fig 2.** CVA plots of Chardonnay sensory profiles for a) 2015 and b) 2016 vintages. Scores and loadings plots for each vintage are displayed as i) and ii), respectively. Attribute categories denote for the following: C_ = colour, A_ = aroma, F_ = flavour, T_ = taste, and MF_ = mouthfeel.

**Fig 3.** MDS plot of Cabernet Sauvignon from vintages 2013 – 2015 (a-c) and Chardonnay wines from vintages 2015 and 2016 (d-e). Descriptions under the plot denote for generic characters of wines associated with different quality as depicted by the arrows. Descriptions in *italic* within the plot denote for characters specific to the samples projected in the different areas of the matrix.

**Fig 4.** GPA of scores from CVA and MDS analyses of Cabernet Sauvignon wines; a) 2013, b) 2014, and c) 2015 vintages. Scores (i) and loadings (ii).

**Fig 5.** GPA run on scores from CVA and MDS analyses of Chardonnay wines; a) 2015 and b) 2016 vintages. Scores (i) and loadings (ii).

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**List of Tables**

**Table 1.** List of samples for Cabernet Sauvignon and Chardonnay across 2013 to 2016 vintages.

| Region | Cabernet Sauvignon | | | Chardonnay | |
|---|---|---|---|---|---|
| | 2013 | 2014 | 2015 | 2015 | 2016* |
| Adelaide Hills† | | | | AH1 | AH1 |
| | | | | AH2 | AH2 |
| Barossa Valley | BV1 | BV1 | BV1 | BV1 | BV1 |
| | BV2 | BV2 | BV2 | BV2 | |
| Clare Valley | CL1 | CL1 | CL1 | CL1 | CL1 |
| | CL2 | CL2 | CL2 | CL2 | CL2 |
| | | | | CL3 | CL3 |
| Coonawarra | CWA1 | CWA1 | CWA2 | CWA1 | CWA1 |
| | CWA2 | CWA2 | CWA3 | | |
| | CWA3 | CWA3 | CWA5 | | |
| | CWA4 | CWA5 | CWA6 | | |
| Eden Valley | EV1 | EV1 | EV1 | EV1 | EV1 |
| | EV2 | EV2 | EV2 | EV2 | EV3 |
| | | | | EV3 | EV4 |
| | | | | | EV5 |
| Langhorne Creek | LC1 | LC1 | LC1 | LC1 | LC1 |
| | LC2 | LC2 | LC2 | | |
| McLaren Vale | McV1 | McV1 | McV1 | McV1 | |
| | McV2 | McV2 | McV2 | McV2 | |
| Padthaway† | - | - | - | - | PWY1 |
| Riverland | RVL1 | RVL3 | RVL3 | RVL1 | RVL3 |
| | RVL2 | RVL4 | RVL4 | RVL2 | RVL4 |

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| | | | | | |
|---|---|---|---|---|---|
| | RVL3 | RVL6 | RVL6 | RVL3 | RVL5 |
| | RVL4 | RVL7 | RVL7 | RVL4 | RVL6 |
| | RVL5 | RVL10 | RVL10 | RVL5 | RVL7 |
| | RVL6 | RVL11 | RVL11 | RVL6 | RVL8 |
| | RVL7 | RVL12 | RVL12 | RVL7 | RVL9 |
| | RVL8 | RVL13 | RVL13 | RVL8 | RVL10 |
| | RVL9 | RVL14 | RVL14 | RVL9 | RVL11 |
| Robe† | | | | RB1 | RB1 |
| Wrattonbully | WBY1 | WBY1 | WBY1 | WBY1 | WBY1 |
| | WBY2 | WBY2 | WBY2 | | |

Note that the samples with the same code names are identical samples only within a variety across vintages

* 2016 vintage Chardonnay consisted of 24 samples; one sample was removed due to its vinification being different than the other Chardonnays.

† Regions specifically harvested only for Chardonnay samples



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**Table 2.** Attribute list for Chardonnay wine descriptive analysis with definitions and reference standards.

| Attribute | Definition (reference standard) |
|---|---|
| **Aroma** | The aroma of … |
| Tropical fruits | Tropical fruits (canned passionfruit (John West, Mentone, VIC, Australia), fresh pineapple, rock melon, banana) |
| Citrus | Lemon and limes (fresh lemons and limes) |
| Green apple | Green apples (fresh granny smith apples) |
| Peach | Peaches (canned peaches (Goulburn Valley, Shepparton, VIC, Australia)) |
| Honey | Honey (honey (Capilano, Richlands, QLD, Australia)) |
| Medicinal | Chemicals (4-ethyl phenol (400 µg/L) (Sigma Aldrich, Castle Hill, NSW, Australia) and surgical tape (Leukoplast GMBH, Hamburg, Germany)) |
| Green[£] | Fresh cut plants (grass and hedge clippings) |
| Earthy[£] | Dampness (mushrooms and damp dirt) |
| **Taste** | The taste associated with … |
| Sourness | Acids (citric acid (1 g/L) (McKenzie's, Altona, VIC, Australia)) |
| Sweetness | Sugars (sucrose (10 g/L) (Woolworths Home brand, Bella Vista, NSW, Australia)) |
| Bitterness | Bitterness (quinine (50 mg/L) (Sigma Aldrich, St Louis, MO, USA)) |
| **Flavor** | The flavor of … |
| Citrus | Lemons and limes (as above) |
| Tropical fruits | Tropical fruits (as above) |
| Green apple | Green apples (as above) |
| Peach | Peaches (as above) |
| **Mouth-feel** | |
| Astringency | Sensation of mouth puckering (Grape seed extract 2 g/L in water (Tarac Technologies, Nuriootpa, SA, Australia)) |
| Heat | Burning sensation in oral cavity (Ethanol in water 15 % (Tarac Technologies,)) |
| Viscosity[£] | Sensation of fullness (Xanthan gum 0.5 g in water (The Melbourne Food Ingredient Depot, East Brunswick, VIC, Australia)) |
| **After-taste** | |
| Length | Duration of mouth sensation |
| Bitterness | The aftertaste of bitterness |
| Sourness | The aftertaste of acids |
| Heat | The persistence of burning sensation in oral cavity |
| Astringency | The persistence of the sensation of mouth puckering |

£ Attributes specific to 2015

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**Table 3.** List of definitions formed by the winemakers prior to sorting of Cabernet Sauvignon and Chardonnay wines.

| Quality grade | Cabernet | | | Chardonnay | |
|---|---|---|---|---|---|
| | 2013 | 2014 | 2015 | 2015 | 2016 |
| **A: Premium** | *Wines that are complex with good structure and tannins, expression of varietal and regional characteristics,* | *Intense, dense with varietal characteristics, excellent structure and balanced tannin, complexity, length and* | *Dark fruits, herbs and spice character. Balanced flavour and acid, weight, length, vibrant colour and flavours.* | *Intense varietal character, complexity, robustness, balanced flavours (no overripe/under ripe characters), full palate, good* | *Wine with balance, persistence, acidity (structure), complexity, creamy, with stone fruit and zesty/citrus flavours, phenolics and tannins, good fruit and flavour intensity,* |
| **B: High** | *Wines with some varietal expression, flavour intensity that is above average, with* | *As explained in A grade, but to a lower intensity and complexity* | *Wines that lack the finesse of grade A. It still has dark fruit, herb and spice characters,* | *Good intensity in varietal character, some complexity and balanced flavours. Good texture, full palate* | *Balanced wines with freshness and vibrancy. Missing some key aspects from grade A. Good complexity, some persistence and* |
| **C: Moderate** | *Wines that are simple, soft and low to moderate flavour intensity and varietal expression.* | *Simple wine that is soft and has moderate varietal characteristics. It has less body and structure.* | *Wines that are green, fruit driven and has confectionary character. They lack varietal definition, length* | *Moderate intensity, some varietal character, round structure, low complexity. Clean, fresh, balanced acidity/fruit, and* | *Overripe or under ripe tropical fruits. Less intense than grade B attributes. Higher amounts of bitterness/phenolics, simple with soft acidity,* |
| **D: Low** | *Wines that either have no varietal expression, lack of balance, or contain faults.* | *Under/overripe (green to jammy) with low flavour intensity, unbalanced structure and lacks varietal* | *Wines that are unbalanced and low in complexity. They are thin/dilute, lacks varietal definition and are dry red* | *Overripe/under ripe, lacks varietal definition, unbalanced. Typically has too low/high acidity, unclean, and short.* | *Low intensity, diluted, soft phenolics, Overripe, high phenolics, bitter. The wine is out of balance. Can have green flavours, simple, short,* |
| **E: Faulty** | - | *Wine that has faults.* | - | - | *Faulty wines, commercially* |

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**Highlights:**

- Discrimination of research wine qualities were better when differences in appearance and texture were present as well as taste, aroma and flavour.
- The sensory descriptions of Cabernet Sauvignon wines associated with different levels of quality were determined
- Sensory properties and quality of Chardonnay wines were poorly discriminated by the descriptive analysis panel and experts.

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Graphics Abstract

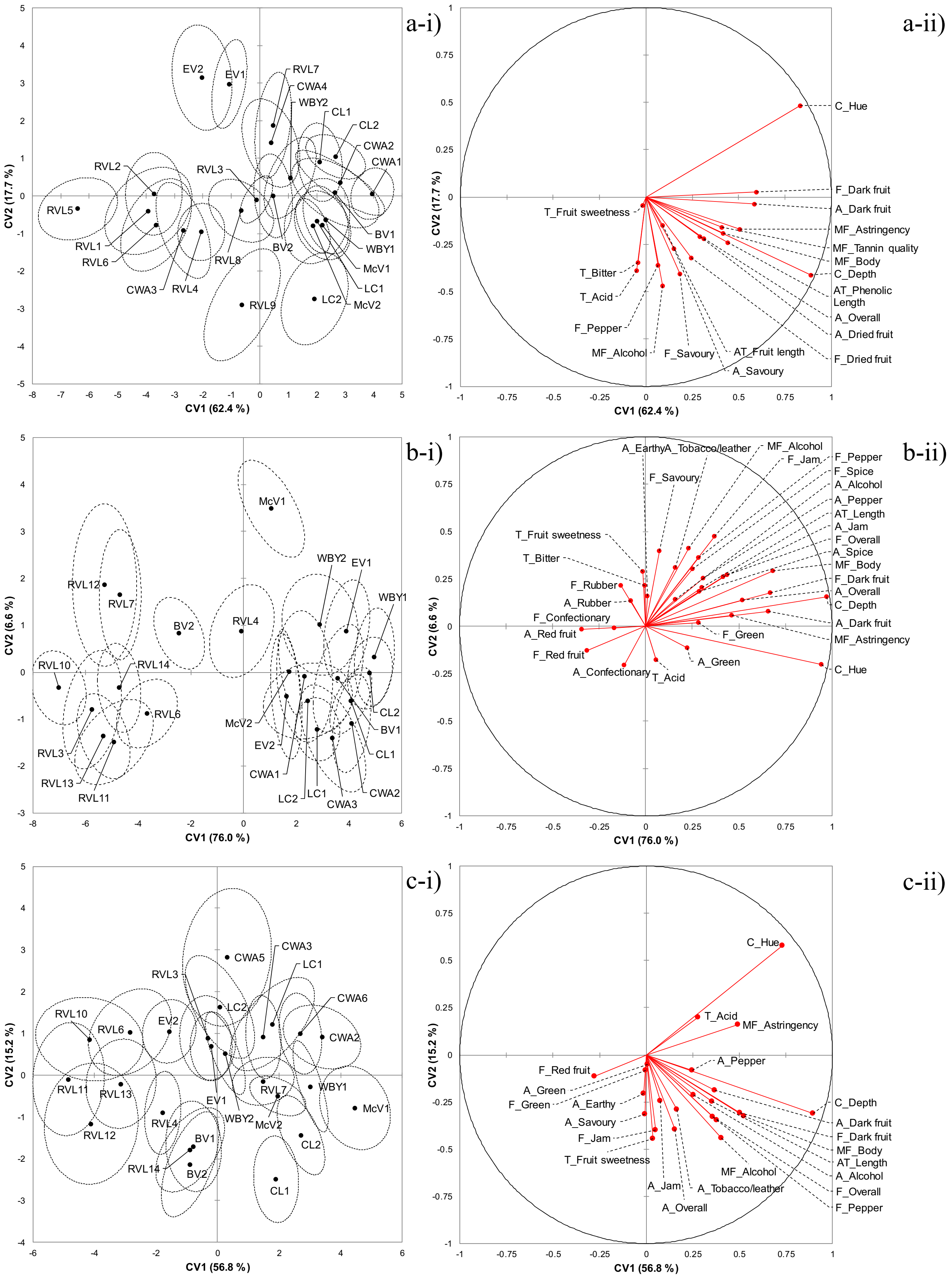
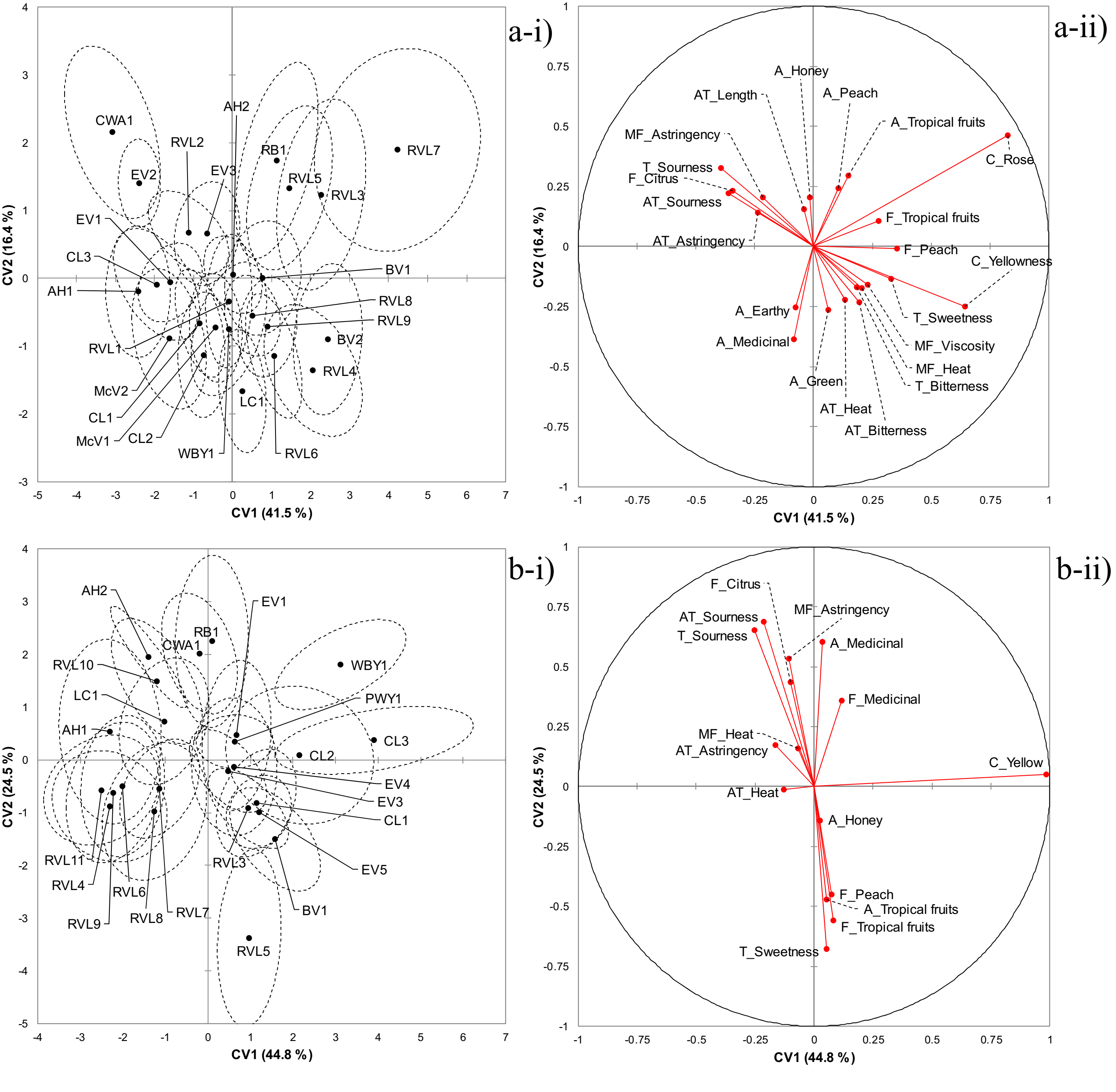

a-i)
a-ii)
b-i)
b-ii)
c-i)
c-ii)
CV1 (62.4 %)
CV2 (17.7 %)
CV1 (76.0 %)
CV2 (6.6 %)
CV1 (56.8 %)
CV2 (15.2 %)
C_Hue
F_Dark fruit
A_Dark fruit
MF_Astringency
MF_Tannin quality
MF_Body
C_Depth
AT_Phenolic Length
A_Overall
A_Dried fruit
F_Dried fruit
T_Fruit sweetness
T_Bitter
T_Acid
F_Pepper
MF_Alcohol
F_Savoury
AT_Fruit length
A_Savoury
A_Earthy
A_Tobacco/leather
F_Jam
F_Spice
A_Alcohol
A_Pepper
AT_Length
A_Jam
F_Overall
A_Spice
F_Rubber
A_Rubber
F_Confectionary
A_Red fruit
F_Red fruit
A_Confectionary
F_Green
A_Green

Figure 1



a-i)
CWA1
EV2
EV1
CL3
AH1
AH2
RVL2
EV3
RB1
RVL5
RVL3
RVL7
BV1
RVL8
RVL9
BV2
RVL4
LC1
RVL6
WBY1
CL2
McV1
CL1
McV2
RVL1
CV1 (41.5 %)
CV2 (16.4 %)
a-ii)
A_Honey
A_Peach
AT_Length
A_Tropical fruits
MF_Astringency
T_Sourness
F_Citrus
AT_Sourness
C_Rose
F_Tropical fruits
AT_Astringency
F_Peach
C_Yellowness
A_Earthy
T_Sweetness
A_Medicinal
MF_Viscosity
MF_Heat
T_Bitterness
A_Green
AT_Heat
AT_Bitterness
CV1 (41.5 %)
CV2 (16.4 %)
b-i)
AH2
EV1
RB1
CWA1
WBY1
RVL10
LC1
PWY1
AH1
CL3
CL2
EV4
EV3
CL1
EV5
RVL11
RVL4
RVL9
RVL6
RVL8
RVL7
RVL3
BV1
RVL5
CV1 (44.8 %)
CV2 (24.5 %)
b-ii)
F_Citrus
AT_Sourness
T_Sourness
MF_Astringency
A_Medicinal
F_Medicinal
MF_Heat
AT_Astringency
C_Yellow
AT_Heat
A_Honey
F_Peach
A_Tropical fruits
F_Tropical fruits
T_Sweetness
CV1 (44.8 %)
CV2 (24.5 %)


Figure 2

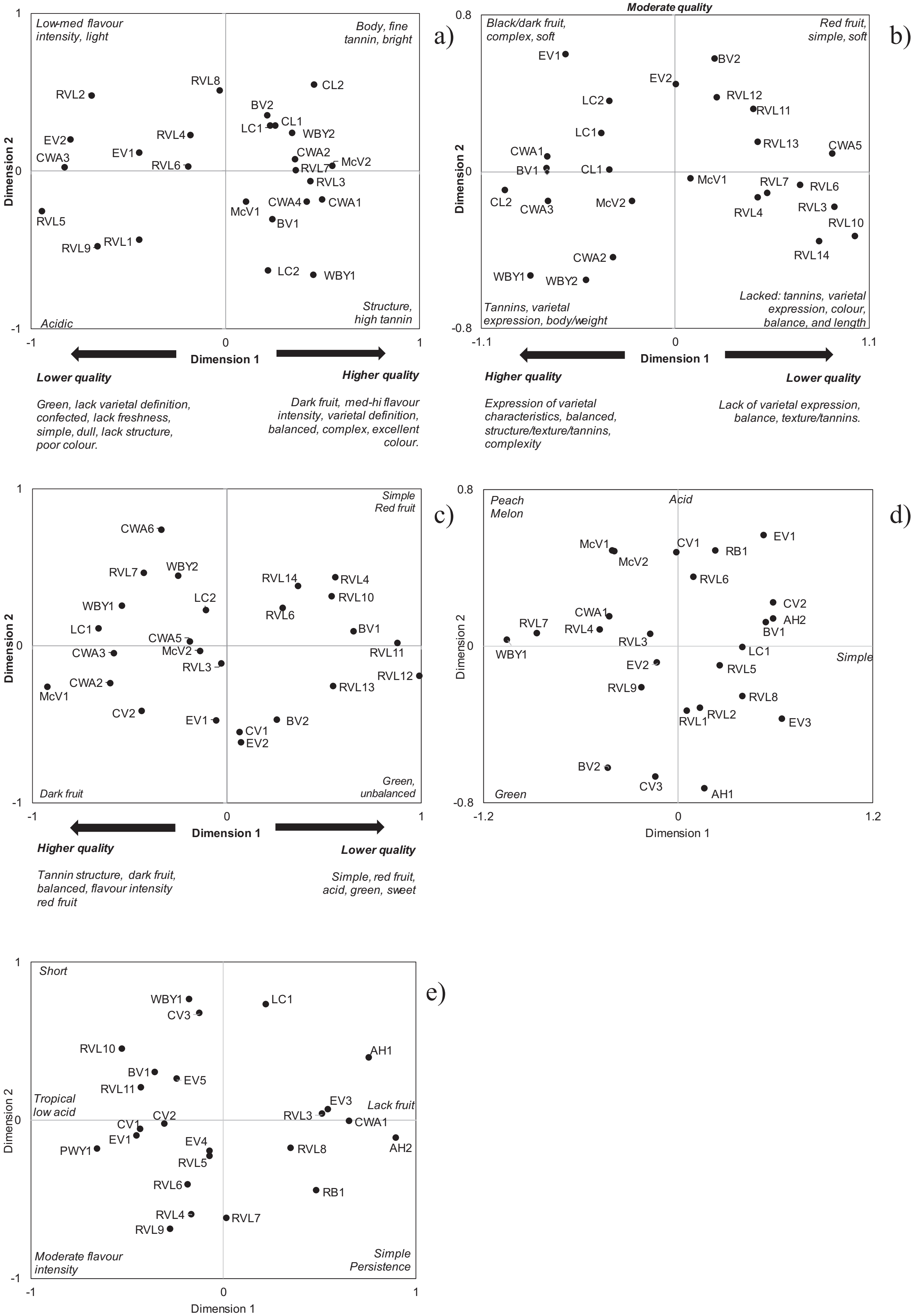

a)
Low-med flavour intensity, light
Body, fine tannin, bright
Acidic
Structure, high tannin
RVL8
RVL2
CL2
BV2
CL1
LC1
RVL4
WBY2
EV2
EV1
CWA2
McV2
CWA3
RVL6
RVL7
RVL3
RVL5
McV1
CWA4
CWA1
BV1
RVL1
RVL9
LC2
WBY1
Dimension 2
Dimension 1
Lower quality
Higher quality
Green, lack varietal definition, confected, lack freshness, simple, dull, lack structure, poor colour.
Dark fruit, med-hi flavour intensity, varietal definition, balanced, complex, excellent colour.
b)
Moderate quality
Black/dark fruit, complex, soft
Red fruit, simple, soft
EV1
BV2
EV2
RVL12
LC2
RVL11
LC1
RVL13
CWA5
CWA1
BV1
CL1
McV1
RVL7
RVL6
CL2
CWA3
McV2
RVL4
RVL3
RVL10
RVL14
CWA2
WBY1
WBY2
Tannins, varietal expression, body/weight
Lacked: tannins, varietal expression, colour, balance, and length
Dimension 2
Dimension 1
Higher quality
Lower quality
Expression of varietal characteristics, balanced, structure/texture/tannins, complexity
Lack of varietal expression, balance, texture/tannins.
c)
Simple Red fruit
CWA6
RVL7
WBY2
RVL14
RVL4
RVL10
LC2
WBY1
RVL6
LC1
BV1
CWA5
CWA3
McV2
RVL11
RVL3
RVL12
CWA2
McV1
RVL13
CV2
EV1
BV2
CV1
EV2
Dark fruit
Green, unbalanced
Dimension 2
Dimension 1
Higher quality
Lower quality
Tannin structure, dark fruit, balanced, flavour intensity red fruit
Simple, red fruit, acid, green, sweet
d)
Peach Melon
Acid
EV1
McV1
CV1
RB1
McV2
RVL6
CV2
CWA1
AH2
RVL7
RVL4
BV1
RVL3
WBY1
LC1
Simple
EV2
RVL5
RVL9
RVL8
RVL1
RVL2
EV3
BV2
CV3
AH1
Green
Dimension 2
Dimension 1
e)
Short
WBY1
LC1
CV3
RVL10
AH1
BV1
EV5
RVL11
Tropical low acid
EV3
Lack fruit
CV2
RVL3
CWA1
CV1
EV1
AH2
PWY1
EV4
RVL8
RVL5
RVL6
RB1
RVL4
RVL7
RVL9
Moderate flavour intensity
Simple Persistence
Dimension 2
Dimension 1

Figure 3

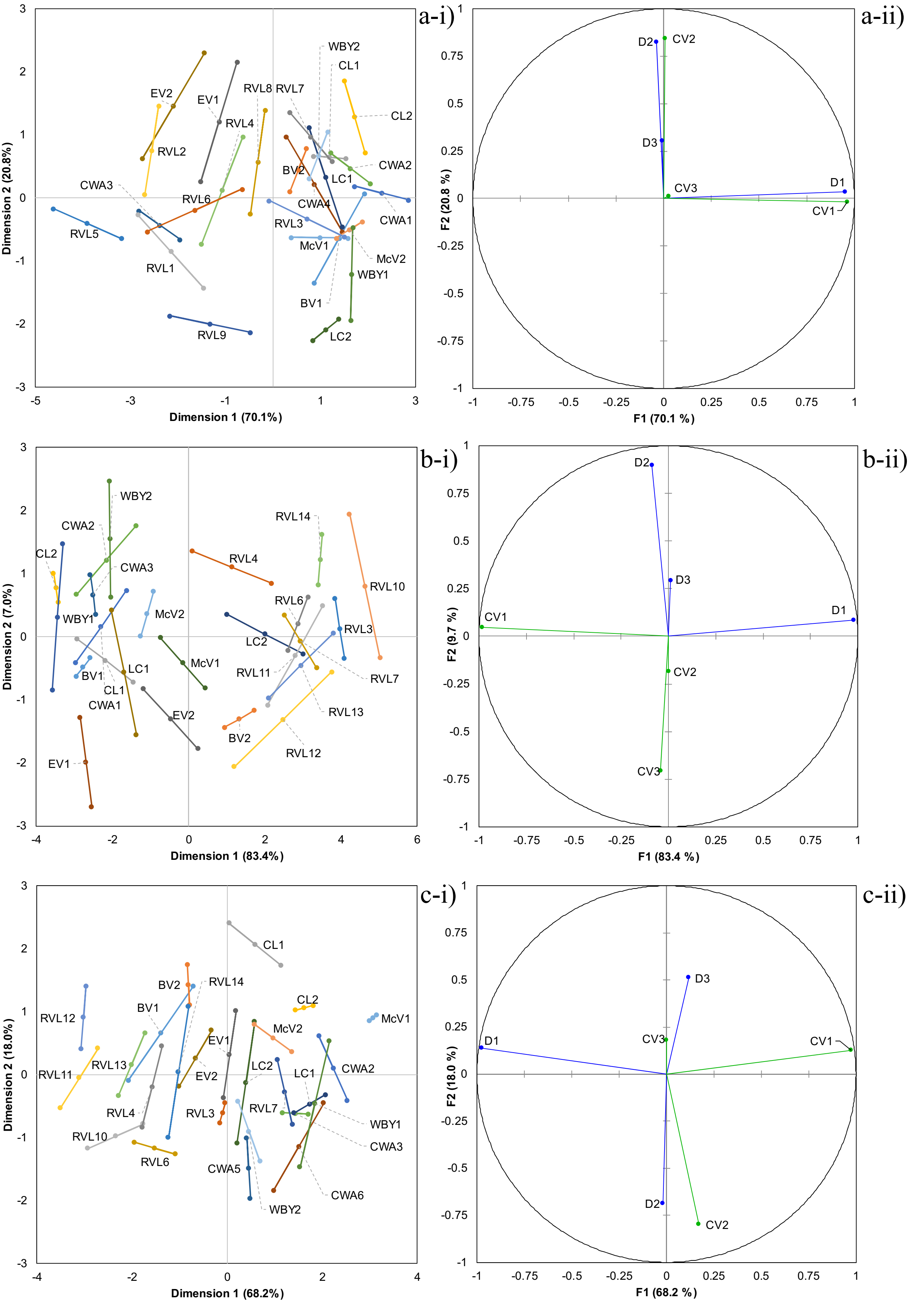

a-i)
a-ii)
b-i)
b-ii)
c-i)
c-ii)
Dimension 1 (70.1%)
Dimension 2 (20.8%)
F1 (70.1 %)
F2 (20.8 %)
Dimension 1 (83.4%)
Dimension 2 (7.0%)
F1 (83.4 %)
F2 (9.7 %)
Dimension 1 (68.2%)
Dimension 2 (18.0%)
F1 (68.2 %)
F2 (18.0 %)
D1
D2
D3
CV1
CV2
CV3

Figure 4

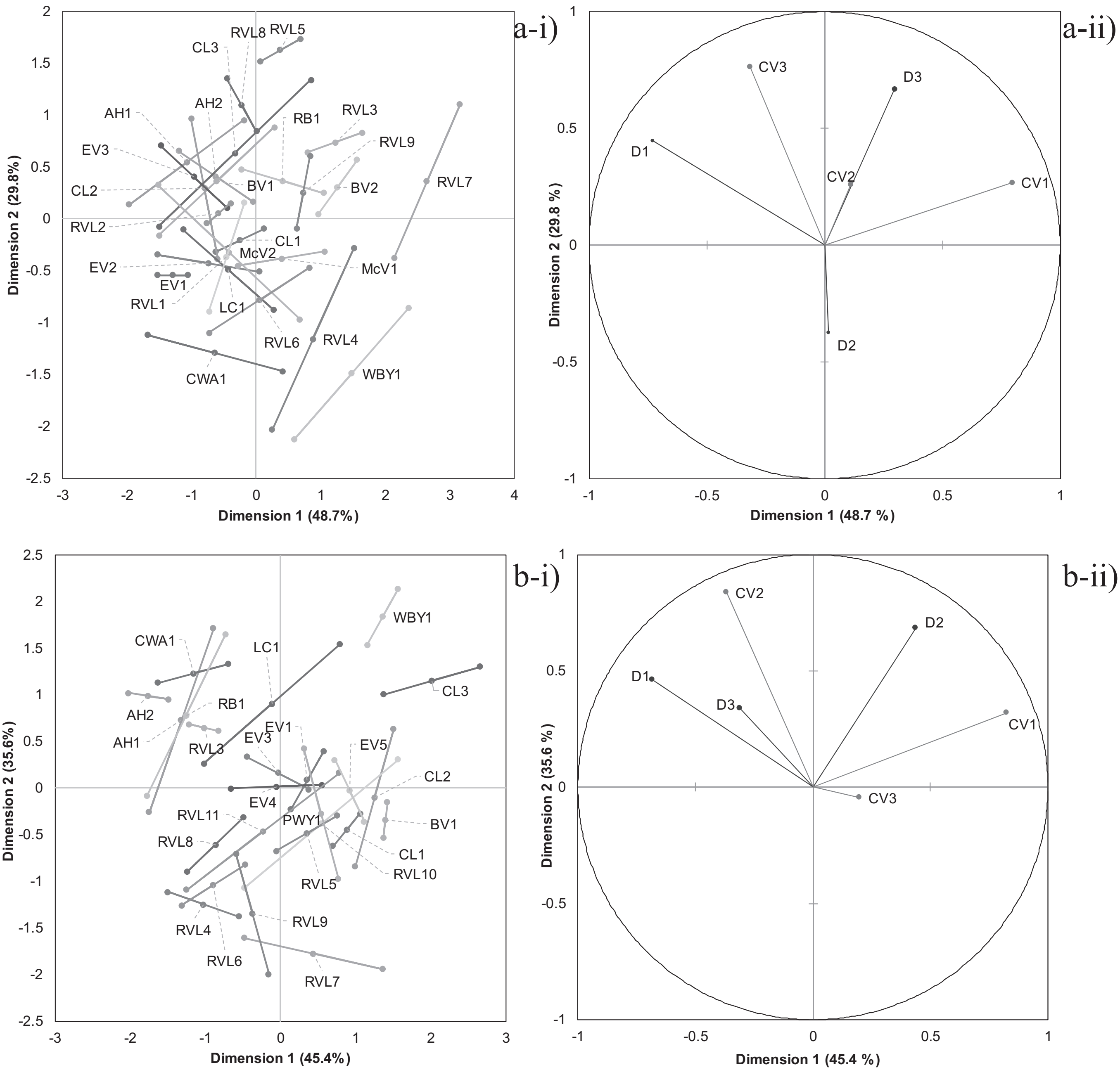

a-i)
a-ii)
b-i)
b-ii)
Dimension 1 (48.7%)
Dimension 2 (29.8%)
Dimension 1 (48.7 %)
Dimension 2 (29.8 %)
Dimension 1 (45.4%)
Dimension 2 (35.6%)
Dimension 1 (45.4 %)
Dimension 2 (35.6 %)
RVL8
RVL5
CL3
AH1
AH2
RB1
RVL3
RVL9
EV3
CL2
BV1
BV2
RVL7
RVL2
CL1
McV2
EV2
McV1
EV1
RVL1
LC1
RVL6
RVL4
CWA1
WBY1
CV3
D3
D1
CV2
CV1
D2
CWA1
LC1
WBY1
CL3
RB1
AH2
AH1
RVL3
EV1
EV3
EV5
CL2
EV4
RVL11
PWY1
BV1
RVL8
CL1
RVL10
RVL5
RVL9
RVL4
RVL6
RVL7
CV2
D2
D1
D3
CV1
CV3

Figure 5