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SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

ASSESSING CLONAL VARIABILITY IN CHARDONNAY AND SHIRAZ FOR FUTURE CLIMATE CHANGE

FINAL REPORT to WINE AUSTRALIA

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Cover photos:

Chardonnay at the late Kym Ludvigsen vineyard, Grampians.
Orange region tasting of Chardonnay clonal wines
Small lot wine making equipment used for WA trial sites.
A Barossa Shiraz clone at veraison.
Small group of Margaret River winemakers assessing Chardonnay clonal wines

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1 Abstract

The aim of this project was to assess the viticultural performance and wine sensory properties of a common selection of Chardonnay and Shiraz clones growing in a range of diverse climates in Australia. Across vintages there were statistically significant differences in small-lot wines between clones within a region, and between regions. The differences in wine descriptors between regions give an insight to how wine styles within each of these regions may change in a warmer climate.

However, there were no consistent trends in sensory differences between clones. At regional tastings participants demonstrated clear preferences for individual clones, but these too varied across regions and between seasons. These outcomes indicate that there is merit in planting a range of clones within vineyards and then using the diversity between the wines for winemakers to determine the specific end-product for the marketplace. Preliminary Shiraz genomics work detected dissimilarities between the clones DNA, and the Australian clones formed a group distinct from the three Shiraz clones recently imported from France.

2 Executive Summary

Chardonnay and Shiraz represent the two major wine grape varieties in Australia. Both varieties are produced across a wide range of climates for different wine styles and price points. Over the last decade, an increasing number of clones of each variety have been planted, sometimes with limited knowledge of their performance and impact on wine attributes. In Australia, historical clonal evaluation has used yield as the main selection criteria, underpinned by industry goals to improve productivity and reduce seasonal yield variation. This project was developed to evaluate grapevine clones through to winemaking and comprehensive sensory assessment, with a view to making resilient and superior planting material available to the industry.

Mature plantings of Shiraz and Chardonnay in Victoria, South Australia and Western Australia were selected that comprised a range of clones, some of which were common to all sites. In choosing these sites, we also sought diverse climates to test our hypothesis that differences in climate between sites could be used as a surrogate for climate change. Our goal was to explore if the sensory attributes of a currently cool region could gradually become similar to those of a currently warm region and, similarly, will the profile of wines from a currently warm region become more like those of a currently hot region into the future? By assessing the fruit from common clones across multiple regions, the interaction between climatic conditions and clone could be investigated.

Suitable sites of Shiraz and Chardonnay were identified in the Riverland and Barossa in South Australia; the Grampians and Drumborg in Victoria, and Margaret River and the Great Southern in Western Australia. Field work commenced in the 2013-14 season. Three consecutive seasons of vine performance and wine sensory data were collected from the four Shiraz sites, and four consecutive years of data from the five Chardonnay sites. The majority of the sites were not replicated clonal trials, rather being row-by row plantings of the different clones, which limited the statistical analysis of the data sets. All of the clones, with the exception of perhaps the Gingin Chardonnay clone, had previously been evaluated for yield performance, so this was not the primary focus.

Heat summation and phenology were recorded at each site and used to predict the future harvest date in a warmer climate. The impact of a 0.5, 1.0. 1.5 or 2.0^{o}C increase in daily temperature between budburst and harvest was modelled using current daily heat summation required to ripen

both Chardonnay and Shiraz to the target maturity required for small lot winemaking. The modelling indicated an earlier harvest date for both varieties at all sites as well as vintage compression.

All wines were made using identical protocols and the same panel conducted the sensory descriptive analysis each year. Statistical analysis of sensory scores revealed significant differences between clonal wines for most of the attributes (approximately 30) in each season. Principal Component Analysis (PCA) was performed using combined data from all clones at the regional level and for all clones within each region, for all vintages. PCA plots at the regional level often resulted in distinct separation between the regions. For example, the 2017 Chardonnay wines from each region occupied a separate quadrat of the PCA plot, with each quadrat containing a completely different set of descriptors characterising the wines from the cool to warm regions. In other cases, wines tended to group together. For example, Chardonnay wines from Margaret River and the great Southern were grouped in the same quadrat for each of the four vintages, suggesting that they were more similar to each other than the other three regions, whilst Riverland Chardonnay wines were in a separate quadrat for three of the four years. In 2016 the four Shiraz regions separated into each of the four quadrats of the PCA plot and in the other two years, wines from the Barossa were separated from all other regions.

Shiraz sensory descriptors were used in each of the three years to determine if there were any common descriptors for each region. Barossa wines were characterised as having dark fruit and sweet spice aroma and high opacity, with Grampians wines having consistent red fruit aroma, floral and confection. Margaret River wines had consistent red fruit aroma. Riverland wines showed considerable variation across the three years, with no consistent traits. PCA plot comparison between vintages was not possible due to the reduced number of sensory attributes that were common across years (especially for the Chardonnay wines).

Overall, the PCA plots give some insight into how regional wine styles may change in a warming climate. At the regional level, the PCA plots separated the clones either within a quadrat or in some cases into different quadrats of the plot, indicating that there were differences in the sensory profile of the clones. In some cases these differences may have been due to maturity at harvest (using wine alcohol concentration as an index). However, there were a number of examples where clonal wines of similar alcohol concentration had distinct sensory profiles. While the regional PCA plots revealed differences between clonal wines in each season, there did not appear to be any consistent pattern in this separation between seasons.

Statistical analysis of the pooled sensory data within a region was used to compare regions and similarly within each region to compare clones. Radar plots, each with Least Significant Difference values included, were constructed using these data sets. There were significant differences in the majority of the sensory scores between regions in each year, however, the much smaller set of sensory attributes that were common to all years did not permit reliable statistical analysis of the effect of season on scores. Within each region there were again significant differences in sensory scores between clones in each year, but the number of attributes that were significantly different varied between regions. For example, for the 2015 Margaret River Chardonnay wines there were 14 significantly different sensory traits compared with seven for the 2017 wines.

Project results were presented to industry through many regional wine tastings, both in the project regions and elsewhere, and these were always well-attended and well-received. At all workshops we asked participants to rank their preferences, based on their overall perception of the wines and their potential as finished commercial wines. At most workshops, there was a most preferred clonal wine, and rankings of the same selection of wines tended to differ between regional groups.

Although the method was different from the descriptive analytical approach used by the AWRI sensory panel, both approaches demonstrate that there were clonal differences between the wines.

The geographically diverse origins of the Shiraz clones used in this work presented the opportunity for a limited investigation of the level of genetic difference between the clones. Phylogenetic relationships between the seven Australian Shiraz clones and three French clones were determined. The phylogenetic tree arranged the French and the Australian-based clones into two distinct and separate groups (clades). The shared nucleotide variants of the Australian clones suggested a common origin for these clones which predates establishment of clonal selection programs and potentially also their original importation to Australia. Despite their shared heritage, the Australian clones appear quite distinct from each other, although they exhibited less intra-clade diversity than the more recently-imported French Shiraz clones.

The origin, selection history and published data on yield performance of all Chardonnay and Shiraz clones used in this study was researched and documented. The clones were also tested for the range of grapevine viruses for which diagnostic protocols are available in Australia. Overall, the clones were remarkably free of virus and virus-like diseases.

Wines of both varieties were presented at multiple workshops across four States for local winemaker/viticulturist assessment, as described above. Preliminary results were presented in a plenary session and workshop at the 2016 Australian Wine Industry Technical Conference and a workshop at the 2019 Conference. Two presentations were made to the Californian Industry in late 2018.

3 Acknowledgements

This project relied heavily on the cooperation we received from the site managers and/or owners as fruit needed to be hand-harvested from each site for three or four consecutive seasons for yield assessment and small lot wine making and, then in each winter, leaving the targeted vines for pruning weight measures. Specifically, we would like to acknowledge the following:

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4 Background

This project was developed to evaluate clones that possess desirable viticultural and winemaking properties, including resilience to future climate challenges. It was designed to contribute to Wine Australia objectives of making resilient and superior planting material available to the industry.

The Australian wine industry relies on a small number of international grapevine varieties for 95% of its production, and, within those, a small number of clones. Chardonnay and Shiraz represent the two major wine grape varieties in Australia. Both varieties are grown in a wide range of climatic sites for different price points and over the last decade, an increasing number of clones of each variety are being planted, albeit in some cases with limited knowledge of their performance and wine attributes. In light of climate change impacts, information on clonal performance of these varieties under different climatic conditions may provide management strategies to mitigate potential adverse effects on fruit quality. Extensive clonal evaluation has been an important part of the European wine industry, with continued acknowledgement of the importance of intra-varietal diversity to identify superior planting material for quality, disease resistance and, more recently, drought and heat tolerance (International Conference on Grape Genetics and Breeding, 2003). In France, the IFV (Institut Francais de la Vigne et du Vins) clonal evaluation programme now includes new varieties for evaluating adaptability to climate change and flavour parameters for market developments.

In Australia the majority of clonal work was conducted in the 1980's and 90's. Some work was recently summarised: Whiting (2003) "Selection of grapevine rootstocks and clones for greater Victoria". Most of the clonal work examined quantity parameters, with yield as the main selection criteria as the key Industry goal was to improve productivity and reduce seasonal yield variation. Few trials carried the evaluation through to winemaking and comprehensive sensory evaluation.

While limited clonal trial work has been undertaken in the last 10 years, there are, for example, mature plantings of replicated clonal trials of the major varieties established in 2005 by RVIC and replicated trials and other plantings in Central Victoria, Barossa and Great Southern in WA that have not yet been evaluated beyond performance assessment. The diverse climates of these plantings offer a unique opportunity to explore if there are significant differences in wine sensory attributes of a number of Chardonnay and Shiraz clones. A successful demonstration of significant differences in wine sensory properties of different clones would hopefully renew interest in clonal selection in Australia and increase the diversity, complexity and other attributes of regional wines.

The diverse climates of the plantings described above, and perhaps others, offer the possibility of using current differences as a surrogate for a warmer future i.e. will the sensory attributes of a currently cool region gradually become similar to those of a currently warm region, and, similarly will the profile of wines from a currently warm region become more like those of a currently hot region into the future? A study such as this would only be possible if fruit from the same clone, or a number of common clones to explore any clone x region influences, was available across a range of climatic regions (to eliminate possible clonal differences); all wines made using the same protocols to minimise regional winemaker preferences; and, all wines assessed together using sound statistical methodology.

The geographically diverse origins of the Shiraz clones presented the opportunity for a limited investigation of the level of genomic differences between the clones. The genetic differences between Australian and French Shiraz clones has not previously been investigated and it is likely that the Australian clones are unique as they were selected prior to the introduction of Phylloxera to Europe. The AWRI sequenced and identified phylogenetic relationships between clones using patterns of single nucleotide polymorphisms (SNPs) deduced from whole genome sequencing.

5 Project Aims and Performance Targets

1. Determine any preferential clones of Shiraz and Chardonnay for warmer climates via comparison of performance of relevant clones across diverse geographical regions over three consecutive vintages
2. Identify any potential advantages in disease tolerance between clones
3. Commence sequencing of a selected number of Shiraz clones for determination of intra-varietal genotypic variation
4. Review and tabulate the detail of clonal history of the clones involved, where possible
5. Package information and extend to the Australian industry via appropriate industry extension avenues.

6 Materials and Methods

We sought mature plantings of own-rooted Shiraz and Chardonnay in Victoria, South Australia and Western Australia that comprised a range of clones, some of which were common to all sites. These could have been adjacent rows (or in close proximity) of different clones or existing replicated clonal trials planted by Vine Improvement groups or state research agencies. There was no list of preferred clones of each variety. A number of sites in the three states were considered, and by process of elimination based on sites with as many clones in common for each variety, and willing collaborators, the sites described in Table 1 and Table 4 were chosen. To overcome the logistical constraints of fruit from the wide geographical spread of the sites chosen being processed into small lot wines at a central location it was agreed that two facilities would be used viz. the Waite Hickinbotham Roseworthy Wine Sciences Laboratory to process fruit from the SA and Victorian sites and the WA Department of Primary Industries and Regional Development Agriculture and Food small –lot winemaking facility at Bunbury for fruit from the WA sites. At the commencement of the project a set of winemaking protocols was established and annually reviewed. Immediately after primary fermentation the WA wines were cold shipped to the Waite for finishing and bottling with the SA and Victorian wines. Further details regarding winemaking protocols are presented in 6.3.

6.1 Site characterisation

6.1.1 Chardonnay

Regional climate

Part of the site selection process was to select sites covering a range of climates from hot to cool, and continental to maritime. Thus the regions selected covered a hot, continental site (Riverland), two differing warm, maritime sites (Margaret River and Great Southern), a cool, maritime site (Drumborg), and a cool, continental site (Grampians) (Smart and Dry 1980). The long term climate data provided by Gladstones (1992) reflects the relative differences between the regions prior to 1992 (Table 1). TinyTag™ data loggers housed in DataMate™ screens were installed at each site and were programmed to record the average temperature for each 15 minute interval. These data sets were subsequently used to calculate appropriate climate site specific indices for each year of the study and used for future harvest date calculations.

The Heat Degree Days (HDD), Biologically Effective Day Degree (BEDD) and mean January temperature (MJT) all reflect the descending temperatures of Riverland > Margaret River > Great Southern > Grampians > Drumborg. The degree of continentality shows the order from most continental to least being Riverland > Grampians > Great Southern > Drumborg > Margaret River. Annual rainfall varies substantially from 269 mm in the Riverland to 1,192 mm in the Margaret River region. Sunshine hours were greatest in the Riverland and least in the Drumborg region.

Site characteristics

Specific site characteristics are provided in Table 2. Three sites were at latitudes around 34°S and the other two were around 37°C and 38°S (Grampians and Drumborg respectively). Altitude varied from 35 m to 390 m above sea level with some within site variations where blocks of vines were on slopes. Three of the sites were duplex soils of differing compositions, one site (Drumborg) showed a gradational profile and the Riverland site was a deep sandy loam over limestone. Soil pH was acidic at three sites, mildly acidic at another and alkaline at the Riverland site. The electrical conductivity of the soils (a measure of salinity) is low at the cooler climate sites and mildly saline at the Riverland site. All vines were at least 10 years old when the studies commenced and most were 10-15 years old. A fairly standard vineyard management of under-vine herbicide and inter-row mowing was applied across all sites.

Table 1. Regional characteristics at five Chardonnay clonal trial sites.

Region	Drumborg	Grampians	Great Southern	Margaret River	Riverland
Recording station	Heywood	Ararat	Mount Barker	Margaret River	Berri
Long term Heat Degree Days (°C)	1,180	1,349	1,441	1,599	2,148
Biologically Effective Day Degrees (°C)	1,180	1,335	1,441	1,529	1,756
Mean January Temperature (°C)	17.4	18.7	19.0	20.0	23.0
Continentality (°C)[1]	8.4	11.7	9.3	7.6	12.8
Annual Rainfall (mm)	861	616	756	1,192	269
Total Sunshine Hours October - April	1,490	1,780	1,518	1,626	2,002

[1] Dry et al. 2004

Table 2. Site characteristics at five Chardonnay clonal trial sites

Region	Drumborg	Grampians	Great Southern	Margaret River	Riverland
Latitude	38.049020°S	37.225290°S	34.630750°S	33.995210°S	34.083900°S
Altitude (m)	90-130	360-390	320	70-100	35
Soil description	Dark red-brown sandy clay over dark red medium clay	Brown gritty loam with quartz and iron concretions over yellow-red gritty clay	Loamy sand to sandy loam over clay loam with ironstone gravel	Gravelly sandy loam over red brown medium clay	Red sandy loam over clay/carbonate layer
Soil class[1]	Deep well structured loamy unigrad soil (Sub-category 9.6)	Non-restrictive duplex soil with thin hard topsoil (Sub-category 7.3)	Restrictive duplex soil with thick well structured topsoil (Sub-category 6.2)	Non-restrictive duplex soil with thick well structured topsoil (Sub-category 7.2)	Loamy calcareous soil (Sub-category 8.6)
Topsoil pH_{water}	5.8-5.9	6.2	5.0-5.9	5.3-6.3 ($CaCl_2$)	7.8
Topsoil Electrical conductivity (dS/m)	0.08-0.11	0.07	0.02-0.06	0.07	0.17
Year(s) of planting	1986, 1997-2000	2004	2005	2001-2004	2003
Soil management	Under-vine herbicide, mid-row mown sward	Under-vine herbicide, mid-row mown	Under-vine herbicide and annual mulch, mid-row mown	Minimal herbicide under-vine, mid-row mown	Herbicide under-vine, mid-row mown

[1] Maschmedt 2004

Vine management

There were some variations in vine management across the sites (Table 3). At two sites the row orientation was east-west, at another two sites the rows were north-south, and at Great Southern the rows were primarily NE-SW. Vine spacing within the row varied from 1.5m to 2m and between row spacing from 2.5 m to 3 m. Vine planting density ranged from 1,667 to 2,667 vines per hectare. The trellises were either single cordon, spur/mechanically pruned, or cane pruned, with the cooler sites utilising movable foliage wires. The cooler sites used vertical shoot positioning (VSP) and at the hottest site the canopy was allowed to sprawl.

Table 3. Vine management practices at five Chardonnay clonal trial sites.

Region	Drumborg	Grampians	Great Southern	Margaret River	Riverland
Row orientation	N-S	E-W	NE-SW	N-S	E-W
Row x vine spacing (m)	2.5 x 1.5	3.0 x 2.0	3.0 x 1.2 or 1.5	2.7 x 1.6	3.0 x 1.9
Trellis	2 fixed wires at 0.9m and 1.1m, movable foliage wires	Single cordon at 0.95m, movable foliage wires	Single wire at 1.0 m, moveable foliage wires	Single wire at 0.85m, movable foliage wires	Single wire at 1.2m, fixed foliage wire
Pruning method	4 canes arched, approx. 40 nodes per vine	Spur, approx. 35 nodes per vine	Cane, approximately 25 nodes per vine	Spur, approximately 25 nodes per vine	Barrel pruned with hand clean up, 50 – 60 buds per vine
Canopy management	Vertical shoot positioned, topped and hedged	Vertical shoot positioned.	Vertical shoot positioned	Vertical shoot positioned, shoot thinned and trimmed	Sprawl with trimming in December

6.1.2 Shiraz

Regional climate

Sites were selected to cover a range of climates ranging from hot to cool, and continental to maritime. Thus the regions selected covered a hot, continental site (Riverland), a warm, continental site (Barossa), a warm, maritime site (Margaret River) and a cool, continental site (Grampians) (Smart and Dry 1980). The long term climate data provided by Gladstones (1992) reflects the relative differences between the regions prior to 1992 (Table 4).

The Heat Degree Days (HDD) and Biologically Effective Day Degree (BEDD) reflect the descending temperatures heat units of Riverland>Margaret River>Barossa>Grampians. The mean January temperature shows Margaret River to be cooler than the Barossa Valley in that month due to the maritime influence. The degree of continentality shows the order from most continental to least being Riverland>Barossa Valley>Grampians>Margaret River. Annual rainfall varies substantially from 269mm in the Riverland to 1,192 mm in the Margaret River region. Sunshine hours were greatest in the Riverland and least in the Margaret River region. TinyTag™ data loggers housed in DataMate™

screens were installed at each site and were programmed to record the average temperature for each 15 minute interval. These data sets were subsequently used to calculate appropriate climate site specific indices for each year of the study and used for future harvest date calculations.

Table 4. Regional climate characteristics for four Shiraz clonal trial sites

Region	Grampians	Barossa Valley	Margaret River	Riverland
Recording station	Ararat	Nuriootpa	Margaret River	Berri
Long term Heat Degree Days (°C)	1,349	1,577	1,599	2,148
Biologically Effective Day Degrees (°C)	1,335	1,487	1,529	1,756
Mean January Temperature (°C)	18.7	20.8	20.0	23.0
Continentality (°C)[1]	11.7	12.4	7.6	12.8
Annual Rainfall (mm)	616	506	1,192	269
Total Sunshine Hours October - April	1,780	1,817	1,626	2,002

[1] Dry et al 2004

Site characteristics

Specific site characteristics are provided in Table 5. Three sites were at latitudes around 34°S and the fourth being Grampians at around 37°S. Altitude varied from 47 m to 375 m above sea level with some within site variations where blocks of vines were on slopes. Three of the sites were duplex soils of differing compositions and the other site (Riverland) was a deep sandy loam over limestone. Soil pH was acidic at one site and close to neutral at the other three sites. The electrical conductivity of the soils (a measure of salinity) is low at the cooler climate sites and mildly saline at the Riverland site. All vines were at least 10 years old when the studies commenced and some were over 20 and 30 years old. A similar standard vineyard management practice of under-vine herbicide and inter-row mowing was applied across all sites.

Table 5. Site characteristics at four Shiraz clonal trial sites

Region	Grampians	Margaret River	Barossa Valley	Riverland
Latitude	37.313980°S	33.995210°S	34.475840°S	34.231675°S
Altitude (m)	375	75	274	47
Soil description	Yellow grey brown fine sandy clay over yellow-brown clay loam	Gravelly sandy loam over red brown medium clay	Sandy loam over clay	Red sand over red clayey sand to sandy clay loam, cacareous at depth
Soil class[1]	Restrictive duplex soil with thin hard topsoil (Sub-category 6.3)	Non-restrictive duplex soil with thick well structured topsoil (Sub-category 7.2)	Depending on topsoil depth 6.1 -6.2	Sandy calcareous soil (Sub-category 8.1)
Topsoil pH_{water}	7.6	5.3-6.3 ($CaCl_2$)	7.3 ($CaCl^2$)	7.5
Topsoil Electrical conductivity (dS/m)	0.13	0.07	0.04	0.17
Year(s) of planting	1991-1992	2002-2004	1982 and 2001	2003
Soil management	Under-vine herbicide, mid-row sward mown	Minimal herbicide under-vine, mid-row sward mown	Under-vine herbicide, mid-row mown	Herbicide under-vine, mid-row nil cultivation

[1] Maschmedt 2004

Vine management

Row orientation was primarily north-south at the two cooler sites and east-west at the two hotter sites (Table 6). Within row vine spacing ranged from 1.5 m to 2.25 m, and between row spacing from 2.75 m to 3.5 m. Vine planting density ranged from 1,270 to 2,424 vines per hectare. At the coolest site the vines were arch cane pruned and lifted into a VSP position with movable foliage wires. The other three sites were spur/mechanically pruned on single wire trellises, with canopies at the two warmest sites left to sprawl.

Table 6. Vine management practices at four Shiraz clonal trial sites.

Region	Grampians	Margaret River	Barossa Valley	Riverland
Row orientation	N-S	N-S	E-W	E-W
Row x vine spacing (m)	2.75 x 1.5	3.0 x 2.0	3.5 x 2.25 3.0 x 2.25	3.0 x 1.5
Trellis	Fixed wires at 1m and 1.2m, movable foliage wires	Single wire at 0.85m, movable foliage wires	Single wire at 1.1m, fixed foliage wire	Single wire at 1.8m
Pruning method	2 canes arched, approx. 24 nodes per vine	Spur, node approximately 12 two bud spurs per vine	Barrel pruned with hand clean up to 20-25 spurs per vine	Machine pruned to box, no set node number
Canopy management	Vertical shoot positioned, topped	Vertical shoot positioned, shoots thinned, trimmed and hedged	Sprawl, trimmed	Sprawl, skirted

6.2 Clones

6.2.1 Chardonnay

Mature plantings (minimum ten years old) of a range of clones of Chardonnay were selected across regions in southern Australia. The clones were in replicated trial sites and/or were in blocks planted in close proximity to each other. In Australia, very old plantings of Chardonnay are rare and most of the expansion of Chardonnay plantings in the past 40 years has been based on imported clones from the United States of America (USA) and France. Clones from the USA were imported in the 1960s and 1970s and were primarily selected for high yields. Most clones from France were imported in the 1980s onwards and were primarily selected for consistency of yield and wine quality. The Chardonnay clones in the trials are summarised in Table 7.

Table 7. Chardonnay clones included in the study
Additional details are included in Appendix 1

Clonal designation	Comments
76	Bernard selection from Burgundy region. Consistent good yield, above average quality.
78	Bernard selection from Burgundy region. High production of below average quality.
95	Bernard selection from Burgundy region. Vigorous, slightly below average production of good quality. Susceptible to coulure and millerandage.
96	Bernard selection from Burgundy region. Very vigorous, high production of good quality.
277	Bernard selection from Burgundy region. Good production of very high quality.
FVI10V1	Selected in California as high yielding from vines originally from France. Also known as Foundation Plant Service (FPS) 06 and Clone 6 in New Zealand
FVI10V5	Selected in California as high yielding from vines originally from France. Also known as FPS 08.
Gingin	Material imported to WA in 1957 directly from California. Subsequent large planting at Moondah Brook vineyard in Gingin, WA was primarily used to supply early plantings. Typified by coulure and millerandage especially in cooler climates.
Penfold 58	Introduced from France into NSW by Penfolds Wines in 1958. Low yield and high quality. Susceptible to coulure and millerandage.

Where it is known the importation clone for each Chardonnay trial site is listed in Table 8.

Table 8. Source of importation of Chardonnay clones at each trial site

	Region				
Clone	Drumborg	Grampians	Margaret River	Great Southern	Riverland
76	Seppelts 1984	Seppelts 1984	Picardy (Pemberton)	ARM Nurseries	Yalumba, private import
78	Seppelts 1984	Seppelts 1984	-	-	-
95	Seppelts 1984	Seppelts 1984	Yalumba nursery	ARM Nurseries	Yalumba, private import
96	Seppelts 1984	Seppelts 1984	Yalumba nursery	ARM Nurseries	Yalumba, private import
277	Seppelts 1984	Seppelts 1984	Picardy, Pemberton	ARM Nurseries	Yalumba, private import
I10V1	IC698127	-	-	ARM Nurseries	-
I10V5	IC698129, SHC Irymple	IC698129	-	-	-
Gingin	-	-	Leeuwin Estate, Margaret River	IW576002	-
Penfold 58	NSW ex Europe, SHC Irymple	-	-	-	-

6.2.2 Shiraz

Mature plantings (minimum ten years old) of a range of clones of Shiraz were selected across regions in southern Australia. The clones were in replicated trial sites and/or were in blocks planted in close proximity to each other. The clones in this project can be divided into a number of groups based on the state where the selection process occurred. All selections were made indirectly from old material imported prior to the outbreak of phylloxera in the latter half of the 1800s. Essentially they are derived from selections gathered from regional vineyards, and subjected to some degree of assessment, primarily for yield, components of yield, basic juice composition and freedom from virus with very little focus on wine quality. The Shiraz clones in the trials are summarised in Table 9.

Table 9 . Shiraz clones included in the study.
Additional details are included in Appendix 1

Clonal designation	Comments
BVRC 12	Selection from clonal trial planted on Nuriootpa Research Centre with clones sourced from Barossa Valley vineyards.
BVRC 30	Selection from clonal trial planted on Nuriootpa Research Centre with clones sourced from Barossa Valley vineyards
1654	Selected from a 1940's planting on the Nuriootpa Research Centre, AS702271, AV702271
SARDI 4	Selected from clonal trial planted on Nuriootpa Research Centre, SARDI 4 sourced from an old vineyard in the Moppa subregion
SARDI 7	Selected from clonal trial planted on Nuriootpa Research Centre, SARDI 7 sourced from an old vineyard in the Koonunga subregion.
PT 15	Selected in the Murrumbidgee Irrigation Area from a pruning trial (PT) on vines sourced from local growers. Also known as NSW15, AN610019, and AS750019
PT 23	Selected in the Murrumbidgee Irrigation Area from a pruning trial (PT) on vines sourced from local growers. Also known as NSW23, and AN610020
R6W	Selected from an old planting at Chateau Tahbilk, Nagambie, Victoria. Usually known as R6V28W or R6WV28, for brevity reported here as R6W.
WA	Origins unknown, Shiraz has been recorded in WA as early as 1891
Bests	Indirectly from an 1868 planting of Shiraz at Bests, Great Western, Victoria.

Details of the direct source of the material for the Shiraz plantings in the study are provided in Table 10.

Table 10. Source of Shiraz clones at each trial site

	Region			
Clone	Barossa Valley	Grampians	Margaret River	Riverland
BVRC 12	SARDI, Nuriootpa	SHC Irymple	WAVIA	SARDI, Nuriootpa
BVRC 30	SARDI, Nuriootpa	SHC Irymple	-	SARDI, Nuriootpa
1654	SARDI, Nuriootpa	SHC Irymple	WAVIA	SARDI, Nuriootpa
SARDI 4	SARDI, Nuriootpa	-	-	SARDI, Nuriootpa
SARDI 7	SARDI, Nuriootpa	-	-	SARDI, Nuriootpa
PT 15	SARDI, Nuriootpa	SHC Irymple	WAVIA	
PT 23		SHC Irymple	-	SARDI, Nuriootpa
R6W	SARDI, Nuriootpa	SHC Irymple	-	SARDI, Nuriootpa
WA	-	-	Cape Mentelle	-
Bests	-	Grower	-	-

6.3 Harvest and wine making protocols

Harvest measurements

At the commencement of the project a set of protocols were determined for grape and vine measurements during the season. Some were modified to fit with the management practices of participating vineyards as the project progressed. Prior to harvest regular monitoring of grape total soluble solids (TSS, sugar) concentrations were undertaken by project staff and/or the vineyard managers. The target TSS concentrations were 22.5 Brix (12.5 Baume) for Chardonnay and 24.3 Brix (13.5 Baume) for Shiraz. These levels were not always achieved because the hand harvesting of fruit for the project had to work in with the harvesting (often mechanical) of the vineyard blocks.

Bunch samples were collected just prior to or at harvest to assess bunch compactness from the second season onwards. Various estimations of bunch compactness were undertaken by Tello and Ibanez (2014) and one in particular was suggested for a relatively quick and simple estimator. The bunch weight divided by the length squared was used in the second season of the project (2014-15). The results did not always reflect a visual ranking of compactness but a relationship incorporating bunch width (bunch weight/((length + width)/2)^2) provided much better correlations with the visual ranking of compactness. The latter equation was used for the subsequent seasons 2015-16 and 2016-17. A sample size of 15 bunches per clone provided an adequate sample size (after Dunn and Martin 1998).

Within each clone, a sub-sample of vines were labelled for monitoring. This varied between regions and ranged from 6 to 20 vines per clone. After each season variability between vines was checked and sample size adjusted to achieve adequate sample size to achieve a percentage error of 15% or better at P=0.05 (Dunn and Martin 1998).

At harvest, berry samples (50 per vine) were collected for mean berry weight and then frozen for subsequent measurement of juice total soluble solids, titratable acidity and pH. The juice measurements were either undertaken by project staff in the region or samples were analysed by the Australian Wine Research Institute (AWRI).

During harvest, bunches were counted and the yield per vine determined. Components of yield such as mean bunch weight and mean berry number per bunch were derived from the measured variables. The sub-sample of monitor vines often did not provide enough fruit for the 100kg required for winemaking. In such cases buffer vines between the monitor vines as well as vines in adjacent rows were harvested to make up the required amount for winemaking.

The harvested fruit and berry samples were either directly dispatched to the processing facility for small scale winemaking after harvest (in SA and WA) or (in Victoria) held in a cool room at 4°C until dispatch under plant biosecurity protocols to the Wine Innovation Cluster (WIC) winemaking facility, Waite Campus, Adelaide.

Other measurements

As previously described dataloggers were placed in the canopy zone in the trial plots in each region. Seasonal temperature data was collected from September to April. Where data was missing, for example when loggers were removed from the trial plots prior to mechanical harvesting, the missing data was estimated from the relationship between daily mean temperatures of the recorded logger data and the nearest appropriate Bureau of Meteorology weather station.

Various other measurements were determined through the season. The mean dates of the phenological stages bud burst, 80% flowering, 50% veraison and harvest maturity were collected

either by frequent observation or by weekly assessments and interpolation of the appropriate date. Canopy surface area and volume were determined by measurement of canopy height and width. Canopy density and associated measurements were determined using the VitiCanopy app (Fuentes et al. 2012) for the seasons 2013-14 to 2015-16. In 2015-16 point quadrat measurements were undertaken (Smart and Robinson 1991).

Pruning weights and associated measurements were collected each season. The weights were of the one year old wood removed during pruning and with cane pruning, the weight of canes retained as replacement canes was estimated by deriving a relationship between cane length and cane weight from a sub-sample of canes from each clone. In some cases shoot numbers and node numbers post-pruning were counted. Other variables such as mean cane weight, mean shoot number per retained node, mean bunch number per shoot and yield to pruning weight ratio were derived from these measurements.

Winemaking

Lots of 100 kg of fruit from each clone were harvested for subsequent wine making. Grapes were either transported to the crushing facility immediately after harvest, or stored in a cool room overnight (for the trials in Victoria), before transport to the winery. The grapes from SA and Victoria were processed at the Wine Innovation Cluster (WIC) Winemaking Facility, Waite Campus, Adelaide, and the grapes in WA were crushed, fermented and stabilised in a DAFWA winemaking laboratory at Bunbury before transport to the WIC winery for finishing and bottling. Where possible duplicate ferments of 50 kg each followed the same prescribed winemaking process in vessels of matching material and volumes. Winemaking protocols were designed to minimise human intervention in the finished wines (Figure 1 & Figure 2). All wines were finished off and bottled at the WIC winery. The wines were not exposed to any wood prior to bottling.

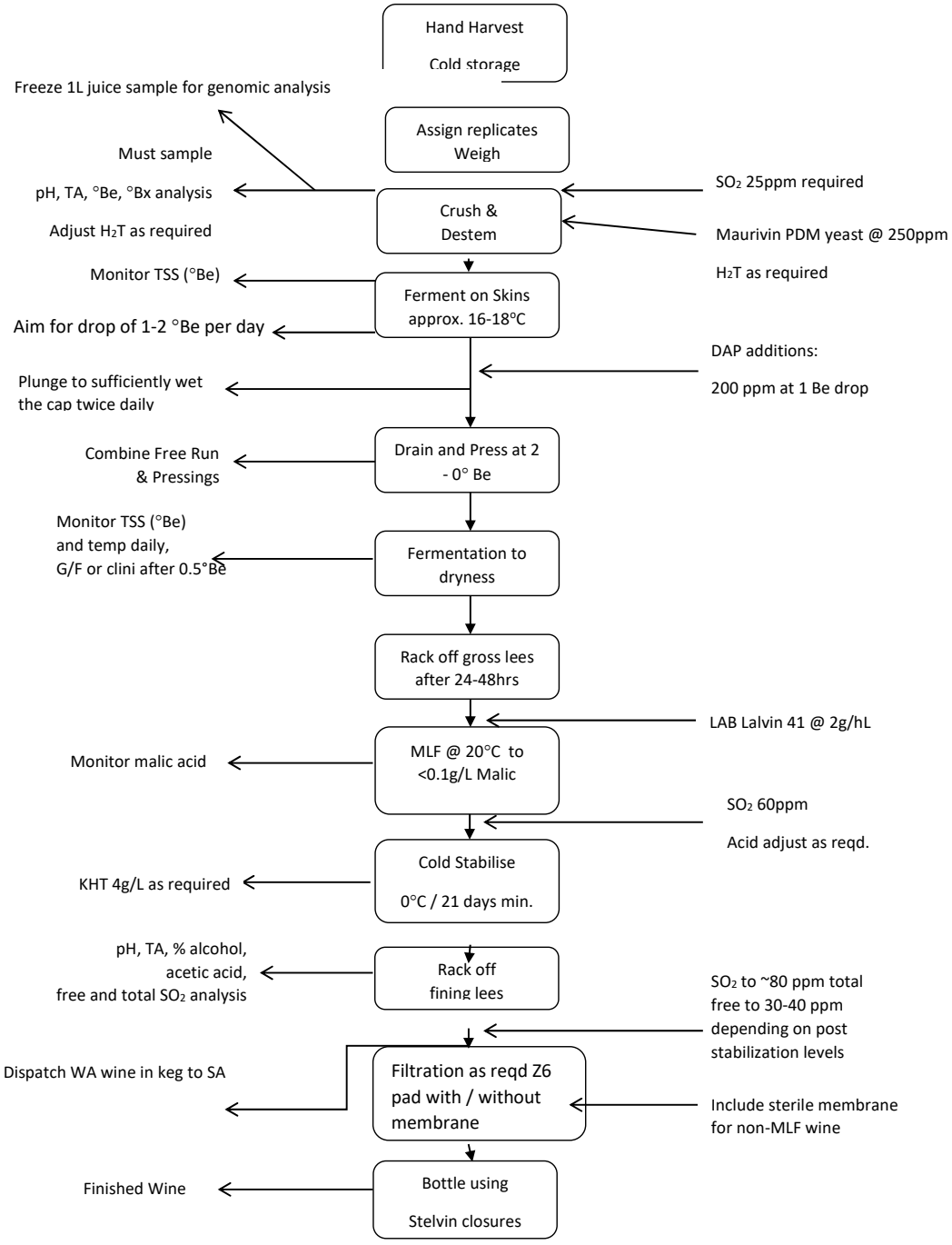


Figure 1. Schematic of Shiraz wine making protocols

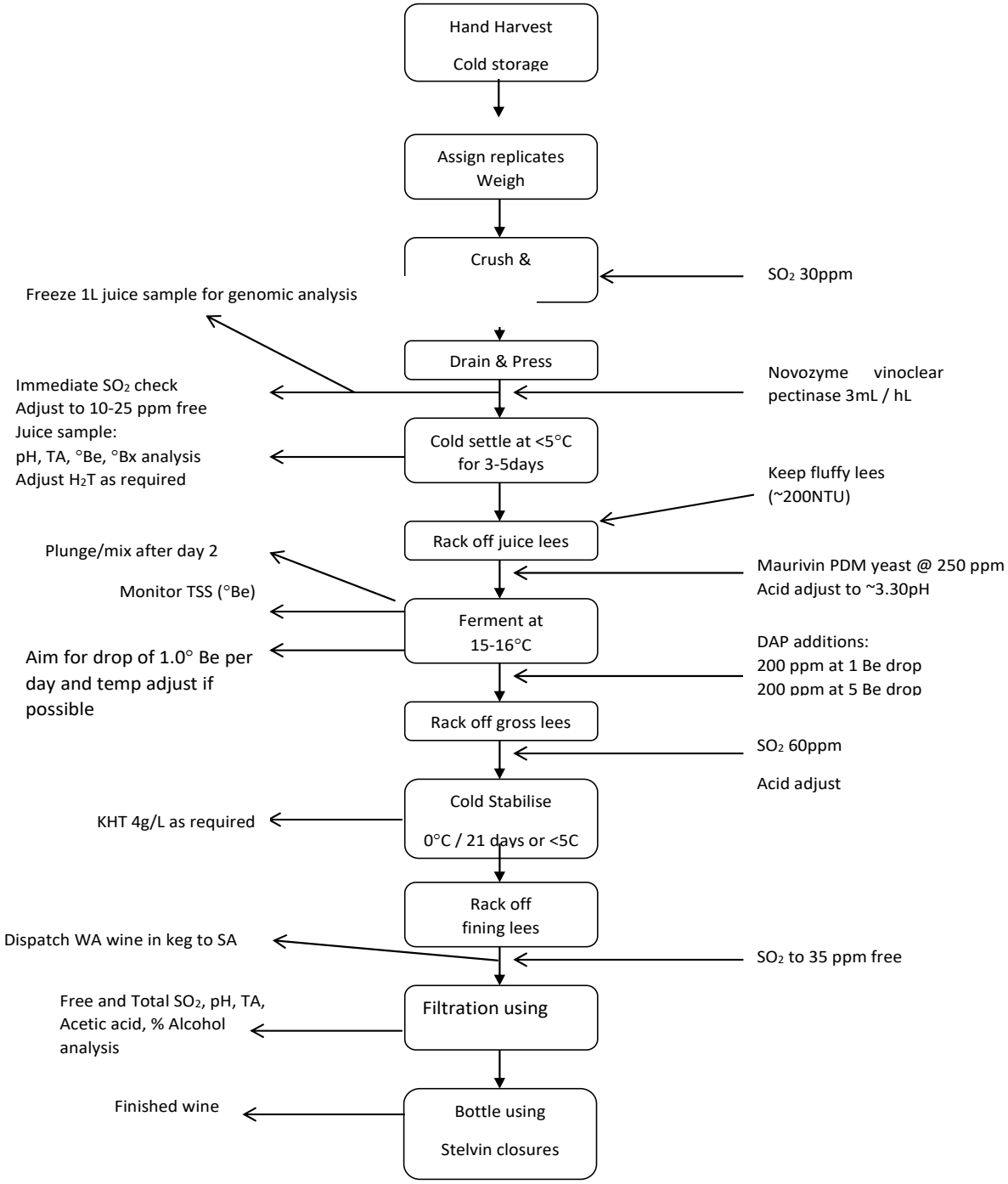


Figure 2. Schematic of Chardonnay wine making protocols

6.4 Wine sensory analysis

In each year wines were made in duplicate (except in several cases when there was insufficient fruit for duplicate ferments) and stored for a minimum of two months under bottle at 15 ^{0}C until sensory descriptive analysis was conducted. Wines were initially bench-top assessed by the sensory team and several experienced AWRI staff and the wines deemed suitable continued to sensory analysis. Both winemaking replicates were assessed with duplicate presentation.

Training and wine attributes

A panel of nine assessors (predominately female), all of whom are part of the AWRI trained descriptive analysis panel, was convened for each sensory assessment.

Assessors attended three training sessions to determine appropriate descriptors for rating in the formal sessions. During these sessions the assessors evaluated wines from the study which represented the full range of sensory properties. These wines were used by the assessors to generate and refine appropriate descriptive attributes and definitions through a consensus-based approach. Wines were initially assessed by appearance, aroma and palate. In sessions two and three, standards for aroma attributes were presented and discussed and these standards were also available during the booth practice session and the formal assessment sessions.

Following the three training sessions, tasters participated in a practice session in the sensory booths under the same conditions as those for the formal sessions. After the practice session, any terms which needed adjustment were discussed and the final list of terms determined. For the formal sessions this list was refined to include one Appearance term, fifteen Aroma terms (fourteen defined and “Other”) and fourteen Palate terms (thirteen defined and “Other”). These attributes, definitions/synonyms and standards provided are shown in Table 11 for Chardonnay and Table 12 for Shiraz including only those attributes which were included in the final attributes list.

Table 11: Attributes, definitions and reference standards evaluated by panellists in formal sessions for Chardonnay wines.

For brevity some attributes, definitions and reference standards may be not be reported.

Attribute	Definition/Synonyms	Standard
Appearance		
Yellow colour intensity	yellow colour.	
Aroma		
Overall fruit intensity aroma	the fruit aromas in the sample.	
Passionfruit	the aroma of passionfruit	1 tsp passionfruit pulp (John West)
Pineapple	the aroma of pineapple.	4 x 2 cm cubes fresh pineapple and 1 tsp tinned Pineapple juice (Golden Circle),
Stonefruit	the aroma of stonefruits: peach, apricot both fresh and dried.	1 T Goulburn Valley canned apricots and peaches
Citrus	the aroma of citrus fruits: lemon, lime, grapefruit and orange.	1 x 2cm pc of Lemon and Lemon rind
Confection	the aroma of confection: red lolly, banana lolly, musk, bubblegum.	1 x Red lolly and 1 x Musk lolly
Floral	the aroma of flowers: violets and blossoms.	80 µL of 100 mg/L Linalool, 10 µL of 200 mg/L 2-phenyl ethanol
Green	the aroma of green grass, green leaves, stalks, green capsicum and cucumber.	Freshly picked grass 20 pieces, no wine
Vegetal	the aroma of various vegetables: cooked vegetables such as asparagus and green beans, water vegetables have been cooked in, drain.	1T Edgells brand tinned mixed vegetables juice
Box Hedge	the aroma of box hedge	Fresh box hedge leaves, no wine
Herbal	the aroma of herbs: mint, eucalyptus, tea leaves, fennel, parsley, ginger.	Fresh mint leaves, dried mixed herbs
Flint	the aroma of flint, wet stones, metals, toast.	20 µL of 1 mg/L Benzyl Mercaptan
Sweaty/Cheesy	the aroma of sweat, cheese, blue cheese, cheddar cheese, body odour, sour milk, raw meat.	100 µL Mix of hexanoic acid and isovaleric acid
Pungent	the aroma and effect of alcohol.	4ml Ethanol
Palate		
Overall fruit flavour intensity	fruit flavours in the sample.	
Tropical Fruit Flavour	the flavour of tropical fruits: pineapple, passionfruit, melon, mango, guava, lychee, paw paw, kiwifruit.	
Stonefruit Flavour	the flavour of stonefruits: peach, apricot.	
Citrus Flavour	the flavour of citrus fruits: lemon, lime, orange, grapefruit.	
Green Flavour	the flavour of green stalks, green leaves, grass and green vegetables, celery.	
Spritz	The perception of the tingling, bubbling, frothing experience in the mouth.	
Sweet	the taste of sucrose.	
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.	
Acid	acid taste in the mouth including aftertaste.	
Hotness	The alcohol hotness perceived in the mouth, after expectoration and the associated burning sensation. Low = warm; High = hot.	
Astringency	The drying and mouth-puckering sensation in the mouth. Low=coating teeth; Medium=mouth coating and drying; High=puckering, lasting astringency.	
Bitter	The bitter taste perceived in the mouth, or after expectoration.	
Fruit AT	The lingering fruit flavour perceived in the mouth after expectorating.	

Table 12. Attributes, definitions and reference standards evaluated by panellists in formal sessions for Shiraz wines.

For brevity some attributes, definitions and reference standards may not be reported.

Attribute	Definition/Synonyms	Standard
Opacity	The degree to which light is not allowed to pass through a sample, colour intensity	
Purple	Intensity of the purple colour in the sample	
Brown	The degree of brown tinge in the sample	
Overall Fruit	Intensity of the fruit aromas in the sample	
Red fruits	Intensity of the aroma of red fruits and berries: raspberries, strawberries, cranberries, redcurrants	3 x frozen Raspberries, Sara Lee brand
Dark Fruit	Intensity of the aroma of dark fruits and berries: blackberries, plums, black currants, black cherries, blueberries	3 x frozen blueberries, 1 x frozen blackberry, Sara Lee brand
Dried Fruit	Intensity of the aroma of dried fruits; dried cranberries, raisins	3 Woolworths select Aussie Sultanas, 4 Ocean Spray Craisins
Cooked Fruit	Intensity of the aroma of cooked fruit, dried fruit, fruit jam	I tsp plum jam, heated for 20 seconds in a microwave, then cooled
Confection	Intensity of the aroma of confection: raspberry lollies, musk lollies	3 x Raspberry lollies, Natural Confectionary Company brand
Floral	Intensity of the aroma of flowers: violets, roses, talc	40 µL of 100mg/L Linalool, 25 µL of 200mg/L 2-phenyl ethanol
Fresh Green	Intensity of the aroma of green stalks, grass and leaves	1 tomato stalk
Green	Intensity of the aroma of green stalks, leaves, green capsicum, geranium	2 cm piece tomato stalk and 1 cm x 1cm cut up fresh snow pea, no wine
Mint	Intensity of the aroma of mint, other fresh herbs	1 fresh mint leaf, crushed, no wine
Tomato/HP Sauce	Intensity of the aroma of tomato and HP sauce	½ tsp HP Sauce, ¼ tsp tomato sauce
Vanilla	Intensity of the aroma of vanilla	1/8 tsp vanilla paste, Queen brand
Sweet Spice	Intensity of the aromas of various sweet spices: cinnamon, cloves, mixed spice, aniseed.	1/8 tsp: mixed spice, nutmeg, cinnamon and 1 dried clove
Pepper	Intensity of the aroma of black and white pepper	Black pepper, ground, 20 mg
Chocolate	Intensity of the aroma of chocolate	1 square Lindt dark chocolate 70%
Meaty	Intensity of the aroma of meat, stock, roasted meat	½ tsp beef stock, Kraft brand
Woody	Intensity of the aroma of wood, wood shavings	1 tsp French oak wood shavings
Earthy	Intensity of the aroma of earth, organic matter, dust, beetroot.	30µL of 4 mg/L Geosmin
Chemical/Plastic	Intensity of the aroma of plastic, chemicals	30 µL of 1 mg/L 2,6 dichlorophenol
Vegetal	Intensity of the aroma of cooked vegetables, drains, cooked asparagus	1/8 tsp tinned mixed vegetables, Edgell brand
Boiled egg	Intensity of the aroma of boiled egg, cooked veg, drains	1/8 tsp ash
Pungent	Intensity of the aroma and effect of alcohol	4ml Ethanol
Barnyard	Intensity of the aroma of a barnyard, cow pat	40 µL of 10.06 mg/L p-cresol, 40 µL of 5.11 g/L 4-methyl phenol
Overall fruit intensity	Intensity of fruit flavours in the sample	
Red fruits	Intensity of the flavour of red fruits and berries: raspberries, strawberries, cherries, cranberries	
Dark Fruits	Intensity of the flavour of various dark fruits: blackberries, currants, plums	
Sweet	Intensity of the taste of sucrose.	
Green	Intensity of the flavour of green stalks, green capsicum, green bean, herbs, rhubarb.	
Salt	Intensity of the taste of salt.	
Chocolate	Intensity of the flavour of chocolate, vanilla	
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.	
Acid	Intensity of acid taste in the mouth including aftertaste	
Hotness	The intensity of alcohol hotness perceived in the mouth, after expectoration and the associated burning sensation. Low = warm; High = hot, burning.	
Astringency	The drying and mouth-puckering sensation in the mouth. Low=coating teeth; Medium=mouth coating and drying; High=puckering, lasting astringency.	
Bitter	The intensity of bitter taste perceived in the mouth, or after expectoration.	
Fruit AT	The lingering fruit flavour perceived in the mouth after expectorating.	

Sensory analysis

Samples were presented to panellists in 30 mL aliquots in 3-digit-coded, covered, ISO standard wine glasses at 22–24 °C, in isolated booths under daytime lighting, with randomised presentation order, except in the practice sessions where there was a constant presentation order. All samples were expectorated. The assessors were required to have a 45 second rest between samples and a ten minute rest between trays. During the ten minute break assessors were requested to leave the booths.

Wines were presented to assessors twice in a modified Williams Latin Square incomplete random block design generated by Fizz sensory acquisition software (version 2.47B, Biosystemes, Couternon, France). Wines were split into blocks of three wines with a final block comprising one or two remaining wines. Panellists assessed five blocks per session. Formal assessment took place over a number of sessions.

The intensity of each attribute was rated using an unstructured 15 cm line scale from 0 to 10, with indented anchor points of 'low' and 'high' placed at 10% and 90% respectively. Data was acquired using Fizz sensory software.

Panel performance was assessed using Fizz and PanelCheck (Matforsk) software, and included analysis of variance for the effect of judge and presentation replicate and their interactions, degree of agreement with the panel mean and degree of discrimination across samples. All judges were found to be performing to an acceptable standard.

Statistical analysis

Analysis of variance (ANOVA) was carried out using Minitab (Minitab Inc., Sydney, NSW). The effects of wine (W), judge (J), presentation replicate (R), ferment replicate (F), presentation replicate nested within Ferment Replicate and Wine, Judge by Wine, and judge by ferment replicate nested in wine were assessed. In addition, separate ANOVAs for the effects of region, judge and replicate were assessed for the clones common to all regions. Following ANOVA, Fisher's least significant difference (LSD) value was calculated (P=0.05). Principal component analysis (PCA) was conducted on the mean values of the significant ($p<0.05$) and nearly significant ($p<0.1$) attributes averaged over panellists and replicates, using the correlation matrix. PCA was also conducted on the mean values of the significant ($p<0.05$) and nearly significant ($p<0.1$) attributes averaged for all clones over regions. The mean values for PCA plots were also used for statistical analysis (Statistix™) and to prepare radar plots of clones in each region. PCA plots were prepared using XLStat™, and radar plots were prepared using SigmaPlot™.

7 Results and Discussion

7.1 Phenology

Budburst, flowering, veraison and harvest dates for the Chardonnay sites are presented in Table 13 and Shiraz sites in Table 14 and in graphical form in Figure 3 and Figure 4. While 23.5 °Brix was the target harvest date for Chardonnay this was not always possible due to the need to harvest fruit prior to the commercial mechanical harvest of each block hence the harvest dates indicated below may be slightly earlier than commercially desired.

Table 13. Budburst, flowering, veraison and harvest dates for the four seasons at the Chardonnay sites

Site	**Season**			
Drumborg	**2013-14**	**2014-15**	**2015-16**	**2016-17**
Budburst	2/09/2013	31/08/2014	31/08/2015	2/09/2016
Flowering	28/11/2013	19/11/2014	13/11/2015	22/11/2016
Veraison	28/01/2014	30/01/2015	28/01/2016	20/2/2017
Harvest	15/03/2014	3/03/2015	22/02/2016	25/03/2017
Grampians				
Budburst	21/09/2013	8/09/2014	14/09/2015	19/09/2016
Flowering	8/12/2013	11/11/2014	12/11/2015	5/12/2016
Veraison	10/02/2014	25/01/2015	25/01/2016	25/2/2017
Harvest	11/03/2014	16/02/2015	12/02/2016	27/03/2017
Great Southern				
Budburst	5/9/2013	19/08/2014	31/08/2015	7/09/2016
Flowering	27/11/2013	6/11/2014	10/11/2015	7/12/2016
Veraison	6/02/2014	2/02/2015	30/01/2016	6/02/2017
Harvest	5/03/2014	24/02/2015	9/03/2016	31/03/2017
Margaret River				
Budburst	2/09/2013	17/08/2014	25/08/2015	28/08/2016
Flowering	9/11/2013	28/10/2014	29/10/2015	23/11/2016
Veraison	16/01/2014	6/01/2015	6/01/2016	24/01/2017
Harvest	16/02/2014	5/02/2015	13/02/2016	5/03/2017
Riverland				
Budburst	26/08/2013	5/09/2014	11/09/2015	12/09/2016
Flowering	6/10/2013	16/10/2014	16/10/2015	31/10/2016
Veraison	13/12/2013	23/12/2014	23/12/2015	10/01/2017
Harvest	4/02/2014	3/02/2015	2/02/2016	27/02/2017

The number of days between each of the four phenological stages and the total number of days between budburst and harvest were calculated and are presented in Figure 5 and Figure 6 using the date of each phenological event listed in Table 13 and Table 14.

The project intended to choose sites that covered a range of climates ranging from hot to cool, and continental to maritime was validated in the range of phenology dates recorded across the eight sites for the seasons data was recorded. The influence of the maritime climate during winter and

spring is reflected in the early Chardonnay budburst in Margaret River, being earlier than the warm continental climate of the Riverland. However the hot, continental climate in the Riverland resulted in that site having the earliest Chardonnay harvest date in each season across the five sites. In contrast the cooler climate of the Shiraz Grampians site resulted in the latest budburst date for all three seasons and the latest harvest date for two of the three seasons.

Table 14. Budburst, flowering, veraison and harvest dates for three seasons at the Shiraz sites

Site	**Season**		
Barossa	**2013/14**	**2014/15**	**2015/16**
Budburst	3/09/2013	12/09/2014	11/09/2015
Flowering	9/11/2013	2/11/2014	3/11/2015
Veraison	17/01/2014	12/01/2015	16/01/2016
Harvest	14/03/2014	18/02/2015	19/02/2016
Grampians			
Budburst	30/09/2013	24/09/2014	19/09/2015
Flowering	10/12/2013	23/11/2014	16/11/2015
Veraison	20/02/2014	9/02/2015	23/01/2016
Harvest	8/04/2014	23/03/2015	20/02/2016
Margaret River			
Budburst	6/09/2013	8/09/2014	9/09/2015
Flowering	16/11/2013	14/11/2014	10/11/2015
Veraison	29/01/2014	23/01/2015	21/01/2016
Harvest	6/03/2014	12/03/2015	8/03/2016
Riverland			
Budburst	10/09/2013	19/09/2014	9/09/2015
Flowering	25/10/2013	26/10/2014	22/10/2015
Veraison	13/01/2014	3/01/2015	4/01/2016
Harvest	13/03/2014	12/02/2015	15/02/2016

Whilst there were seasonal impacts on budburst date there was also an influence of vineyard location. Chardonnay vines at Drumborg exhibited the smallest variation in budburst date over three days and Margaret River Shiraz over four days, both being maritime sites. In contrast there was a difference of 11 days between the earliest and latest budburst date at the Grampians Shiraz site and 19 days for the Great Southern Chardonnay.

The Great Southern site also recorded the longest growing season of all the Chardonnay sites of 205 days in the 2016-17 season, albeit only one day longer than for Drumborg in the same season. In contrast the Riverland Chardonnay recorded the shortest growing season of 144 days in 2015-16. The shorter growing length in the Riverland was primarily the result of a shorter interval between budburst and flowering with a mean of 42 days across the four seasons, compared to between 70 and 81 days for the other sites. A similar pattern was evident for Shiraz also with a mean of 42 days between budburst and flowering in the Riverland compared with 57 to 67 days at the other sites. This is discussed further in section 7.2.

The decision to harvest the Shiraz sites at lower ^{o}Brix than commercial practise (to minimise small lot winemaking issues) is reflected in the often shorter number of days between budburst and harvest compared with Chardonnay. The shortest Shiraz season was 146 days in the Riverland (2014-15) and

the longest of 192 days for the Barossa and 190 at the Grampians site in 2013-14 and although less, do align with the timing of commercial practise of a progression of harvest dates beginning with the Riverland followed by the Barossa, Grampians and Margaret River.

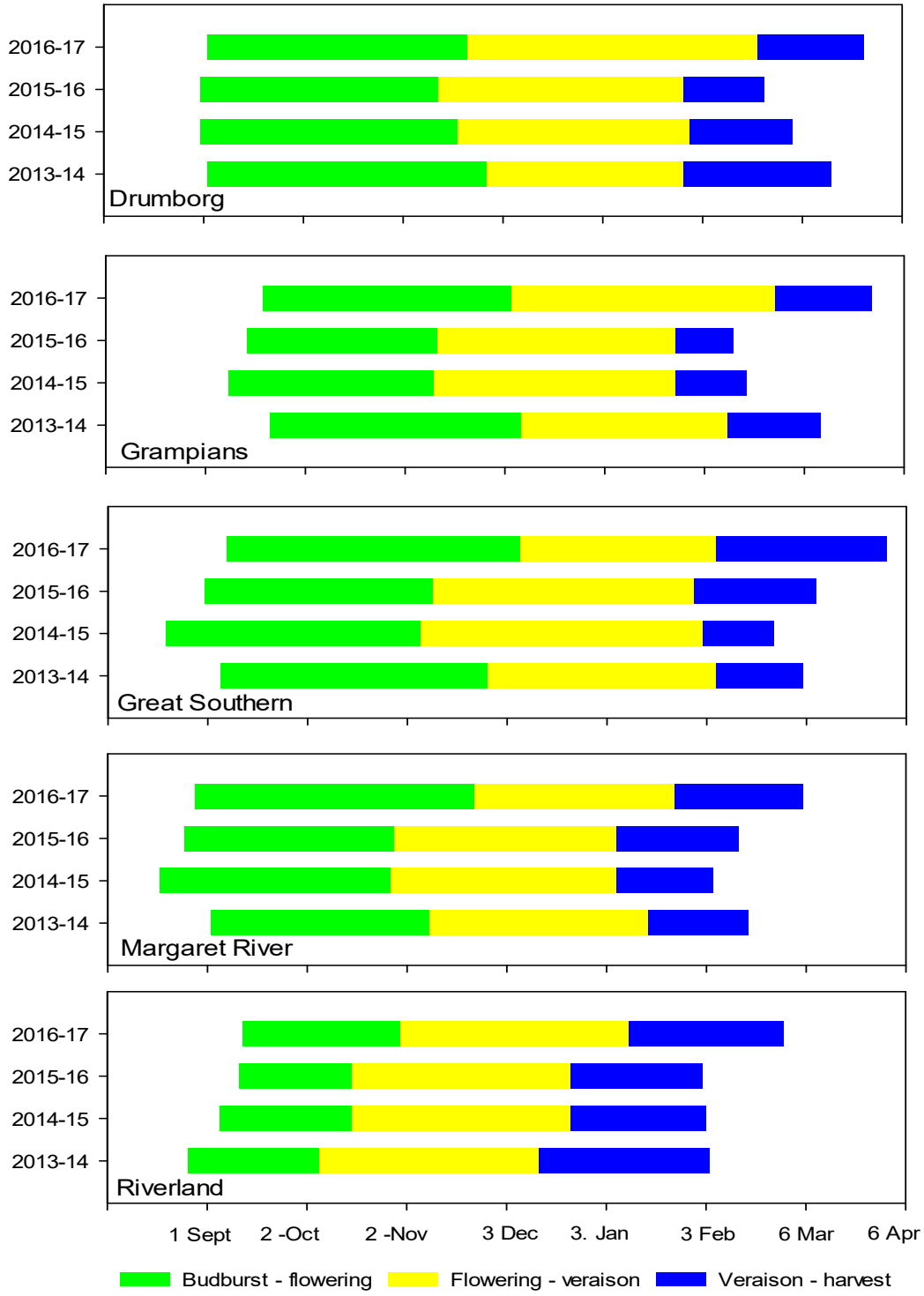


Figure 3 Dates of key phenological events between budburst and harvest for each of the Chardonnay sites for the four seasons

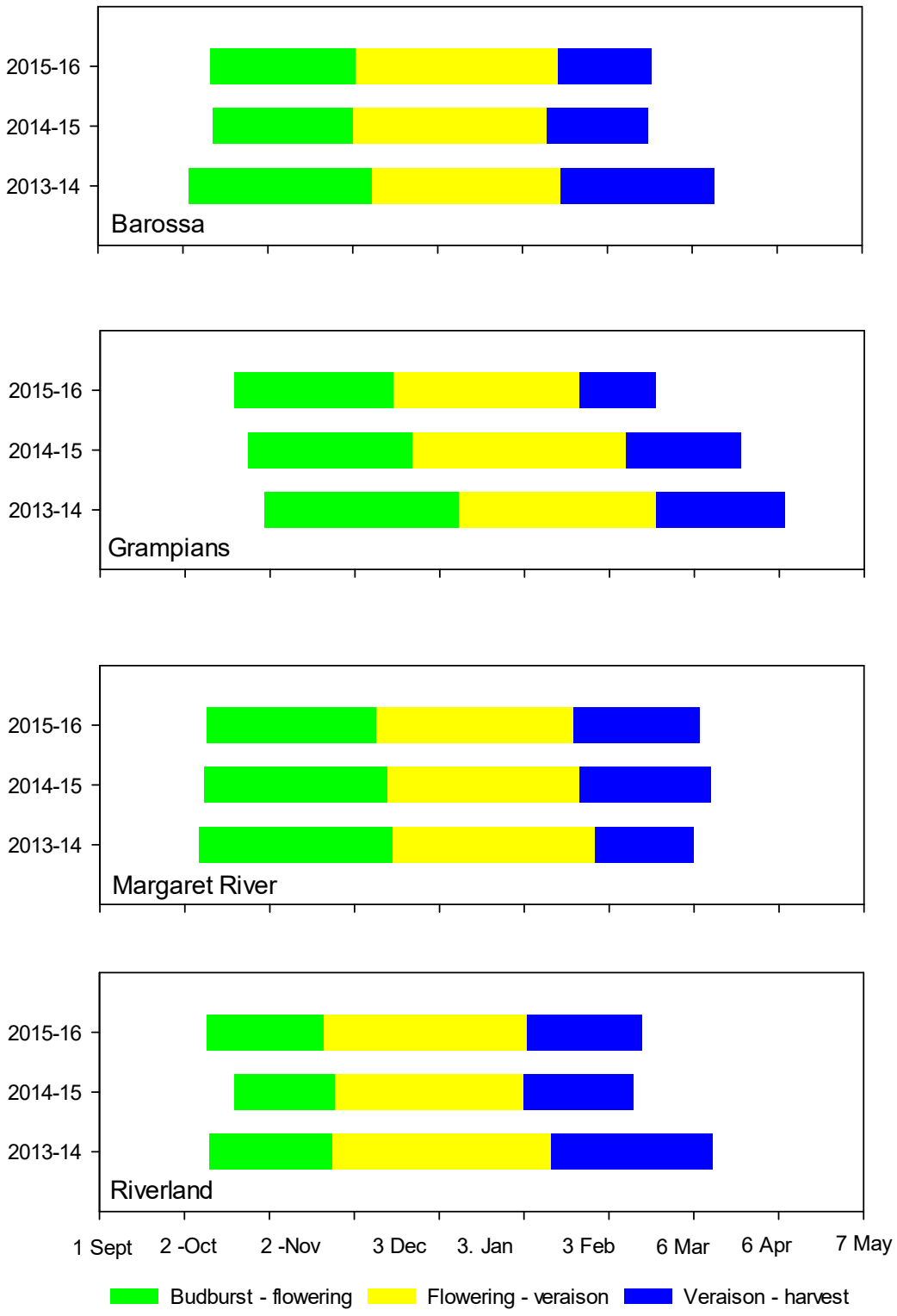


Figure 4. Dates of key phenological events between budburst and harvest for each of the Shiraz sites for the three seasons

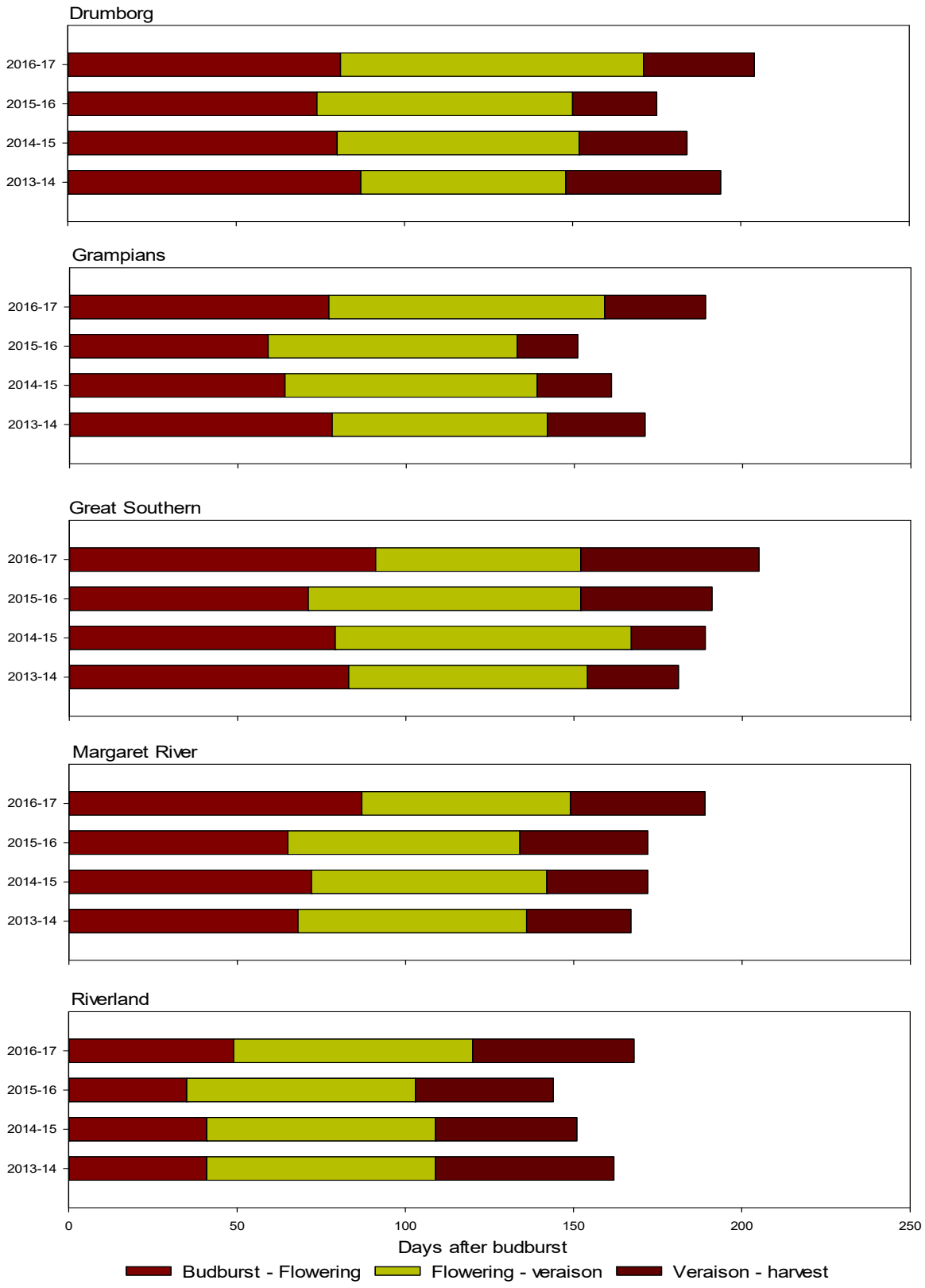


Figure 5.Number of days between each of the four key phenological stages and total number of days between budburst and harvest for each of the Chardonnay sites for the four seasons.

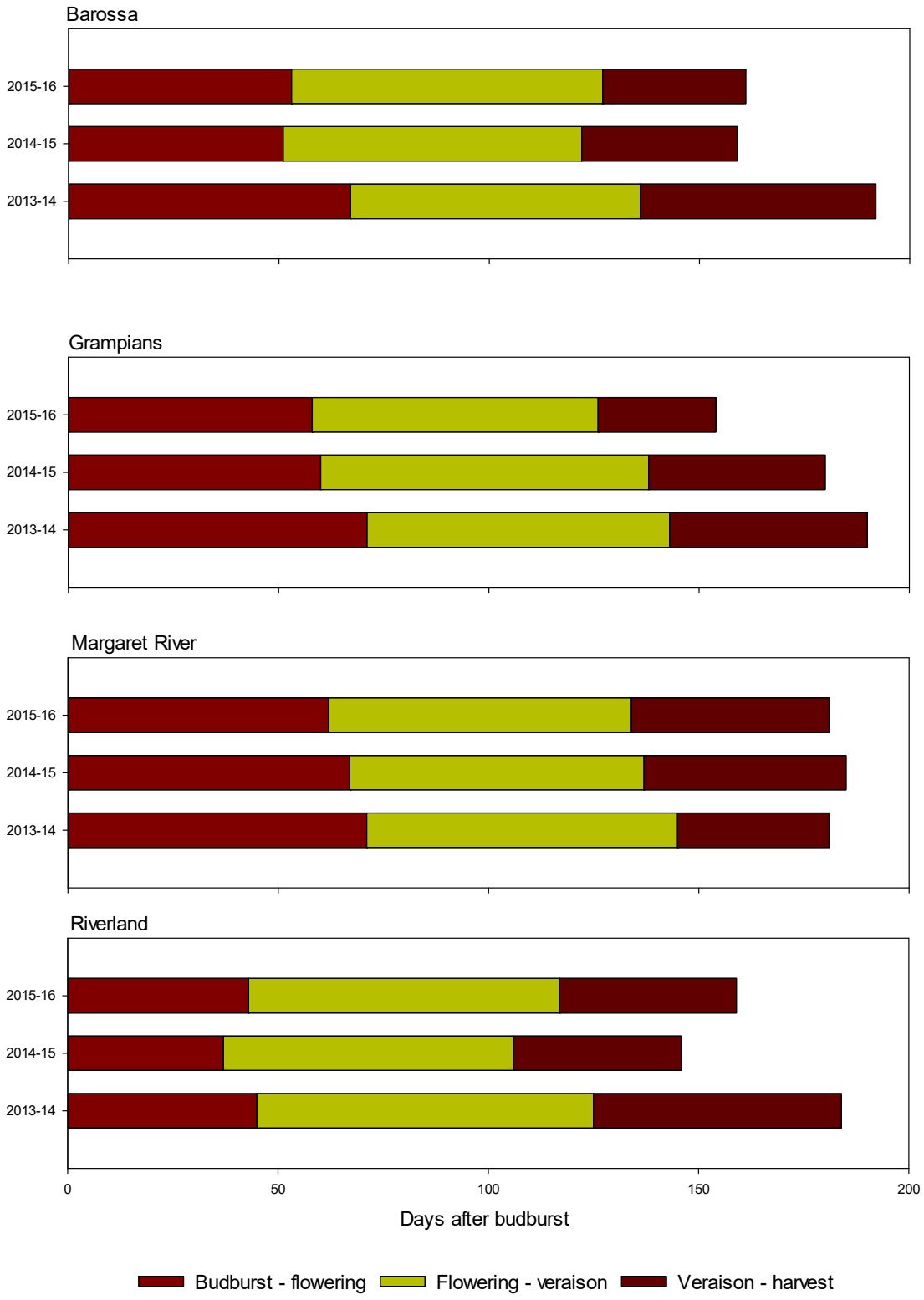


Figure 6. Number of days between each of the four key phenological stages and total number of days between budburst and harvest for each of the Shiraz sites for the three seasons

7.2 Climate Descriptors

Temperature data recorded by the TinyTag™ data loggers was used to calculate Growing Degree Days (GDD) and Raw Biologically Effective Day Degrees (BEDD) (Gladstones 1992) for the periods October to April.

Jones and Hall (2010) calculated GDD and BEDD for Australia GI regions using a 30 year data set from 1971 to 2000 and also adjusted BEDD for latitude. Data from selected project sites are presented in Table 15 as the mean of three years 2013-14 to 2015-16 (Shiraz) or four years 2013-14 to 2016-17 (Chardonnay) with no adjustment for latitude in the BEDD data. The Hall and Jones (2009 and 2010) data is used to compare with our trial site data because it is more recent than the data provided in Gladstones (1992). Both sets of data use daily temperature data.

Table 15. GDD and BEDD for the relevant GI region and for selected project sites

GI name	GDD		BEDD	
	Hall and Jones (2010) median	Project site[1]	Hall and Jones (2009) median	Project site[1]
Barossa Valley	1852	2064	1597	1554
Grampians	1408	1639	1361	1350
Great Southern	1705	1723	1548	1434
Henty (Drumborg)	1354	1451	1312	1294
Margaret River)	1887	1751	1692	1518
Riverland	2305	2260	1787	1655

[1] Barossa Valley Shiraz site, Chardonnay sites for all other data.

For GDD the project sites ranged from -7% to +16% difference and BEDD from -1% to -10% difference from those of Hall and Jones (2009, 2010). This is not unexpected due to the difference in the number of years used in each study. There were some periods of higher-than-average temperatures experienced over the three/four seasons reported here. Site-specific data collected from data loggers is in the proximity of vine canopies as opposed to interpolated data from the Bureau of Meteorology network of weather stations, which are normally located in grassed areas away from vineyards.

To account for the large variation in harvest dates between the diverse sites (Table 13 and Table 14) GDD & BEDD were calculated for the period between budburst and harvest at each site and for each of the periods between budburst, flowering, veraison and harvest.

The Riverland Chardonnay site consistently recorded the largest GDD for the period budburst to harvest over the four seasons and Drumborg the least GDD (Figure 75). GDD in the 2014-15 season was lower than most other seasons at each of the sites except Great Southern while the largest GDD differed between seasons for each site, for example in 2016-17 for the Riverland and Grampians, in 2013-14 at Drumborg, and in 2015-16 for Margaret River and Great Southern.

There was also considerable variation in the GDD between similar phenological intervals across the sites (Figure 75). In 2014-15 budburst to flowering GDD in the Riverland was 211 units compared with 498 in the Great Southern in 2016-17. For the period between flowering and veraison, the GDD range was 504 in Margaret River in 2016-17 to 807 in the Grampians in 2016-17. For the period

veraison to harvest the range was (758) units in the Riverland in 2013-14 to (157) units in the Grampians in 2014-15.

The low number of days when the average daily average temperature was above 19^{o}C in Drumborg, and conversely, the considerable number of days at the Riverland Chardonnay site above 19^{o}C, is reflected in the plots of Raw BEDD presented in Figure 8. For the Riverland and Barossa, the difference between the mean GDD & BEDD for the four seasons was 605 and 510 units, respectively, whereas for Drumborg the difference was 157. The sites in the Margaret River, Great Southern and Grampians were intermediate with differences between GDD and BEDD of 233, 289 and 289 units respectively. While BEDD removed any daily heat spikes there was still considerable variation between sites in accumulated BEDD heat units for the same phenological interval. The Riverland Chardonnay site required an average of 217 units for vines to develop from budburst to flowering, while in the Margaret River Chardonnay site the same interval for the same variety required 354 units.

A similar pattern was evident for GDD and BEDD for the Shiraz sites.

The Riverland site recorded the largest GDD in all three seasons however the conditions in the Barossa in 2015-16 resulted in greater GDD than in the cooler Riverland 2014-15 season. Thus a hot season in the Barossa Valley can be equivalent to the Riverland in some seasons. The Margaret River site was similar to the Barossa while the Grampians site recorded the least GDD between budburst and harvest in each of the three seasons. GDD was lowest in 2014-15 for three of the four sites and across all sites the highest GDDs were in 2015-16 for the Barossa and Riverland, and in 2013-14 for the Grampians and Margaret River sites.

The Shiraz sites exhibited a similar variability to Chardonnay in the GDD accumulated between each phenological stages (Figure 9).

Discounting days when the daily average temperature was above 19 ^{o}C reduced the Raw BEDD between budburst and harvest at the Riverland Shiraz site (Figure 10) in a similar manner as for the Riverland Chardonnay site. BEDD was also reduced at the Barossa site by 412, 336 and 512 units for each of the three seasons (respectively 2013-14, 2014-15 and 2015-16) again highlighting that the Barossa does experience periods of high temperatures. The small difference between GDD and BEDD is evidence of the influence of the Indian and Southern Oceans on the maritime environment of Margaret River in minimizing the occurrence of heatwaves.

McCarthy (1997), in reporting a study on Shiraz in the Riverland suggested that GDD (base 10^{o}C) based models were not able to accurately predict key phenological stages due to large variation between four consecutive seasons; models based on BEDD did not reduce this variability. While heat summation indices may be suitable for broadly classifying grape growing regions they do not account for other climate features such as the impact of, for example, damaging frosts which delay development, and as reported by Nicholas et al (2007), and the stalling of ripening after extreme heat events.

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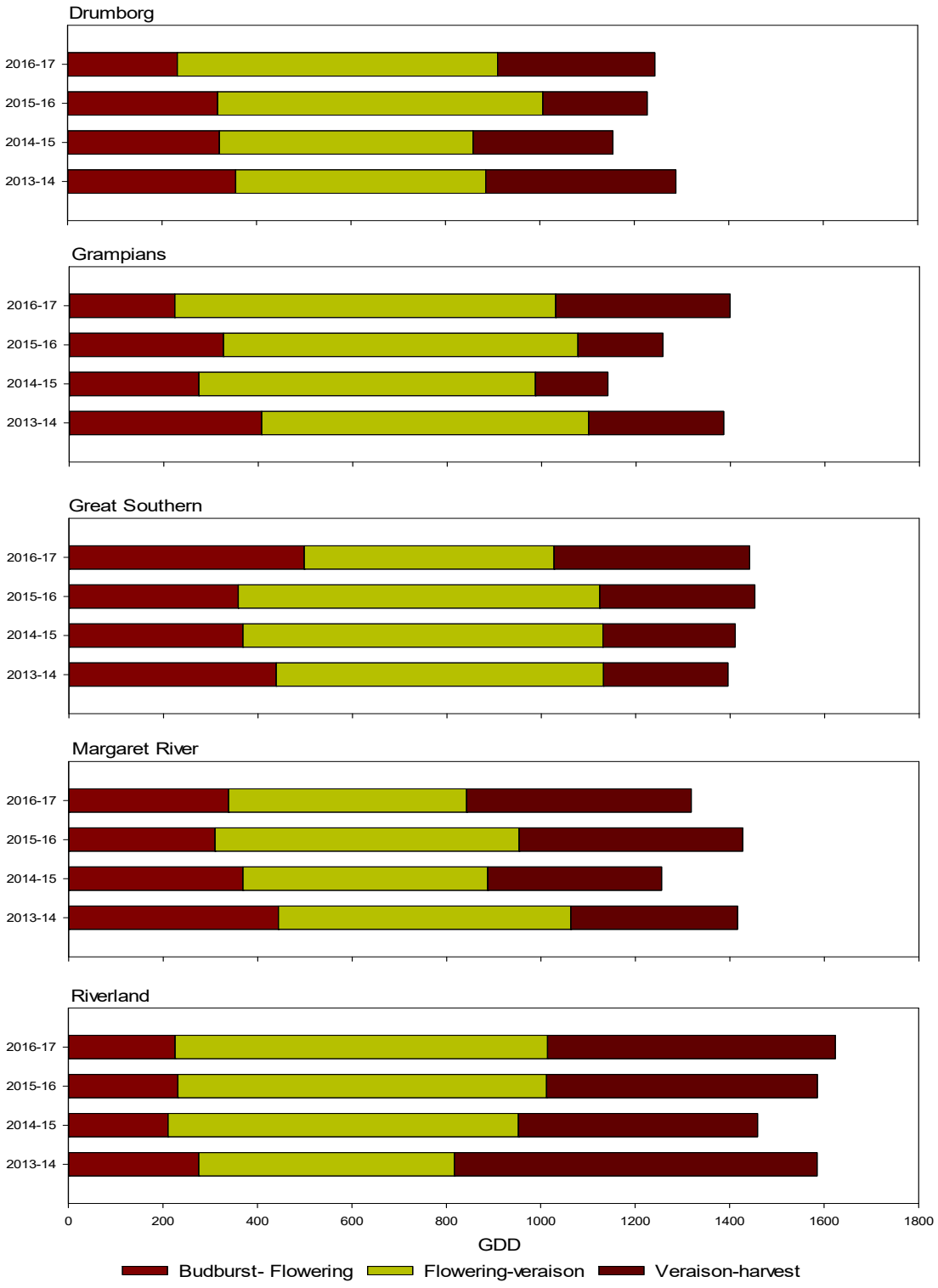


Figure 7. Growing Degree Days (GDD) between each of the four key phenological stages and total GDD s between budburst and harvest for each of the Chardonnay sites for the four seasons.



Figure 8. Biologically Effective Growing Degree Days (BEDD) between each of the four key phenological stages and total BEDD between budburst and harvest for each of the Chardonnay sites for the four seasons.

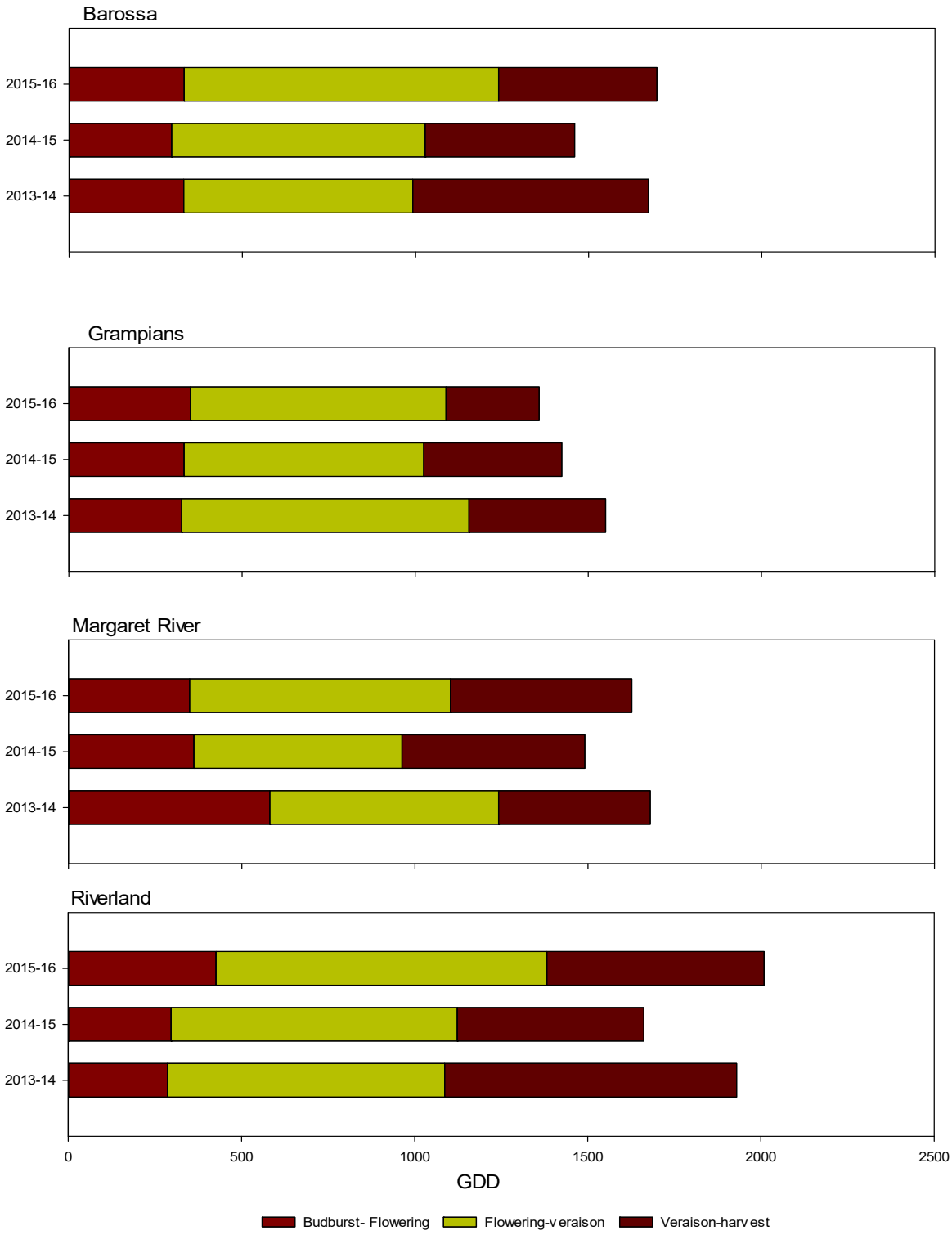


Figure 9. Growing Degree Days (GDD) between each of the four key phenological stages and total GDD between budburst and harvest for each of the Shiraz sites for the three seasons

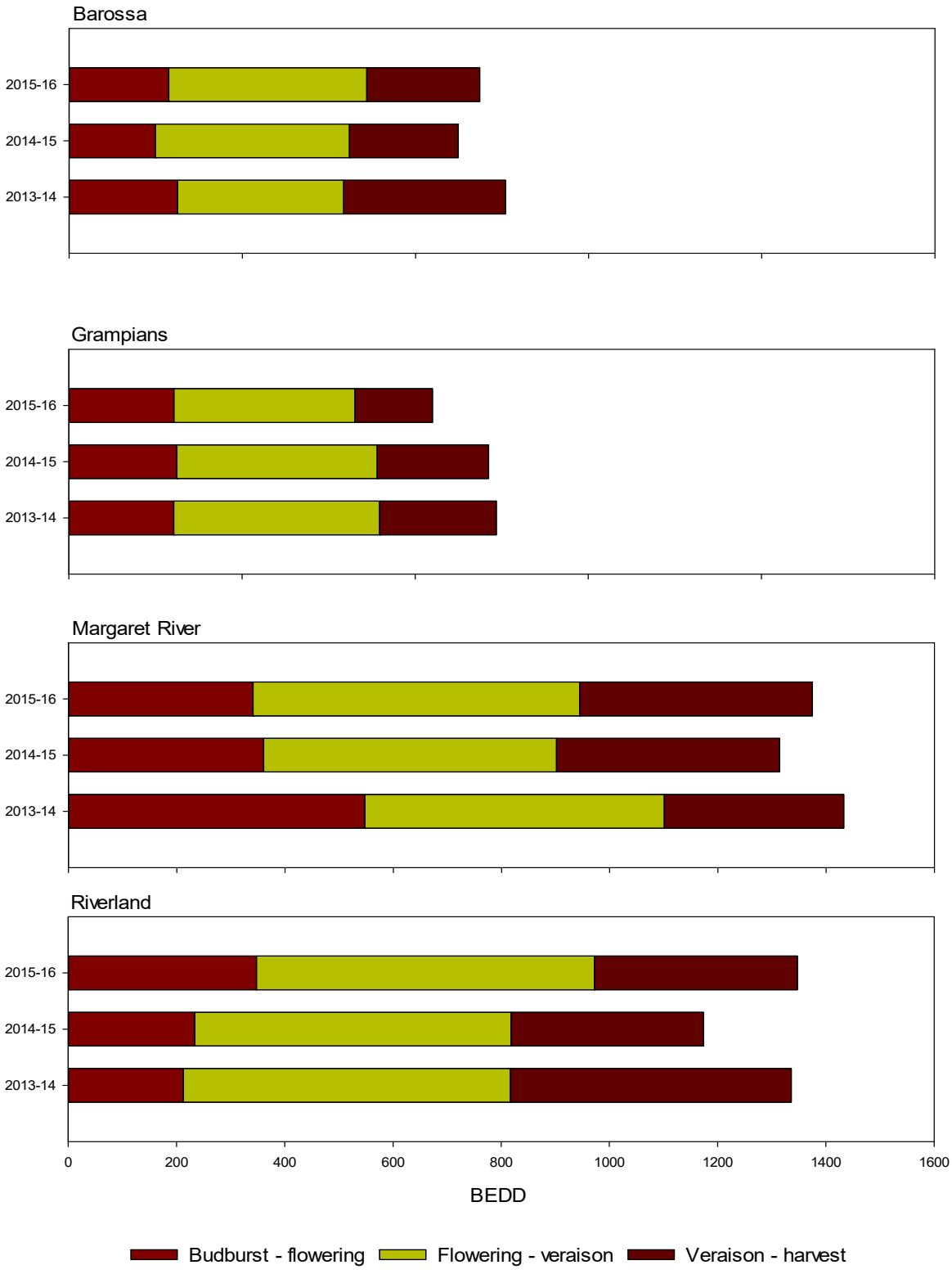


Figure 10. Biologically Effective Growing Degree Days (BEDD) between each of the four key phenological stages and total BEDD between budburst and harvest for each of the Shiraz sites for the three seasons.

7.3 Future harvest date projections

Current daily heat summations using GDD and calendar days between budburst and harvest were used to calculate the mean daily heat summation between budburst and the earliest and latest harvest dates for the Chardonnay (four seasons) and Shiraz (three seasons) sites where data was available. To estimate future harvest dates an increase 0.5, 1.0, 1.5 and 2 ^{o}C in the daily GDD was calculated and this data set was used with no adjustment in budburst date.

For Chardonnay there was an advancement in harvest date of between 9 and 50 days depending on the magnitude of the increase in daily temperature (Figure 11). At Drumborg and Margaret River (maritime sites) an increase of 1 ^{o}C would result in the current earliest harvest date being approximately the latest projected date. In the Riverland this would occur with a 1.5 ^{o}C increase in average daily temperature while at the Grampians site a 2 ^{o}C increase would be required, however, this future range in harvest dates is broad due to the wide range in harvest dates experienced between the 2014 and 2017 harvests at the latter site. Vintage compression is also apparent at the Drumborg, Grampians and Riverland sites, and, while less obvious for Margaret River, Figure 11 indicates Margaret River may have the earliest advancement in projected harvest date compared with the other three regions.

A similar pattern is apparent for Shiraz (Figure 12) with an advancement in harvest date of between 8 and 39 days. For Margaret River the current small difference of only six days in harvest date over the three seasons resulted in a distinct differentiation of future harvest date range, and an increasingly narrow window of this range suggests a larger data set with greater diversity is required. For the Barossa site a 1 ^{o}C warming could result in the current earliest harvest date becoming approximately the latest and with some vintage compression, and for the Riverland an increase of approximately 1.5 ^{o}C resulted in a similar outcome. However, for the Grampians site, there is overlap for all temperature increase scenarios as a result of the existing wide range in harvest dates. Figure 12 also suggests a vintage compression with warming conditions.

In previous work, Petrie and Sadras (2009) reported that the rate of change in time of a designated maturity per unit change in November temperature was -9.3 ± 2.67 days per ^{o}C. For the pooled data for all sites, and for the period budburst to harvest presented here only a 0.5 ^{o}C increase in temperature was required to advance maturity by approximately the same number of days (Shiraz – 9 days, Chardonnay - 11 days). However, this difference is not unexpected; Petrie and Sadras used one month whereas in the study presented here the daily temperature was increased each day for between 122 and 189 days. When the daily temperature was increased by 1 ^{o}C the advancement in harvest date was 17 days for Shiraz and 20 days for Chardonnay and for the next 1 ^{o}C increase the advancement was an additional 14 and 16 days for Shiraz and Chardonnay respectively. Notwithstanding the differences in the two data sets both highlight the considerable impact of warmer temperatures on harvest advancement and as noted by Petrie and Sadras (2009) has substantial implications for crop management and winemaking.

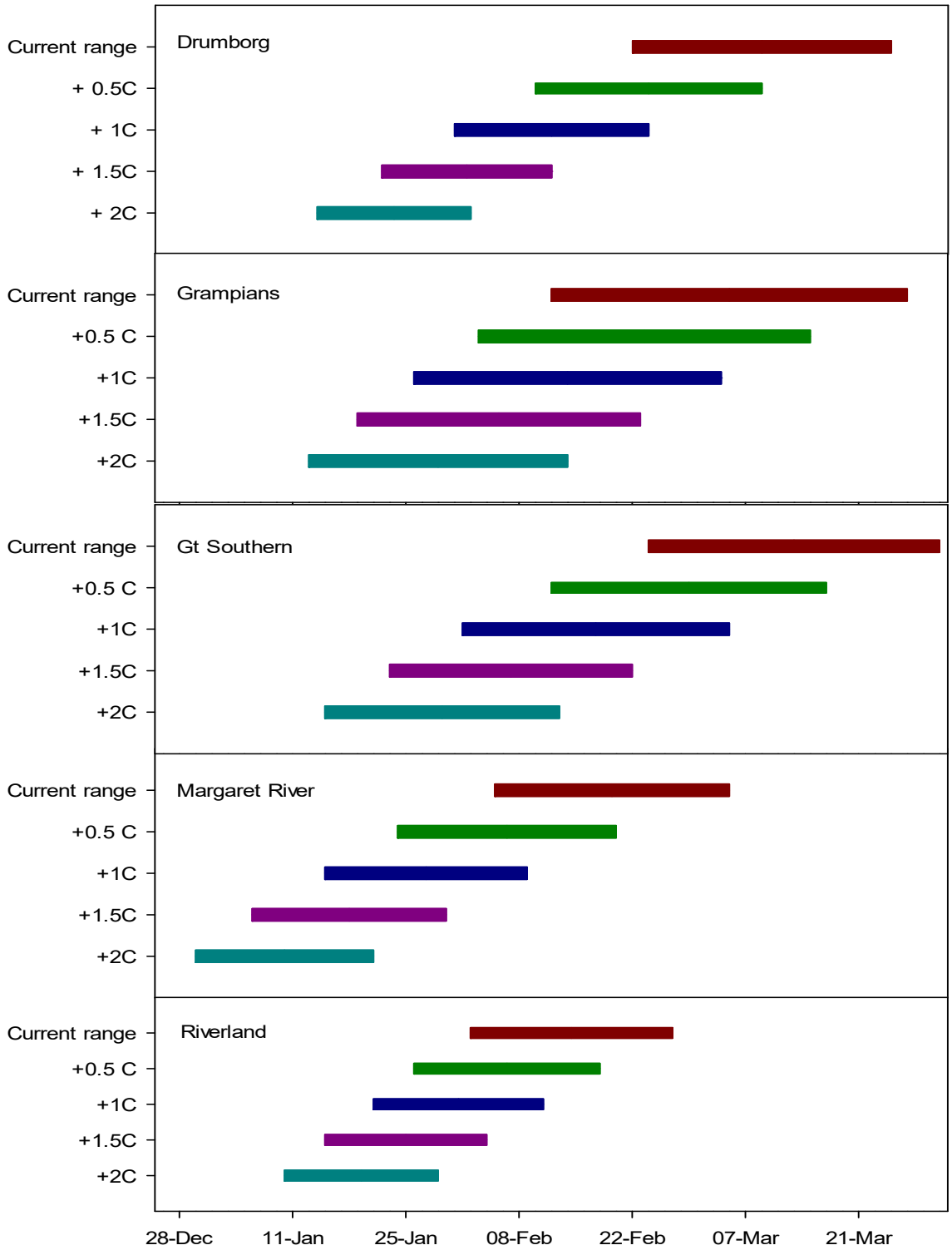


Figure 11 Harvest date range for an increase in the daily average temperature of between 0.5 and 2 ^{o}C for four Chardonnay sites based on the range in harvest dates for the 2014 to 2017 seasons.

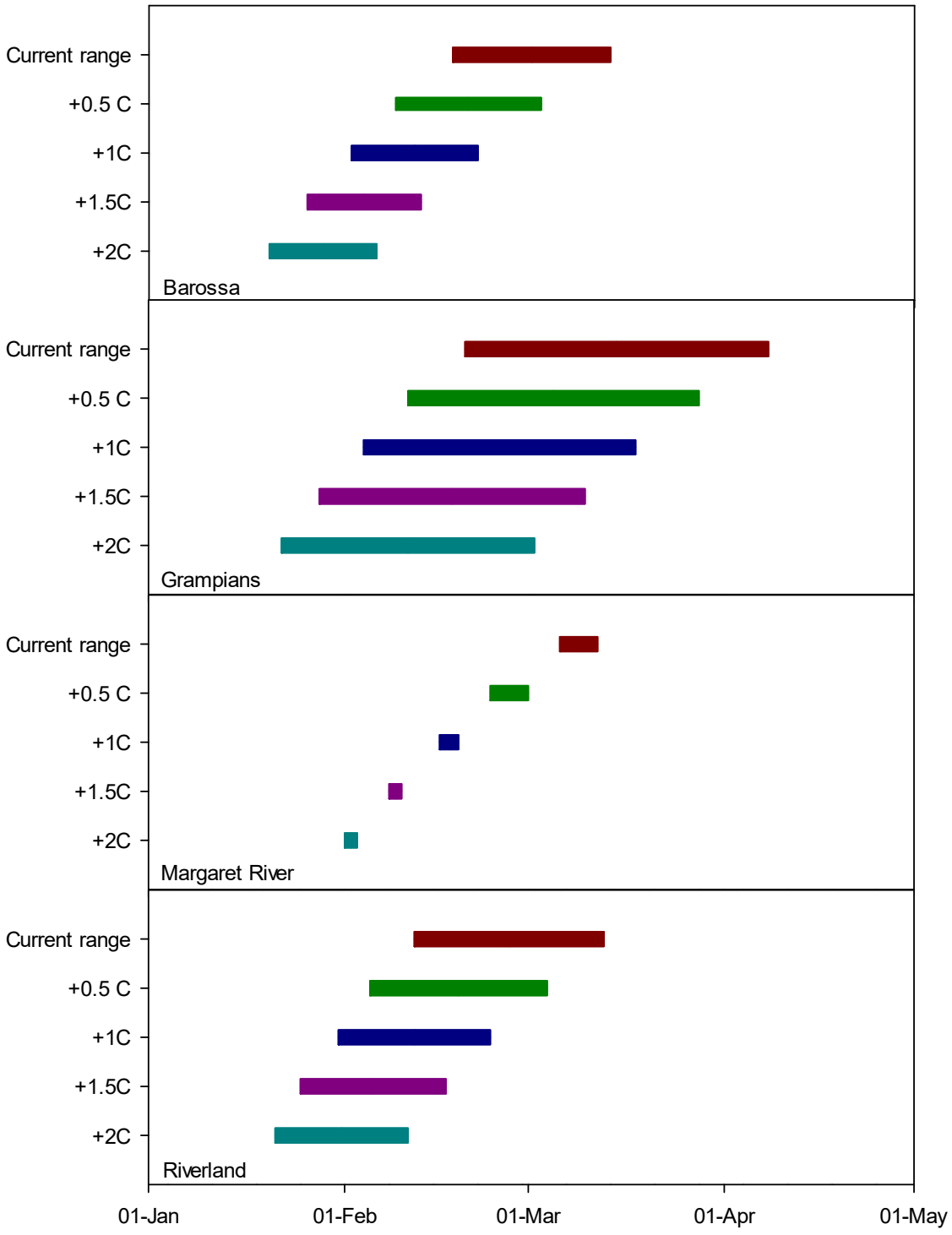


Figure 12. Harvest date range for an increase in the daily average temperature of between 0.5 and 2 ^{o}C for the four Shiraz sites based on the range in harvest dates for the 2014 to 2016 seasons.

7.4 Canopy aspects

Some measurements of canopy size and density were conducted to determine if there were differences between clones within regions and between seasons that may have impinged on the sensory results and also to quantify differences between the diverse regions. Differences in canopy measures between sites were expected due to different pruning methods (spur vs cane pruning) and for some sites a change in pruning method and level, for example changing from cane to spur or increasing the number of canes retained at pruning. The results are presented as the mean and standard deviation where this was possible with the data sets collected.

7.4.1 Chardonnay

Canopy volume

The largest differences in canopy volume were between regions, with the warm-irrigated Riverland vines having canopies of more than twice the volume of the other four regions (Figure 13). There were smaller differences within each region. At the Riverland site, clone 277 grew the smallest canopy volume in 2015-16 with the other three clones being similar, at Drumborg I10V1 clone had by far the highest canopy volume. This clone was grafted to a rootstock and protected by a wind break. At the other extreme the Penfold 58 was in an exposed site away from any wind breaks and had the lowest canopy volume. The five Bernard clones in the same block had consistent canopy volumes. In the Grampians region, I10V5 visually had the largest canopy and this is reflected in its measured volume. Bernard 78 had the lowest volume and included some younger replant vines while in the Great Southern the Gingin clone had the smallest canopy volume and in Margaret River the standard deviation of the Gingin clone suggests that it was of a similar volume to the other four clones.

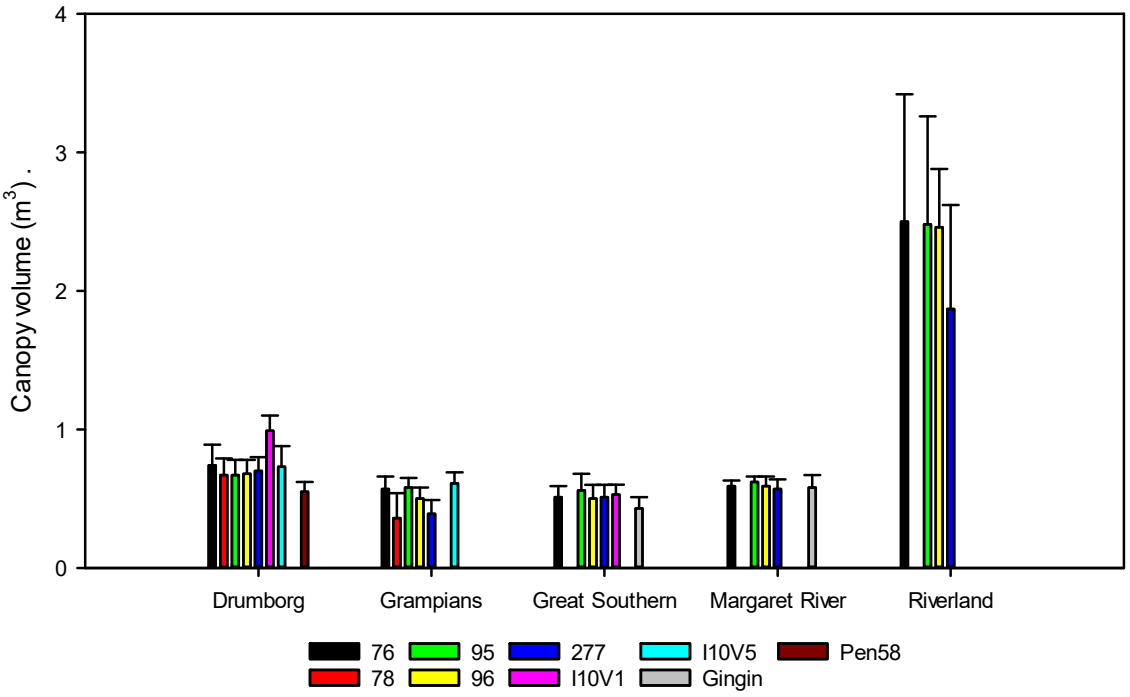


Figure 13. Canopy volume (m^3) of Chardonnay clones at all sites in the 2015-16 seasonVertical bars indicate the standard deviation for each mean value.

Canopy surface area

The canopy surface area (Figure 14) mirrored the results for canopy volume with the Riverland site having the largest surface area and Great Southern the smallest. The differences between clones in each region similarly reflected the differences in canopy volume.

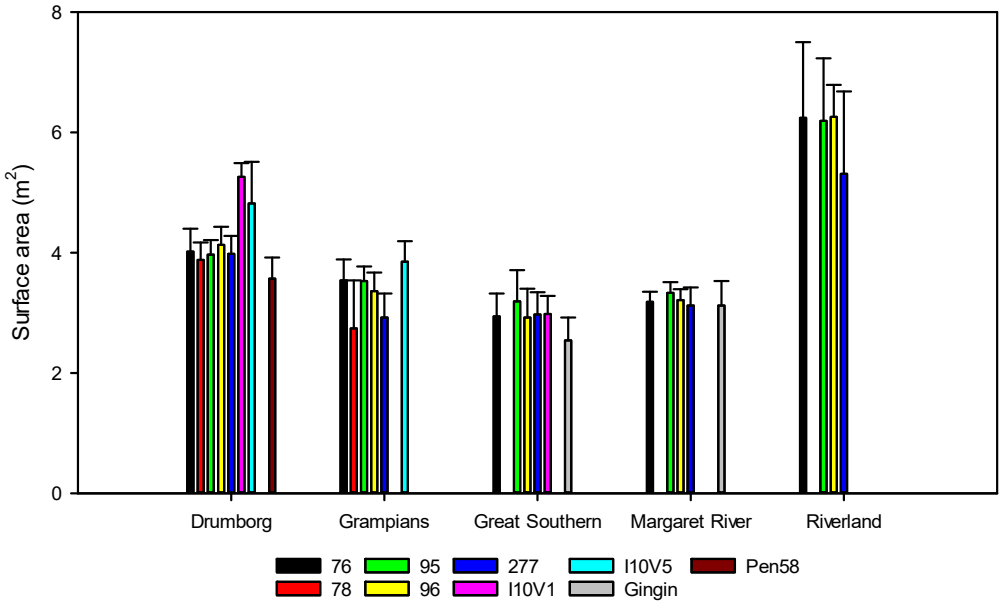


Figure 14. Canopy surface area (m^2) of Chardonnay clones at each site in the 2015-16 season. Vertical bars indicate the standard deviation for each mean value.

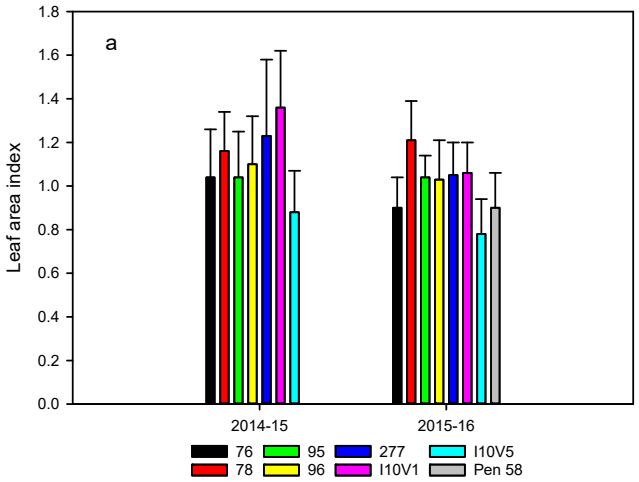
Leaf area index (LAIe)

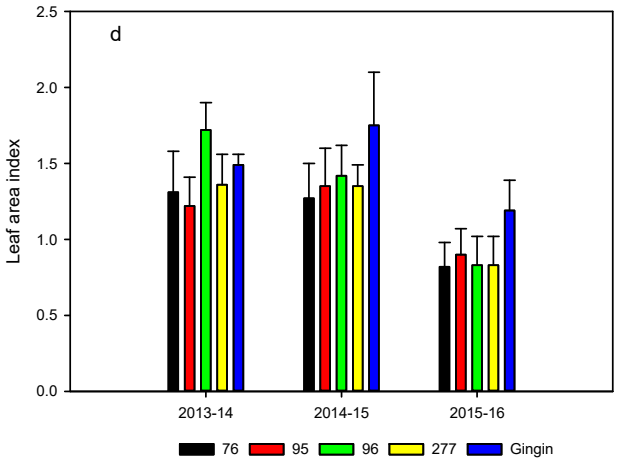
The leaf area index (LAIe) derived from the smartphone app VitiCanopy is an index of the leaf area per unit ground surface area. The higher the value, the more shading on the soil and hence a denser canopy and this is reflected in the larger values for the Riverland site in each of the three seasons LAIe was calculated (Figure 15).

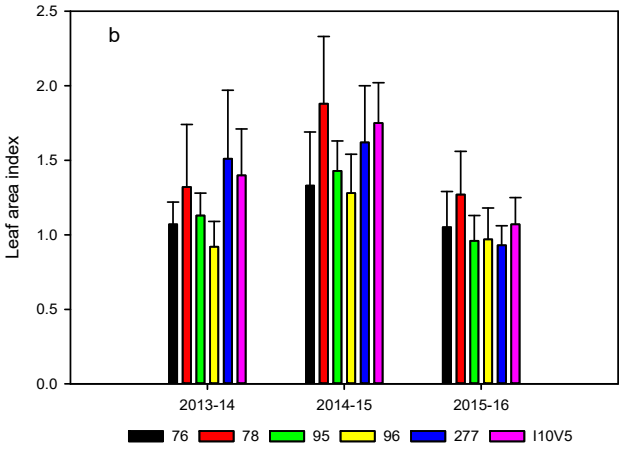
At the Drumborg site I10V1 had the highest and second highest LAIe and I10V5 the lowest LAIe in both seasons. The latter clone was in a conversion phase from spur to cane pruning and optimum cane numbers were still being established. The LAIe values between the two seasons were relatively even, largely due to the consistent canopy size obtained from top and side trimming.

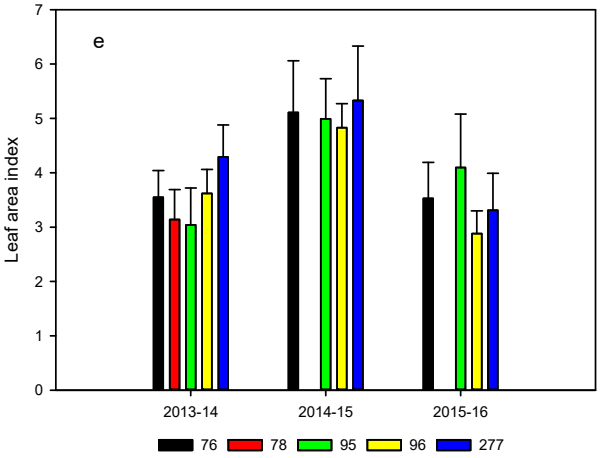
At the Grampians site the LAIe was highest in two of three seasons with the Bernard 78 clone perhaps due to it being an outside row that was more wind affected than other clones (the wind blew the canopy to one side producing a wider canopy). The LAIe was higher in the 2014-15 season and lowest in the 2015-16 season, the latter was the hottest of the three seasons and leaf growth was less. This pattern was repeated at Margaret River and the Great Southern with lower LAIe values in the 2015-16 season compared with the previous two. At both of these sites the Gingin clone tended to have the highest or equal highest LAIe across the seasons i.e. denser canopies with more shaded fruit

There were no consistent differences between the clones at the Riverland site (Figure 15 e), for example 277 grew the densest canopies in year one and two but was less dense than 95 in year three.









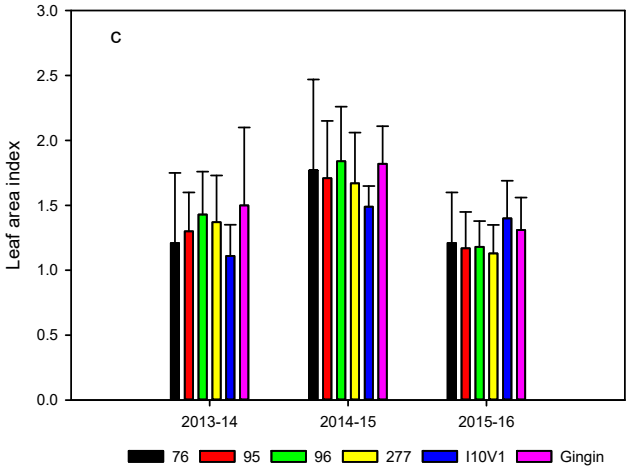


Figure 15.. Leaf area index of Chardonnay clones for sites and years data were collected.

a = Drumborg

b = Grampians

c = Great Southern

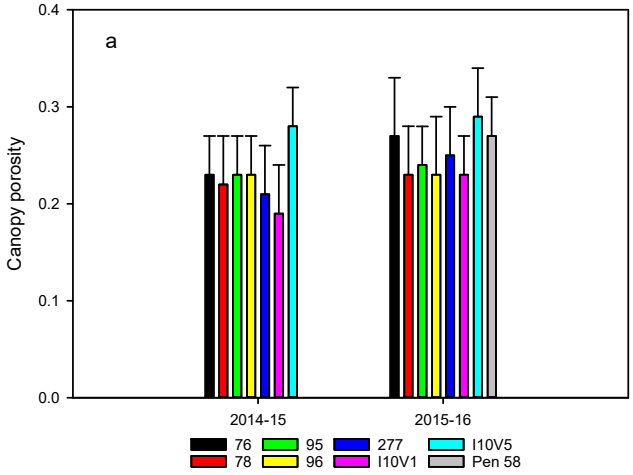
d = Margaret River

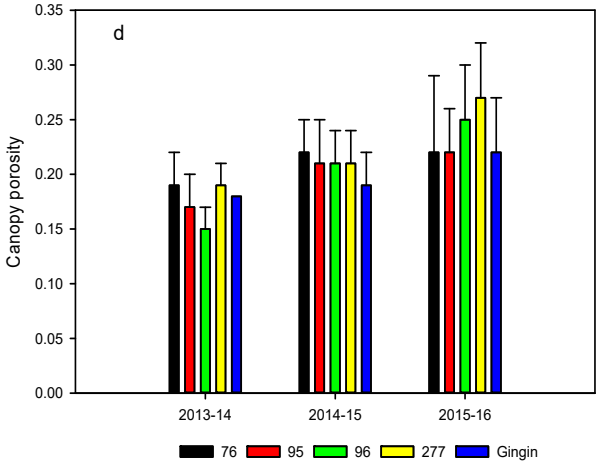
e = Riverland

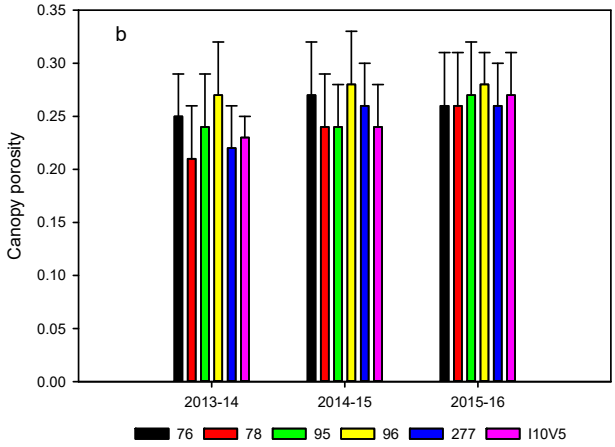
Vertical bars represent the standard deviation for each mean value where it was calculated.

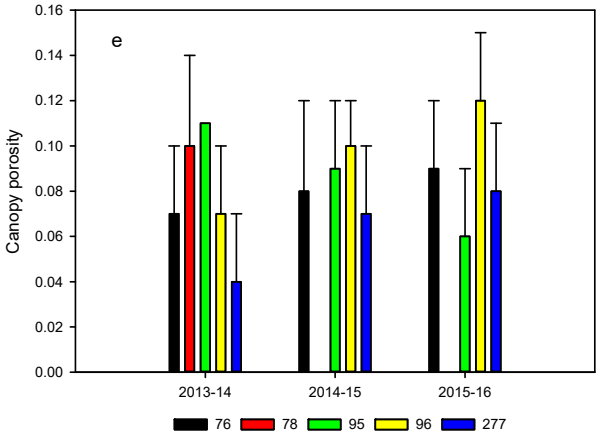
Canopy porosity

Canopy porosity is an estimate of the gaps in the canopy that allow light to reach the vineyard floor, however this is not the same as the amount of sunlight that actually reaches the bunches and training system (for example a sprawling canopy versus a tightly managed vertical shoot position canopy as used in the sites reported here). As reported above there were differences between sites over the three years (Figure 16) and with the exception of the Riverland site where clones 76 and 277 had consistently higher canopy porosity there were only small and inconsistent differences between clones.









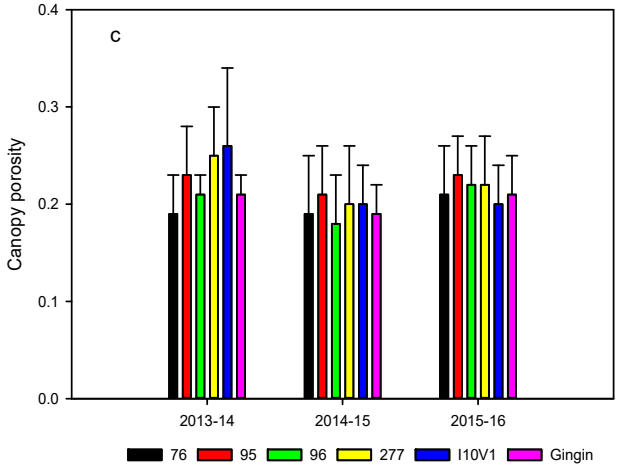


Figure 16. Canopy porosity of Chardonnay clones for sites and years data were collected.

a = Drumborg

b = Grampians

c = Great Southern

d = Margaret River

e = Riverland

Vertical bars represent the standard deviation for each mean value where it was calculated.

Leaf layer number

Leaf layer number is proposed as a measure of canopy density. The results appeared reasonably consistent at all sites for the clones (Figure 17) probably due to the hedging and foliage wire lifting conducted at four of the sites and the light pruning style used at the Riverland site. The Great Southern site had the highest leaf layer number, however the large standard deviation associated with a number of the assessments indicates that the differences observed were not significant.

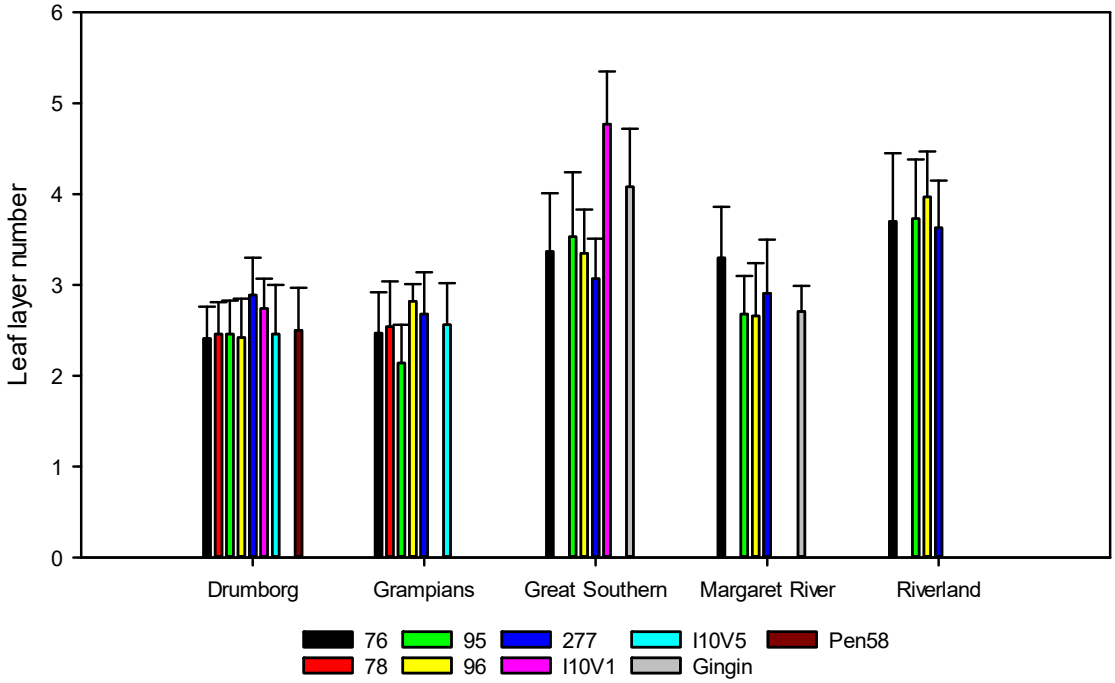


Figure 17. Leaf layer number of Chardonnay clones at all sites in the 2015-16 season.

Vertical bars indicate the standard deviation for each mean value.

Percent internal bunches

The percent internal bunches is meant to reflect possible shading of bunches. The variability of the data is quite high at four of the sites, making significant differences unlikely (Figure 18), and there were only minor differences between clones at the Riverland site. This site had the highest percentage of internal bunches, reflecting the pruning and training method for this warm-irrigated site where minimal fruit exposure is the goal.

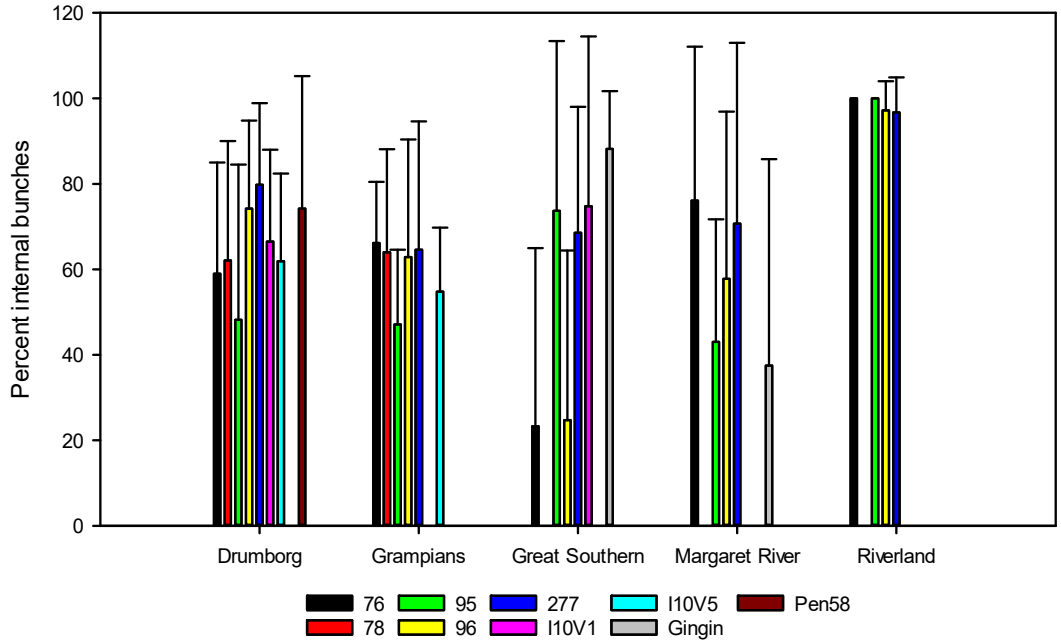


Figure 18. Percent internal bunches of Chardonnay clones at all sites in the 2015-16 season.

Vertical bars indicate the standard deviation for each mean value.

Shiraz

Canopy volume

The Shiraz vines at the Grampians and Margaret River sites had the foliage lifted and/or canopy trimmed, producing relatively even canopy sizes, as demonstrated by canopy volume (Figure 19). The Riverland vines at the trial site were smaller in size compared with other vineyards in the region due to the conservative irrigation regime, while clones at the Barossa site had the largest canopy volume, reflecting the sprawling nature of the cordon pruning and a single foliage catch wire. BVRC 12 and BVRC 30 had the smallest canopy volume at the Barossa site, with PT 15 and R6W having the largest.

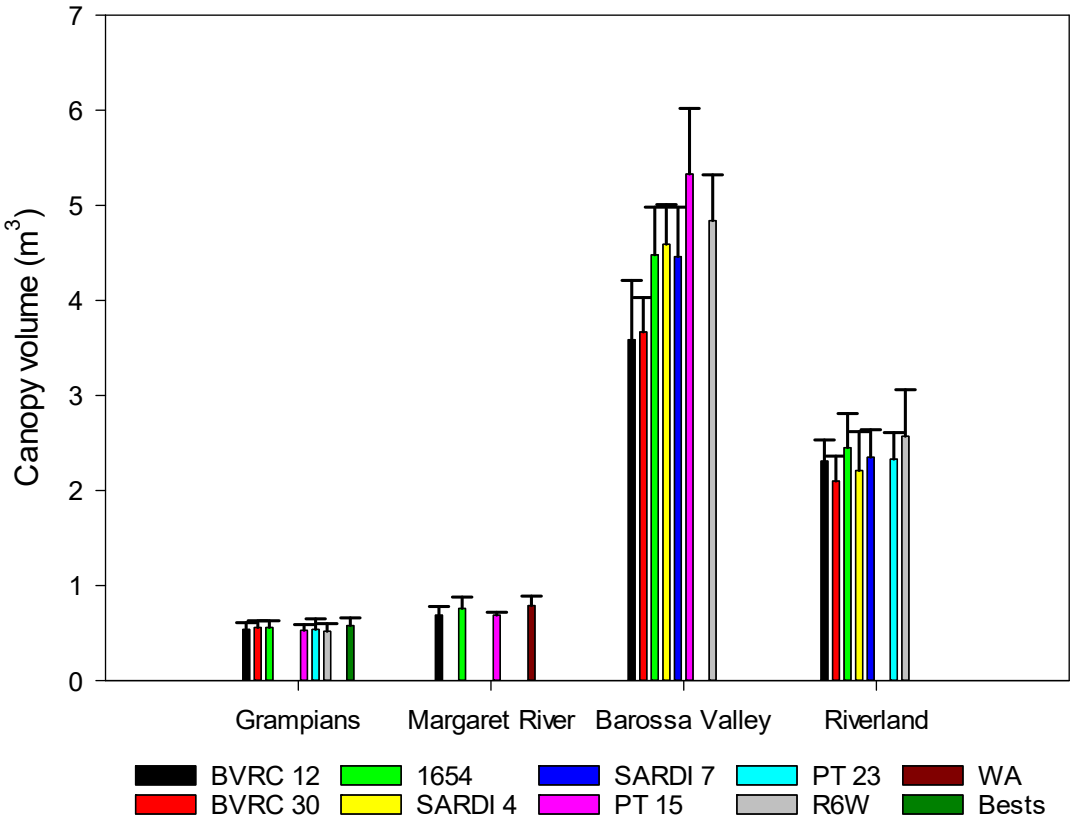


Figure 19. Canopy volume (m^3) of Shiraz clones at all sites in the 2015-16 seasons

Vertical bars indicate the standard deviation for each mean value.

Canopy surface area

Similar to the Chardonnay canopy surface area data, the Shiraz canopy surface area data reflected the canopy volume distribution (Figure 20) with the Barossa site recoding canopy surface area nearly double that of the next highest in the Riverland. There were no significant differences in the canopy surface area between clones at any of the four sites.

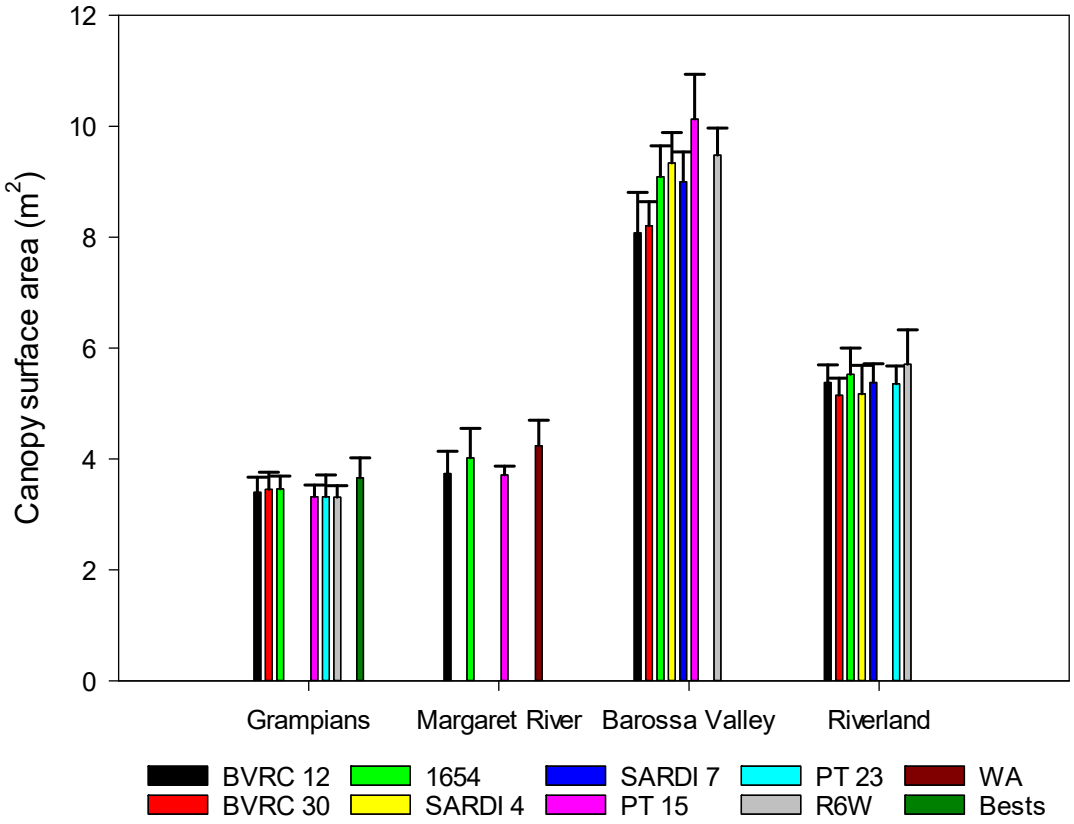


Figure 20. Canopy surface area (m^2) of Shiraz clones at each site in the 2015-16 season.

Vertical bars indicate the standard deviation for each mean value.

Leaf area index (LAIe)

As with the Chardonnay, the leaf area index (LAIe) was calculated using the VitiCanopy smartphone app as an index of the leaf area per unit ground surface area. The higher the value, the more shading on the soil and hence a larger and denser canopy. The Shiraz canopies in the Riverland were markedly larger than the other sites, while the recorded size of the shoot positioned canopies in the Grampians and Margaret River was lower. In the Riverland and Barossa the canopies were larger in 2014-15 than the other two seasons and in the Margaret River the canopies were smallest in 2015-16.

In the Barossa the BVRC 12, SARDI 4 and PT 15 canopies were normally smaller than the others. The leaf area index (LAIe) values were reasonably consistent between clones and across seasons in the Grampians region (Figure 21). The Bests clones had the highest LAIe in both seasons when it was measured. There was no consistent effect of clone on LAIe for the Riverland and Margaret River.

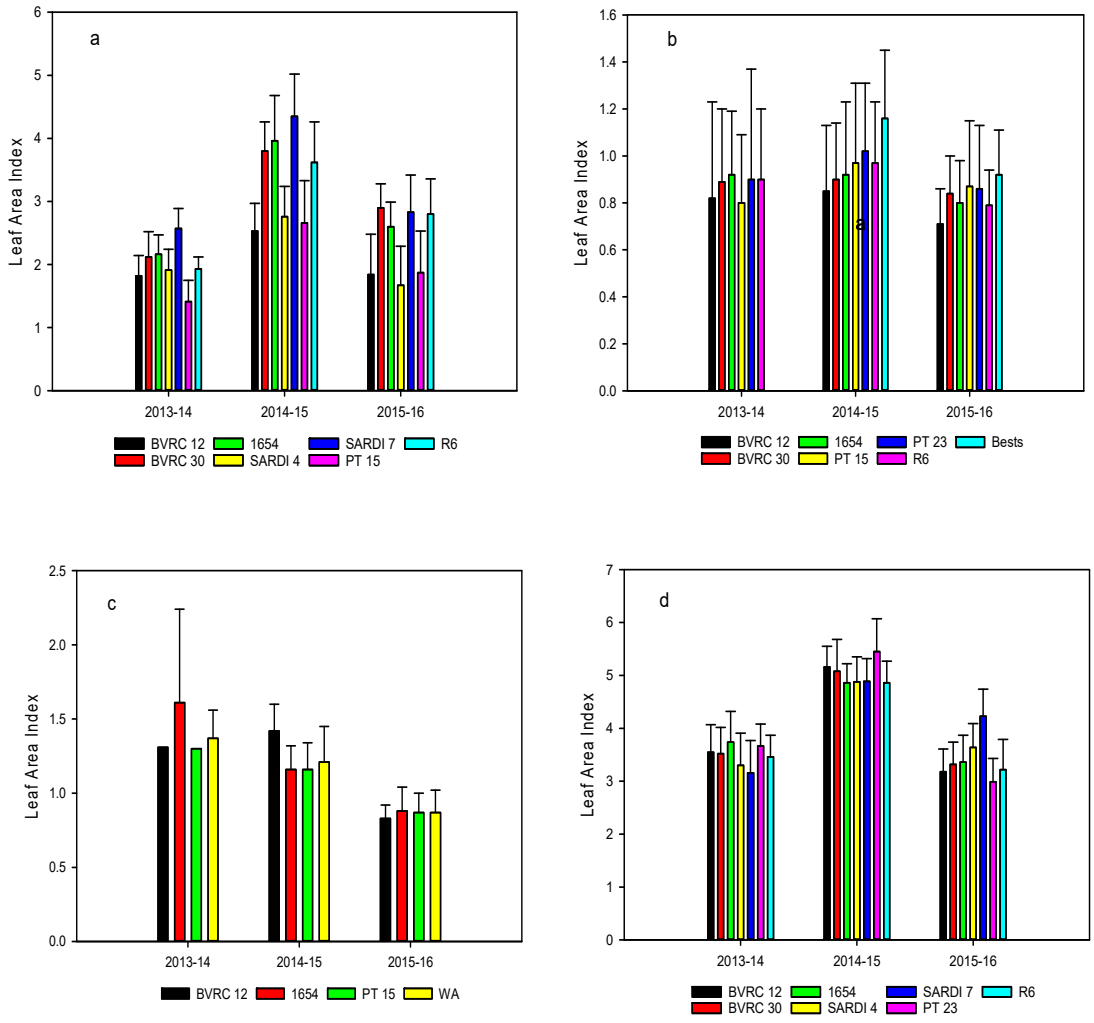


Figure 21. Leaf area index of Shiraz clones at all sites in the 2013-14, 2014-15 and 2015-16 seasons.

(a) Barossa b) Grampians c) Margaret River d) Riverland.
R6W abbreviated to R6.

Vertical bars indicate the standard deviation for each mean value.

Canopy porosity

The canopy porosity is an estimate of the gaps within the canopy that allow light to reach the vineyard floor, however this is not necessarily an indication of the bunch exposure; for example a sprawling canopy versus is likely to be more porous than a tightly managed vertical shoot position canopy, but the bunches in the vertically shoot positioned canopy can still be more exposed.

The canopies in the Riverland were the densest (porosity values below 0.12), while those in the Grampians had the highest porosity values (Figure 22). Across all sites there was relatively little variation between seasons. In the Barossa BVRC 12, SARDI 4 and PT15 consistently had higher

porosity values, but clone did not have a consistent effect in Margaret River or the Riverland. The canopy porosity values were reasonably even between clones and across seasons in the Grampians region (Figure 22). The Bests clones had the lowest porosity in both seasons it was measured, reflecting a denser canopy. There was no consistent impact of clone on canopy porosity.

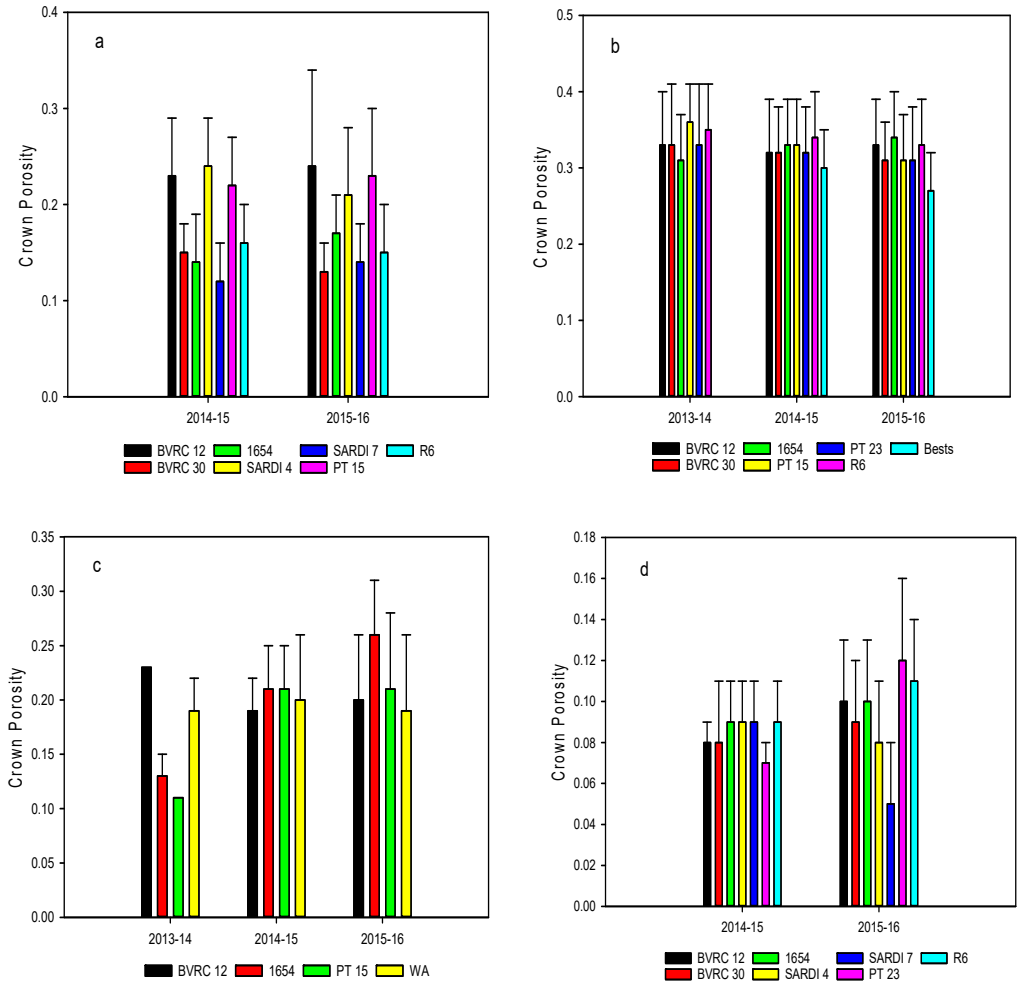


Figure 22. Canopy porosity of Shiraz clones at all sites in the 2013-14, 2014-15 and 2015-16 seasons.

(a) Barossa b) Grampians c) Margaret River d) Riverland.
R6W abbreviated to R6.

Vertical bars indicate the standard deviation for each mean value.

Leaf layer number

The recorded leaf layer numbers were similar in the Grampians and Margaret River and likewise in the Barossa Valley and the Riverland; this is probably a reflection of the different training systems (vertical shoot positioning vs sprawling) used in these regions (Figure 23). The BVRC 30 in the Barossa had the largest and greatest variation in leaf layer number. In the Grampians region the leaf layer number was reasonably even between clones. There was no consistent impact of clone on leaf layer number across the regions.

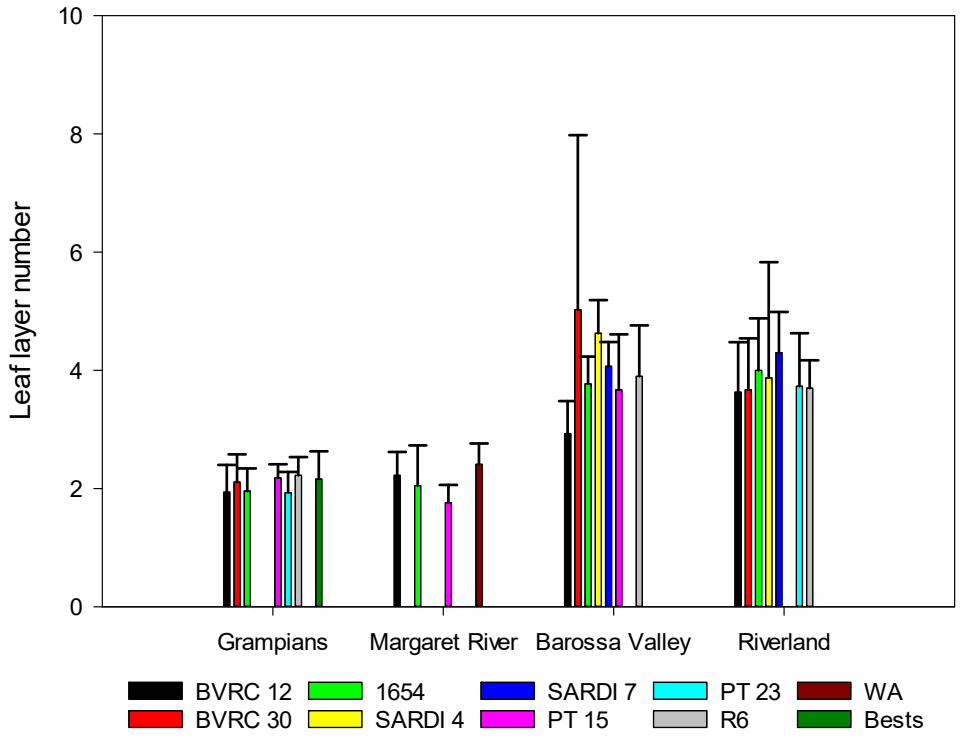


Figure 23. Leaf layer number of Shiraz clones at all sites in the 2015-16 season.

R6W abbreviated to R6.
Vertical bars indicate the standard deviation for each mean value.

Percent internal bunches

The sprawling canopies in the Barossa and Riverland had almost double the proportion of internal bunches compared to Margaret River or the Grampians. The variability within the vines of each Shiraz clone for percentage internal bunches was high, precluding any conclusions about possible differences between clones (Figure 24).

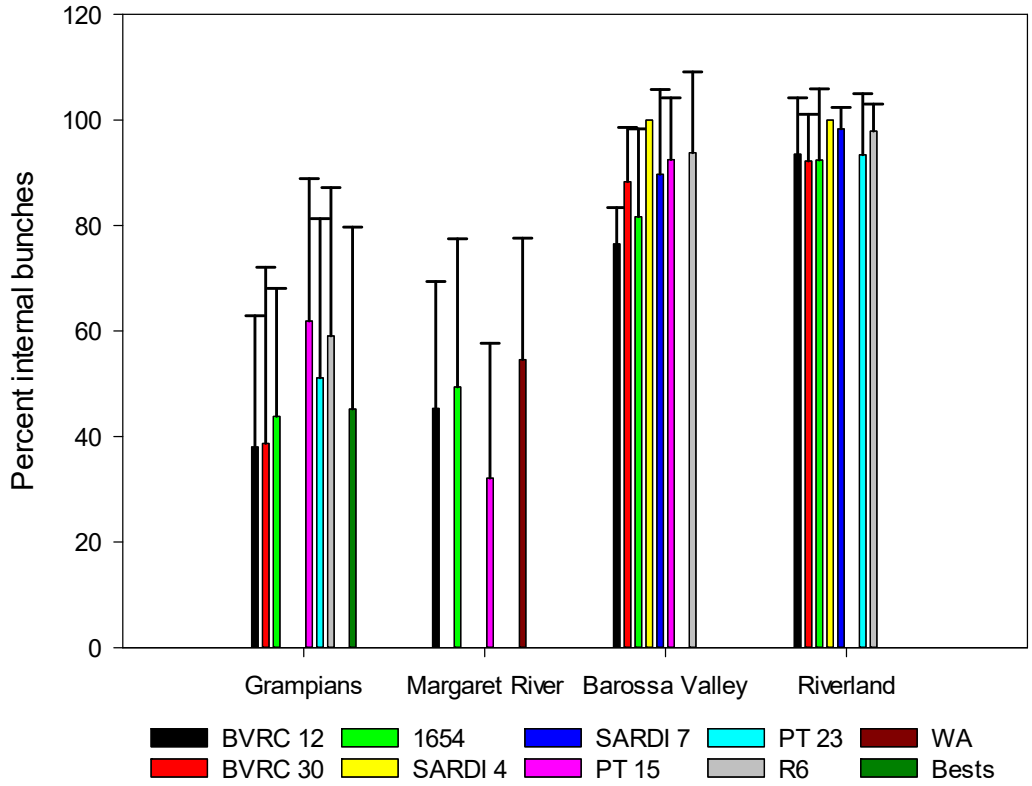


Figure 24. Percent internal bunches of Shiraz clones at all sites in the 2015-16 season.

R6W abbreviated to R6.
Vertical bars indicate the standard deviation for each mean value.

Bunch compactness

Bunch compactness was assessed to determine if there were likely to be differences in susceptibility to botrytis between clones. The relationship determined by Tello and Ibanez (2014) was modified to achieve a closer relationship to the measurable and a ranking of visual bunch compactness. A lower index relates to less compact bunches and a high index relates to greater compactness, and therefore a higher susceptibility to botrytis. In the 2013-14 season the original relationship devised by Tello and Ibanez (2014) was used and in subsequent seasons the modified relationship was used.

Chardonnay

There was a difference in bunch compactness between years (Figure 25) and between sites, but there was no consistent pattern in the ranking of clones. The often high standard deviation indicates that variability was high, rendering the difference between clones not significant. The exception was the Gingin clones at the two Western Australia sites. In Margaret River the Gingin clone recorded the lowest bunch compactness in all three years while in Great Southern, Gingin had the lowest bunch compactness in two of the three years and equal lowest in the other year. As reported later, the Gingin clone differentiated from other clones in a number of other measures including sensory assessment.

Shiraz

Similar to the Chardonnay clones, there were differences between years and sites (

Figure 26) but with no consistent pattern in the ranking of the clones at each site. For the sites where R6W was assessed this clone recorded the lowest or next to lowest bunch compactness and in a similar manner to the Gingin Chardonnay clone, R6W differentiated from other clones in a number of other measures including sensory assessment.

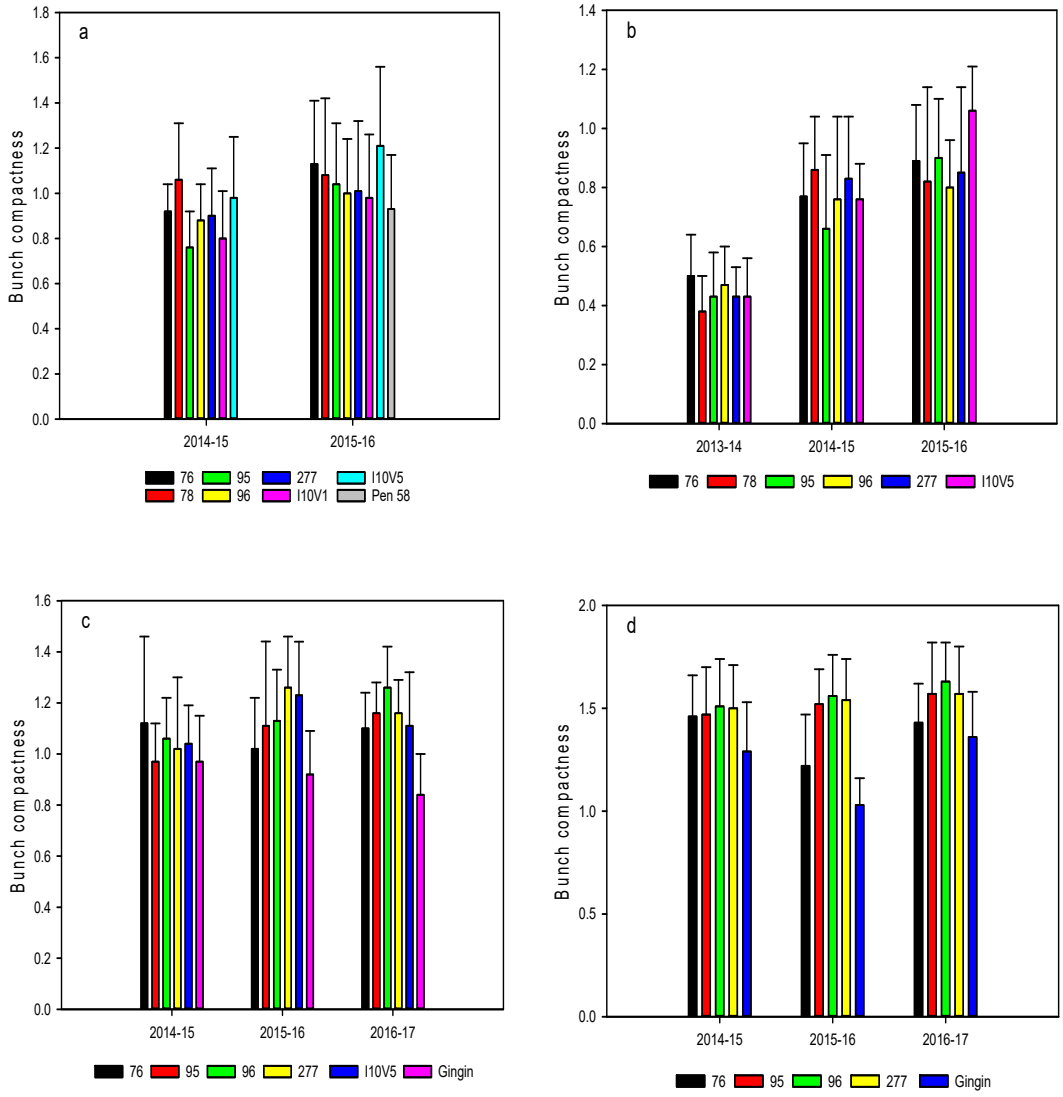


Figure 25 Bunch compactness of Chardonnay clones at four sites for either two or three seasons.

a = Drumborg, b = Grampians, c = Great Southern, d = Margaret River

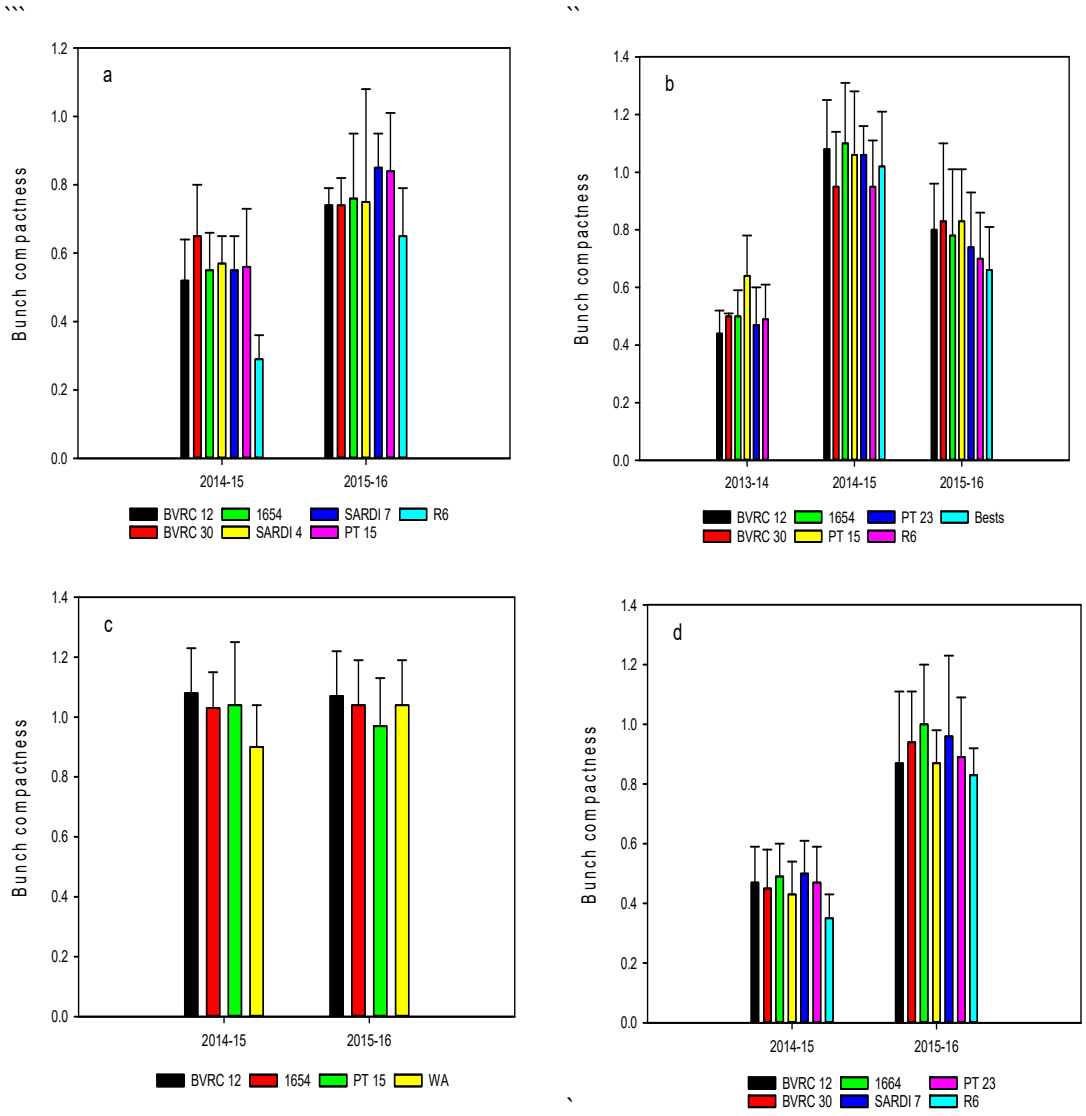


Figure 26 Bunch compactness of Shiraz clones at four sites for either two or three seasons.

a = Barossa, b = Grampians, c = Margaret River, d = Riverland.

R6W abbreviated to R6.

Vine vigour

Chardonnay

*Pruning weight, y*ield to pruning weight ratio

The pruning weights per metre of row were remarkably even across four seasons at the Drumborg site (Figure 27a) for the Bernard Chardonnay clones, with the 2015-16 season producing higher pruning weight than the other three seasons. The pruning weight for the I10V5 clone was lower in seasons 2014-15 and 2015-16 due to a conversion phase from spur to cane pruning affecting pruning weights. The pruning weights across the five Bernard clones were quite consistent, with 76 having the highest weights in three of the four seasons. The I10V1 clone was highest in the two years it was assessed, consistent with other canopy measures (see above). The yield:pruning weight ratio varied considerably between seasons at the Drumborg region site (Figure 28a). Given that pruning weights were reasonably consistent, the main cause of the variation in yield:pruning weight results were fluctuating yields. The 2016-17 season had a particularly low crop and 2015-16 season had a relatively high crop. The clone I10V5 had the highest yield:pruning weight ratio in two seasons it was assessed, primarily due to low pruning weights during a conversion process from spur to cane pruning.

At the Grampians site the pruning weights declined over the first three seasons (Figure 27b) before increasing in the 2016-17 season to the highest values across all seasons. The I10V5 clone had the highest pruning weight in the three seasons it was measured and the Bernard clones had relatively similar pruning weights. In the Grampians, the yield:pruning weight ratio increased from 2013-14 to 2015-16 (Figure 28b) when the vines became overcropped. The number of buds retained at pruning were reduced for the 2016-17 season and the yield:pruning weight ratio reduced from the previous season. Across the clones, Bernard 277 had the highest yield:pruning weight ratio in three of the four seasons and I10V5 the lowest in two of the three seasons it was assessed.

At the Great Southern site there was no distinct pattern in the weight or prunings harvested from each Chardonnay clone across the four years (Figure 27c) with the exception of the Gingin clone which recorded the lowest weight in two of the four years and was at the lower end of the range of weights in the other two years. Both the Gingin clone and I10V1 exhibited large variation on the yield:pruning weight ratio (Figure 28c) however the range was much smaller than those recorded at the Grampians site and consequently the vines at the Great Southern site were probably neither under-or over-cropped.

The trend of the lower weight of prunings with the Gingin clone in the Great Southern was also apparent in Margaret River where it recorded lower weight of prunings (Figure 27d), particularly in the first year; and while lower in the second and third year there were only small differences between clones, which, based on the standard deviation values were probably not significantly different. The Gingin clone exhibited the greatest variation in yield:pruning weight ratio (Figure 28d), being greater than the other four clones in each of the three years. Calculation of the ratio showed that it was approximately double that of all other clones in 2015-16 and hence the vines were potentially over-cropped.

At the Riverland site there was no change in the pruning method across the four years and there was a consistent pattern, with clone 76 having the heaviest weight of prunings in each of the four years (Figure 27e) and 95 being the next highest. Clone 96 always recorded the lowest pruning weight per vine, however, the high standard deviation associated with this data indicates that the difference in the weight of prunings between clones may not have always been significant. Similar to the other regions there was a wide range in yield:pruning weight across the four years (Figure 28e) with the lowest ratios in the final year. The Riverland site also recorded the highest ratio of all the sites in 2015-16 with 277 yielding approximately 24 kg fruit per kg pruning weight, which in the other regions would be indicative of over-cropping. The previously reported higher yield of clone 76 at this

site combined with higher pruning weight per metre cordon resulted in the yield:pruning weight ratio being similar to 96 and 277 and greater than Bernard 95.

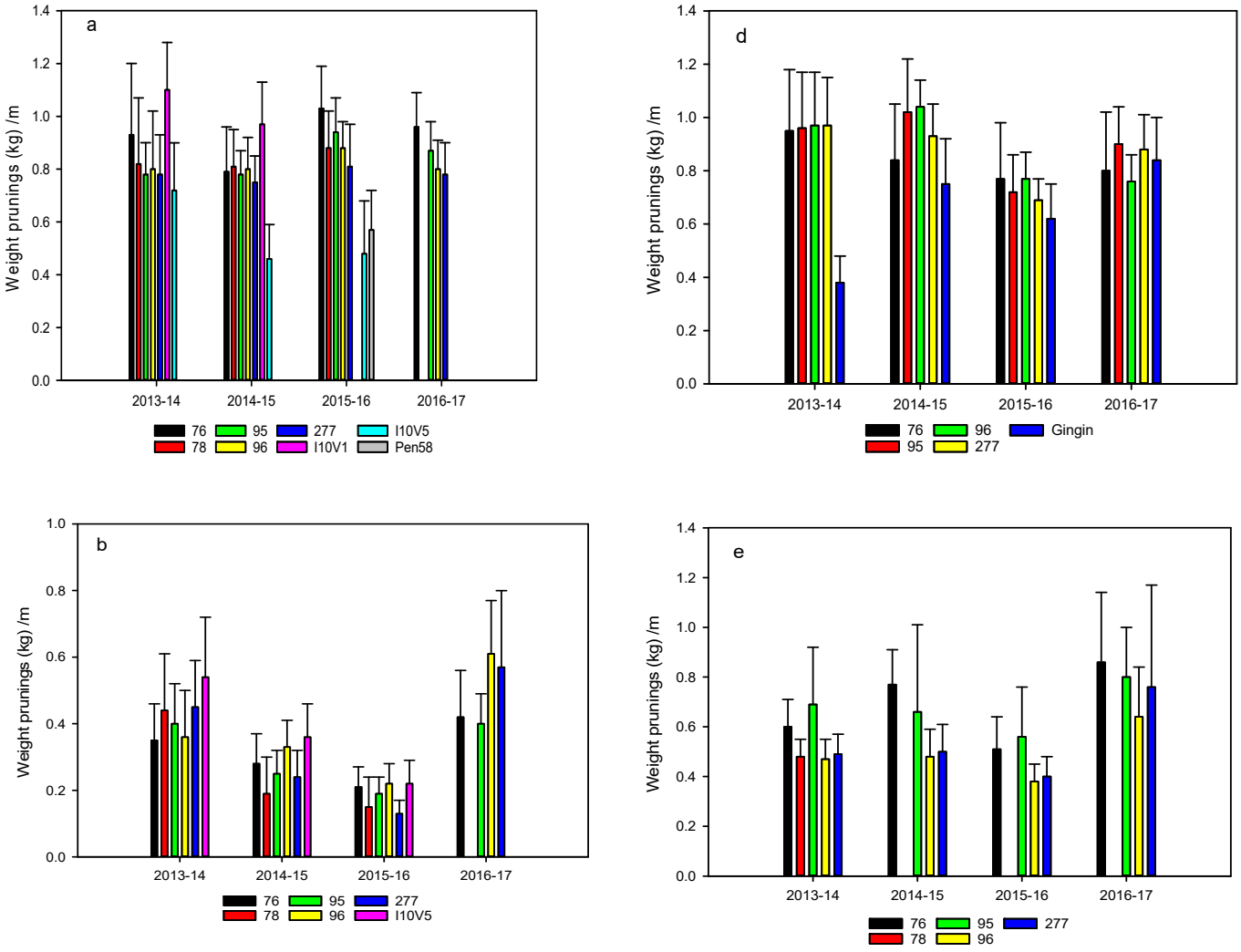


Figure 27. Pruning weight (kg) per metre of Chardonnay clones for sites and years in which data were collected.

a = Drumborg

b = Grampians

c = Great Southern

d = Margaret River

e = Riverland

Vertical bars represent the standard deviation for each mean value where it was calculated.

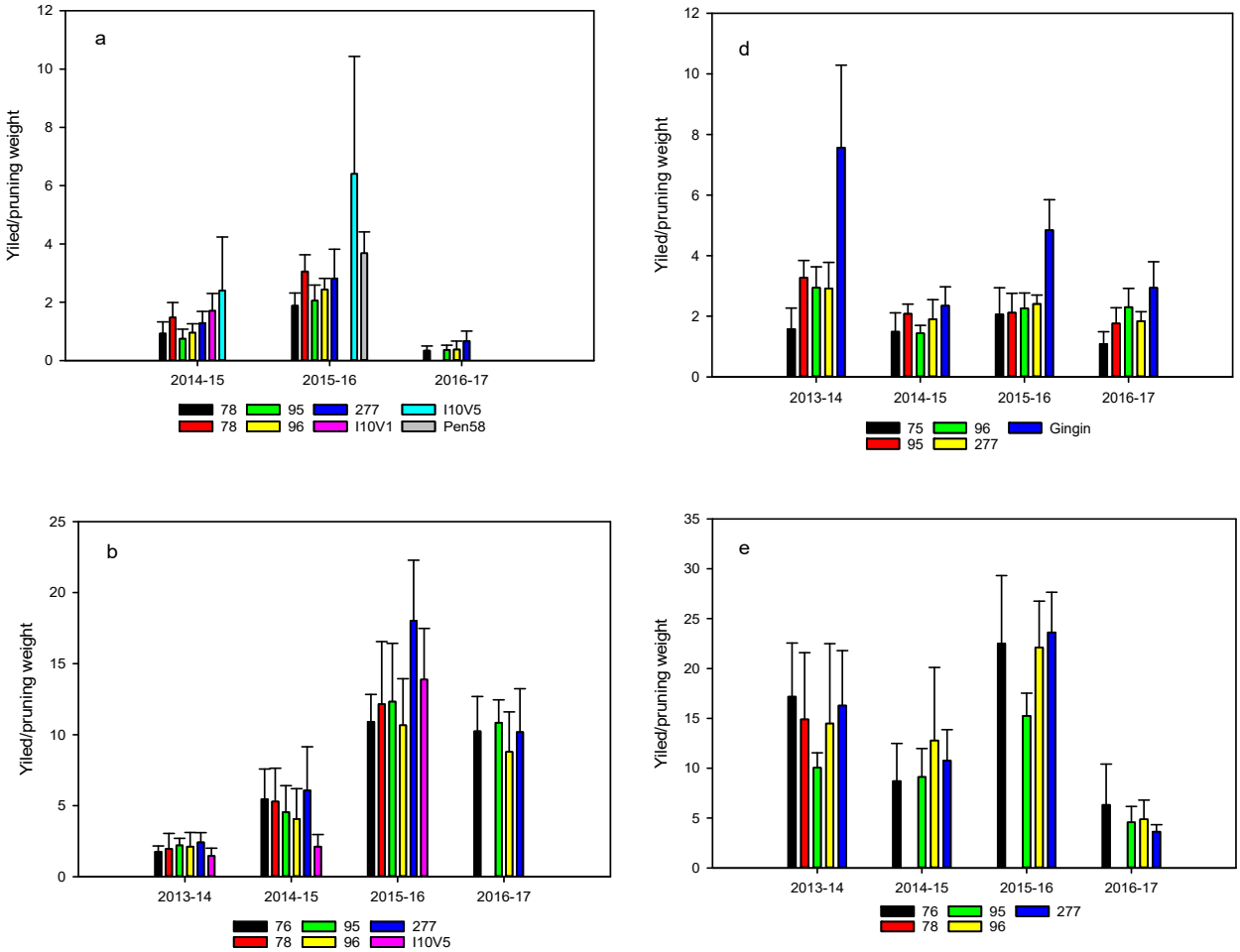


Figure 28. Yield:pruning weight of Chardonnay clones for sites and years in which data were collected.

a = Drumborg

b = Grampians

c = Great Southern

d = Margaret River

e = Riverland

Vertical bars represent the standard deviation for each mean value where it was calculated.

Shiraz

Pruning weight, yield to pruning weight ratio

There was a wide range in the weight of Shiraz prunings per metre cordon recorded at the Barossa site across the three years from less than 0.5 kg/m to more than 2 kg/m cordon (Figure 29a) and there was a similar ranking of the clones in each year with the clones separating into two groups. The lower pruning weight group comprised BVRC 12, SARDI 4 and PT15 while BVRC 30, 1654, SARDI 7 and R6W had higher pruning weights. BVRC 12 and R6W are planted in adjacent rows on the Nuriootpa Research Centre suggesting these differences are clonal, not spatial influences. There was wide range in the yield:pruning weight ratio across the three years (Figure 30a) and between clones within each year with no consistent pattern with the exception perhaps of BVRC 12 and R6W being lower; however with a range from approximately 1 to 6.5 across the three seasons the usefulness of this ratio is questionable.

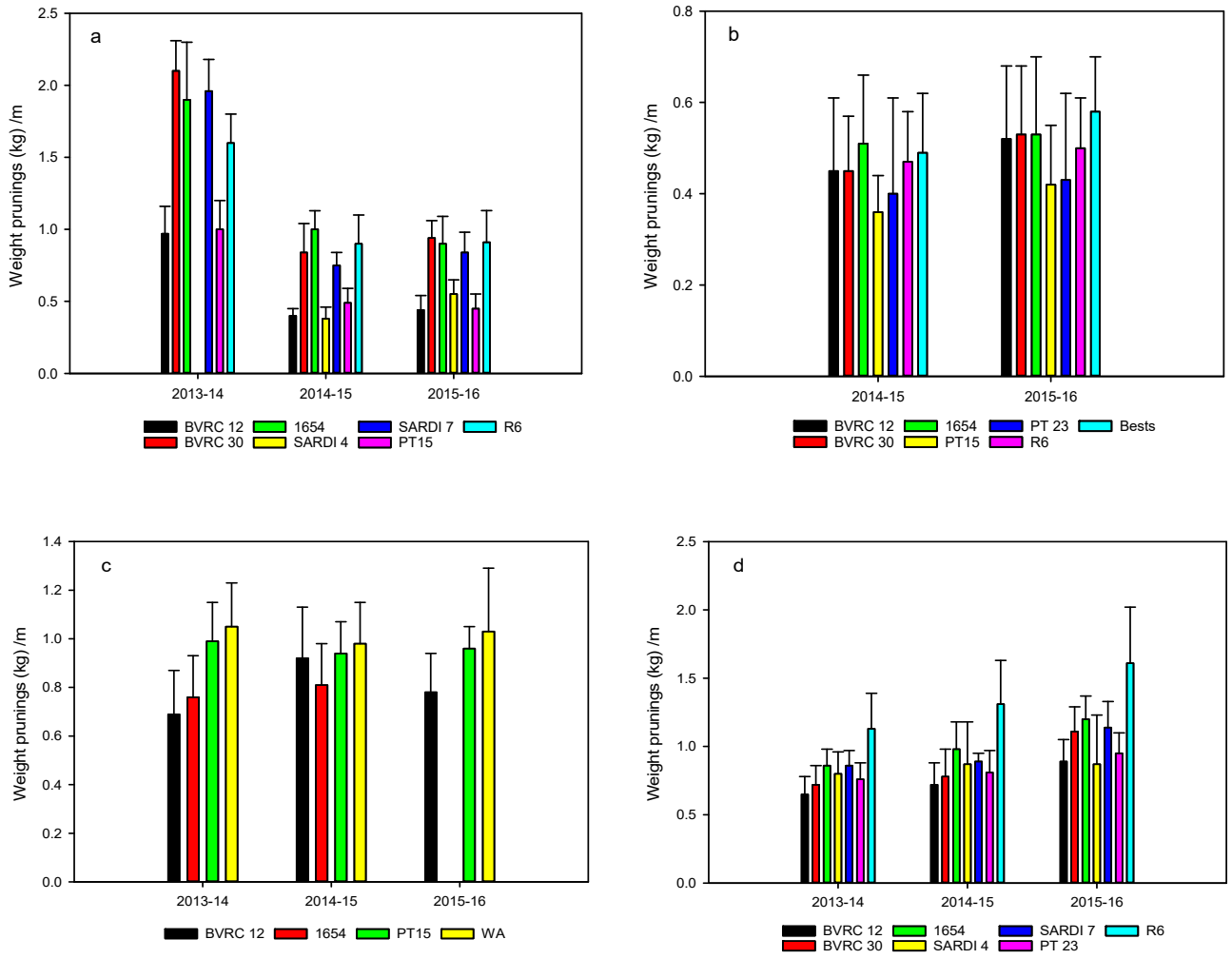


Figure 29. Pruning weight (kg) per metre of Shiraz clones for sites and years in which data were collected.

a = Barossa. b = Grampians, c= Margaret River, d= Riverland.
R6W abbreviated to R6.
Vertical bars represent the standard deviation for each mean value.

Pruning weights per metre of vine row were reasonably consistent across the two seasons it was assessed at the Grampians site due to very consistent bud numbers retained at pruning in all seasons (Figure 29b). Consistent differences between clones were few but PT15 had the lowest pruning weight in each season. The yield:pruning weight ratios were consistently higher in 2014-15 than 2015-16 across all clones (Figure 30b). Within the clones, Bests clone had the lowest yield:pruning weight ratio in each season it was recorded.

The WA local clonal selection had the heaviest prunings in each of the three years at Margaret River, with BVRC 12 being the least vigorous (although probably similar to 1654; Figure 29c). These differences were reflected in the yield:pruning weight ratios which exhibited the same wide range between years with no consistent pattern, for example with BVRC 12 and PT15 ranging from the highest to lowest ration between different years (Figure 30c). In the Riverland, R6W recorded the heaviest weight of prunings in each of the three years (Figure 29 d) and BVRC 12 the lowest or second-to-lowest weight and while the weight of prunings removed in 2016 was slightly higher than the previous two years, the three years were similar. While R6W recorded the heaviest prunings, it had the lowest yield:pruning weight ratio in the two years it was calculated (Figure 30d). The ranking of the other clones was remarkably similar for both years, ranging from BVRC 30 being the lowest ratio to PT23 being the highest in both years.

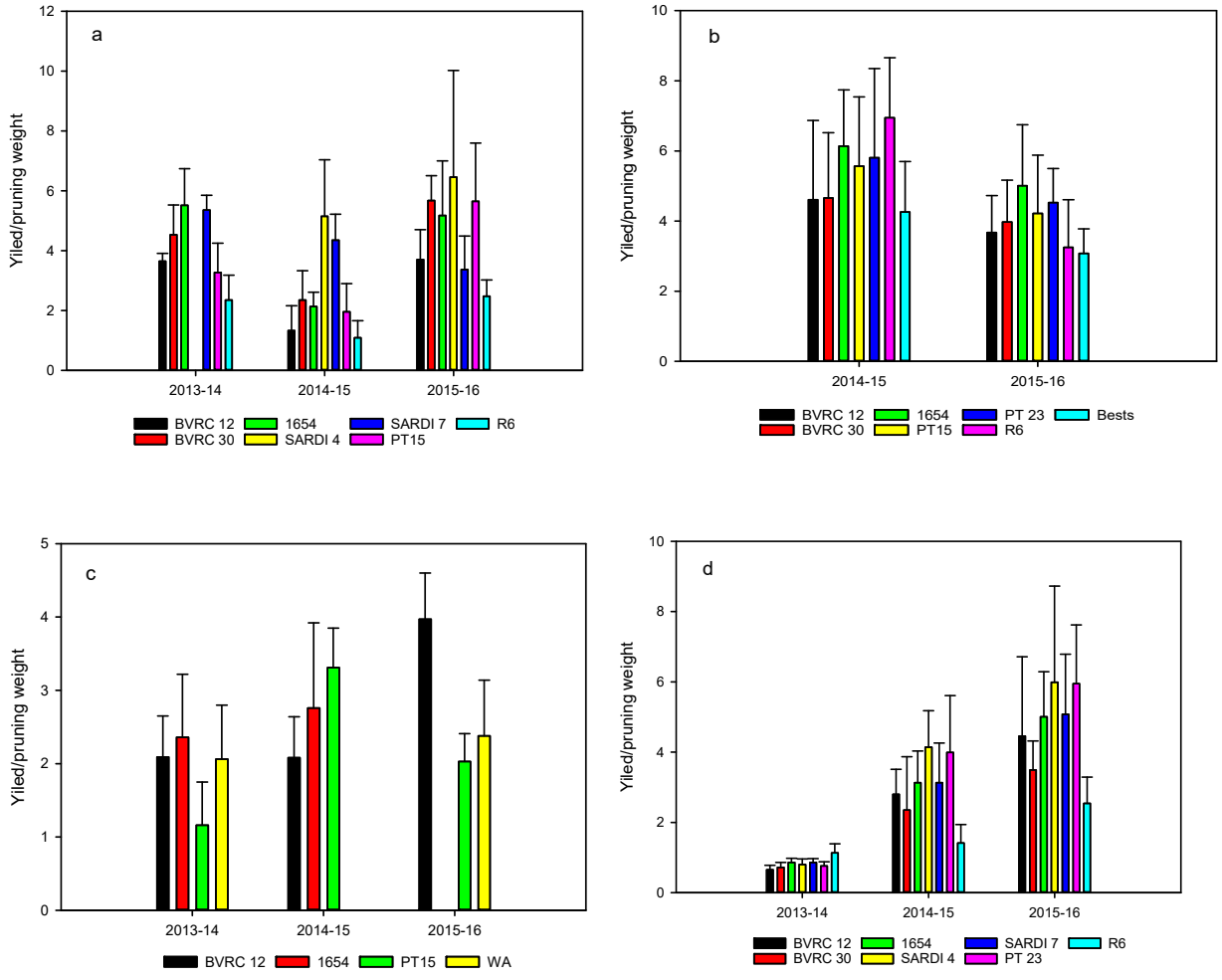


Figure 30. Yield:pruning weight of Shiraz clones for sites and years in which data were collected.

a = Barossa. b = Grampians, c= Margaret River, d= Riverland.
R6W abbreviated to R6. Vertical bars represent the standard deviation for each mean value.

7.5 Yield and components of yield

7.5.1 Chardonnay

Yield per vine, bunches per vine and bunch weight

There were large differences in Chardonnay yield between the seasons at the Drumborg site (Figure 31a) reflecting the challenging climatic conditions in this cool region. No crop was harvested in the 2013-14 season of the project due to inclement weather conditions during flowering. Similar conditions occurred at flowering in the 2016-17 season resulting in another low yield (equivalent to 1.45 tonne per hectare averaged over all clones). The highest yielding season was 2015-16 where the conditions during flowering were reasonably warm and the yield across all clones was equivalent to 7.23 tonne per hectare. The yield in 2014-15 was intermediate between the other two years at 4.24 tonne per hectare.

The clones I10V1 and I10V5 were the highest yielding in the two years they were assessed. The I10V1 and I10V5 clones were planted in different blocks from the Bernard clones. The I10V1 block was protected by a windbreak and the vines were planted on a rootstock, resulting in stronger growth, reflected in a bigger canopy (see Section 7.4), and more and heavier bunches (see below). The I10V5 clone also was more protected by windbreaks and at a lower elevation than the more exposed Bernard clones block, and again, the yield difference was due to more and heavier bunches.

At Drumborg, the highest bunch number per vine was in 2015-16 (the season of highest yields) and the lowest bunch number per vine was in 2016-17 (the season of lowest yields vines were harvested) (Figure 32a). The clone I10V1 had the highest bunch number per vine in both of the seasons it was assessed and 95 had the lowest bunch number per vine in the same two seasons. Among the five Bernard clones, 277 had the highest bunch number per vine in all three seasons assessed.

Mean bunch weights were highest across all clones in the 2015-16 season and lowest in the 2016-17 season (Figure 33a). Clones I10V1 and I10V5 were highest or second highest in the two seasons where data was collected and 95 had the lowest bunch weight in the same two seasons. Of the Bernard clones, 78 had the highest bunch weight in each of the two seasons it was assessed.

In the Grampians region 2013-14 had the lowest crop due to cool conditions during flowering (similar to the Drumborg site) (Figure 31b). The mean yield in 2013-14 across the four Bernard clones assessed in all four seasons was 2.75 tonnes per hectare. 'Hen and chicken' was evident in many bunches and there were some differences between clones (see below) but the differences were not related to the final yields. The 2016-17 season produced a very high crop (equivalent to 11.18 tonnes per hectare across all clones) and was overcropped (see Section 7.4). The high yield in the 2016-17 season was due more to higher bunch weights than bunch number per vine relative to previous seasons. The yield in the 2015-16 season was considered more appropriate as the target yield for the vineyard (around 7 tonne per hectare).

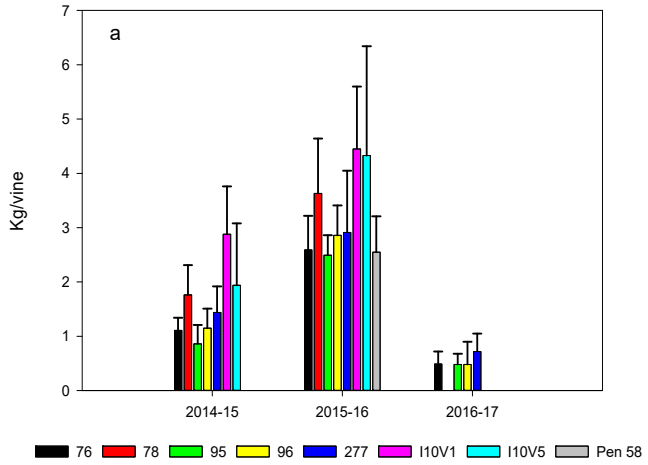
Chardonnay clonal performance in the Grampians region site was variable across the seasons. For example 76 had the lowest yield in two of four seasons and the highest in one season. Across the five Bernard clones, 277 had the highest or second highest yield in all four seasons. At this site the highest bunch numbers per vine were in 2015-16 and the lowest in 2013-14 (Figure 32b). Clone 78 had the lowest bunch number per vine in two of three seasons it was assessed (there were a few young vines in plantings of this clone). 96 had the highest or second highest bunch number per vine in three out of four seasons, and clones 95 and 277 had the highest or second highest bunch number per vine in two of four seasons. The lowest bunch weights were recorded in the first year (Figure 33b; associated with 'hen and chicken') and the 2016-17 season had the highest bunch weights. Clone 277 had the highest or second

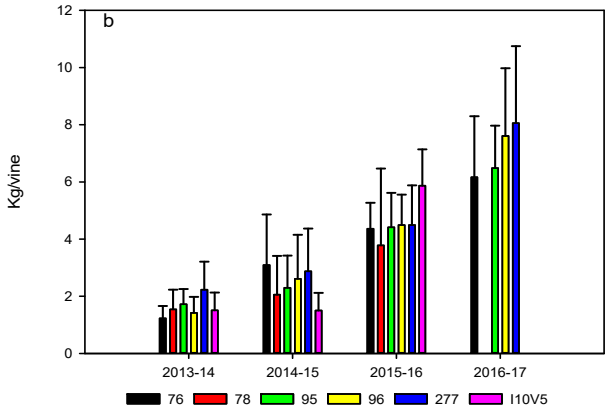
highest bunch weight in all four seasons, and clones 76 and 96 the lowest bunch weights in two of the four seasons.

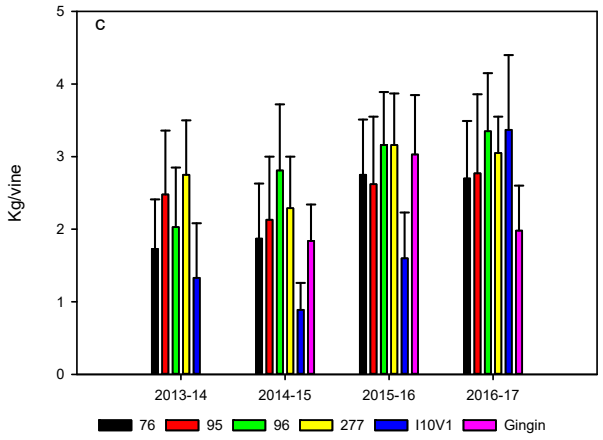
In the Great Southern region, whilst I10V1 was the lowest yielding clone in the 2013-14 to 2015-16 seasons, it was one of the highest yielding clones in the 2016-17 season. The Gingin clone exhibited similar large variations in yield between seasons, for example between 2015 and 2016 harvests (Figure 31c). For the three years that the Gingin clone was assessed, it recorded the highest number of bunches per vine (Figure 32c) but the average bunch weight was the lowest or second-to-lowest across the three years (Figure 33c). The 227 and 96 clones were consistently higher yielding and perhaps the most stable in yield across the four seasons and, for just the Bernard clones, 76 was the lowest yielding clone in three of the four seasons.

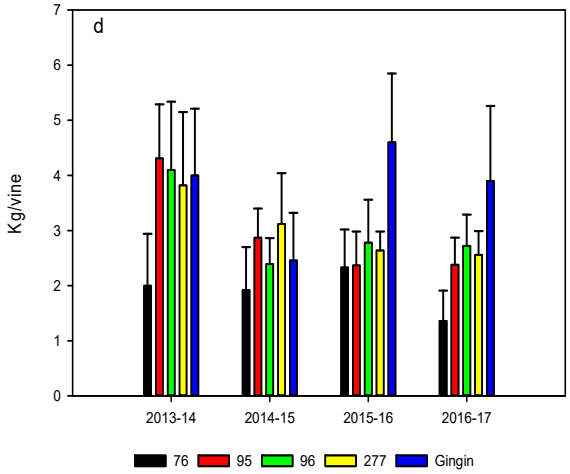
The 76 clone was also the lowest yielding clone in each of the four seasons at Margaret River (Figure 31d) while the yields of the other three Bernard clones were very similar to each other and to the Gingin clone in the 2013-14 and 2014-15 seasons. Seasonal conditions in 2015-16 and 2016-17 clearly suited the Gingin clone as it out-yielded all other clones although the larger standard deviation for the data suggests there was high vine-to-vine variability. Similar to at the Great Southern site, the Gingin clone recorded the highest number of bunches per vine in three of the four seasons at Margaret River (Figure 32d), although average bunch weight, with the exception of clone 76, was similar to the other three Bernard clones (Figure 33d). In summary, for the two WA sites where the Gingin clone was evaluated, this clone exhibited different cropping characteristics from the other clones assessed.

The warm-irrigated conditions at the Riverland site are conducive to higher-yielding vines than at the other four sites and this is reflected in yield per Chardonnay vine being generally in the range of 15 to 25 kg (Figure 31e). In contrast to the other sites, clone 76 was consistently the highest yielding clone at the Riverland site even with the large seasonal variation in yield between 2015-16 and 2016-17. The higher yield for 76 was primarily due to more bunches per vine (Figure 32e) as there was little difference in bunch weight between clones (Figure 33e). The 76 clone recorded the highest number of bunches per vine for all sites and clones for the four years of data collection. The other Bernard clones were relatively similar in yield in each of the four years. While 277 recorded the second highest number of bunches per vine over the four seasons, it had relatively lower average bunch weights than the other clones.









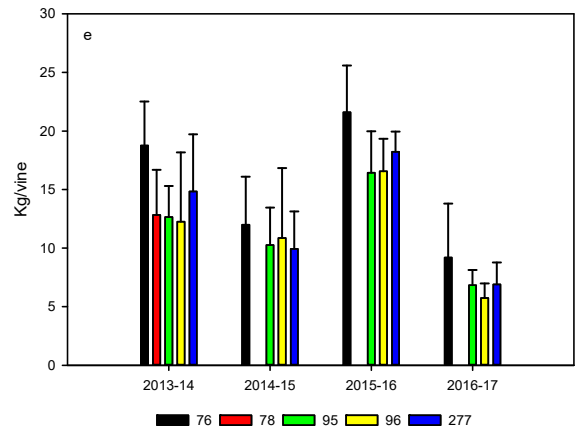


Figure 31. Yield per vine of Chardonnay clones at each of the sites for harvest years 2014, 2015, 2016 and 2017.

a = Drumborg

b = Grampians

c = Great Southern

d = Margaret River

e = Riverland

Vertical bars represent the standard deviation for each mean value.

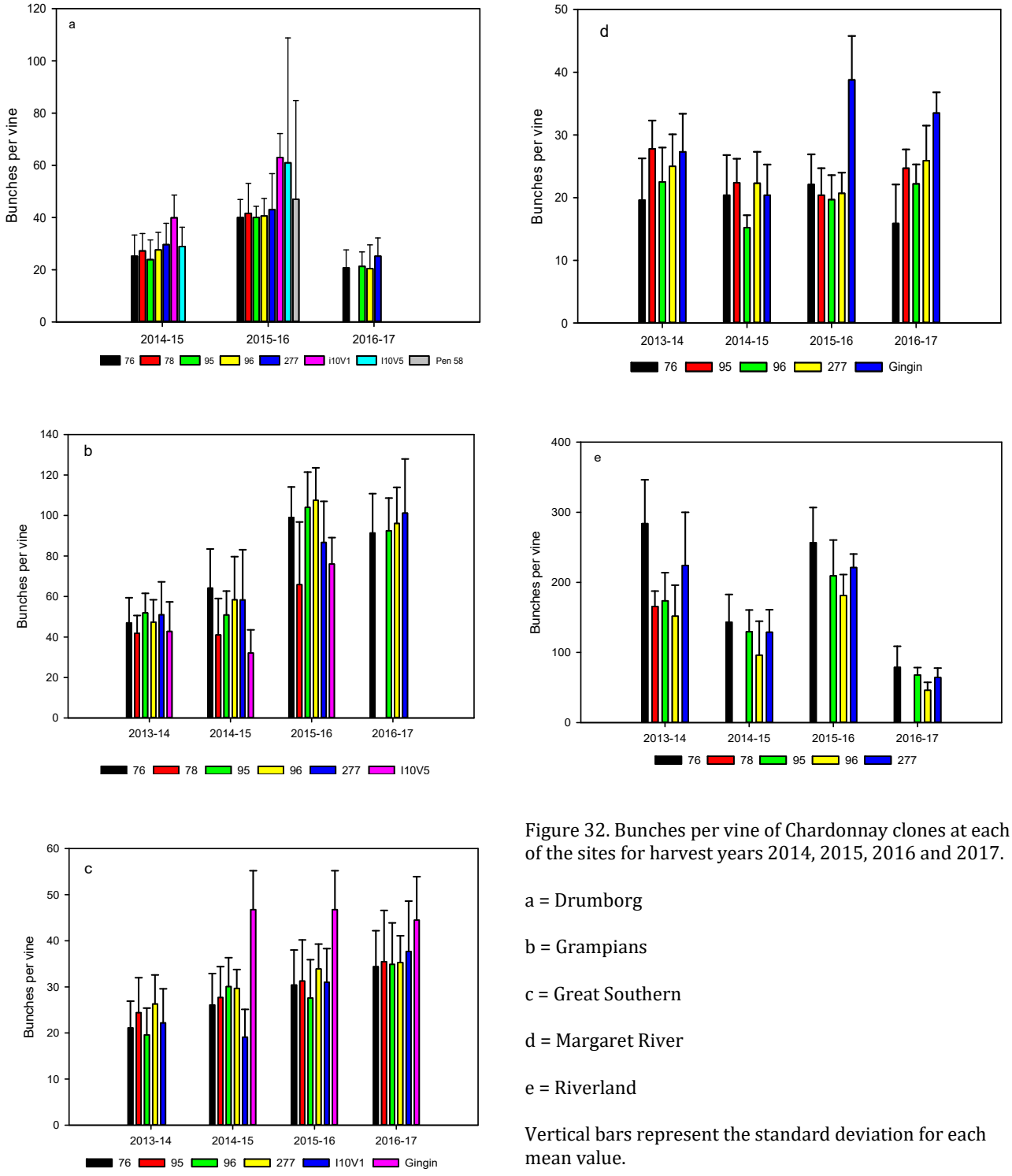


Figure 32. Bunches per vine of Chardonnay clones at each of the sites for harvest years 2014, 2015, 2016 and 2017.

a = Drumborg

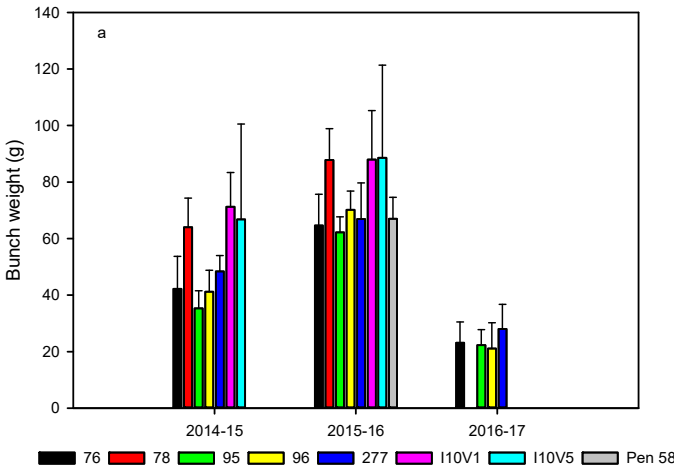
b = Grampians

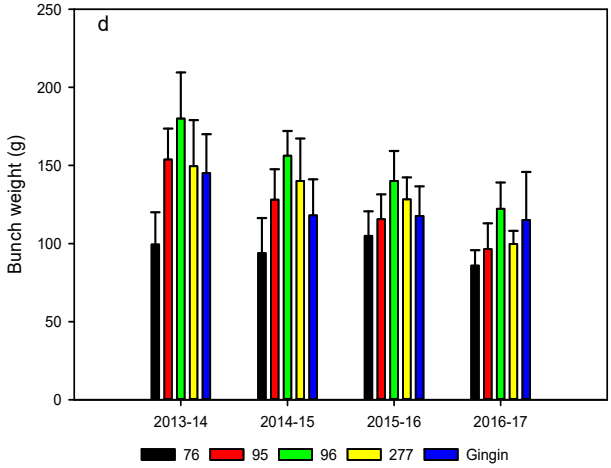
c = Great Southern

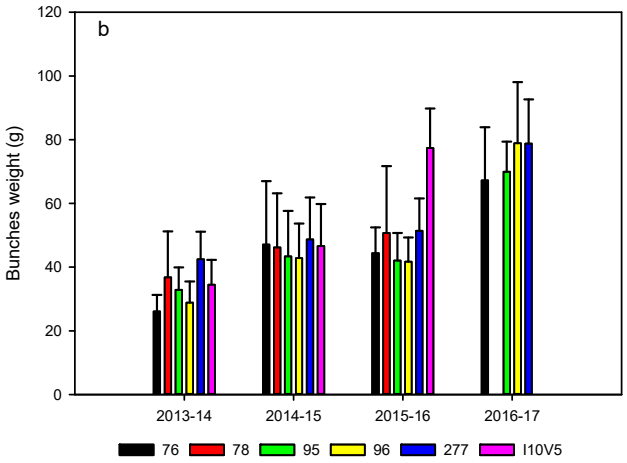
d = Margaret River

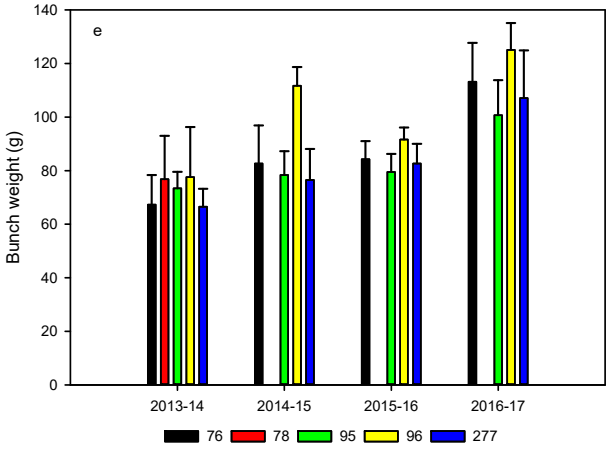
e = Riverland

Vertical bars represent the standard deviation for each mean value.









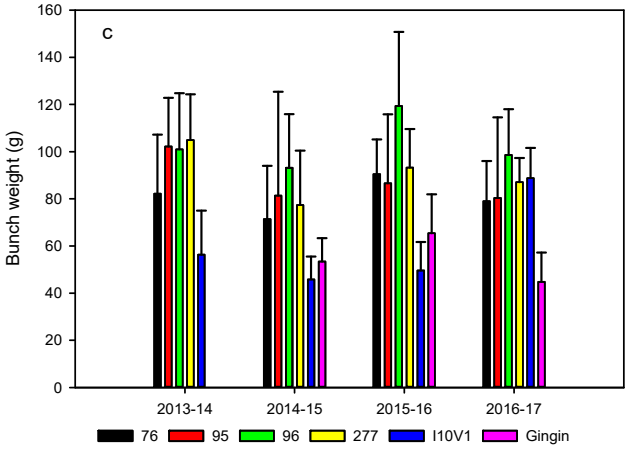


Figure 33. Bunch weight (g) of Chardonnay clones at each of the sites for harvest years 2014, 2015, 2016 and 2017.

a = Drumborg

b = Grampians

c = Great Southern

d = Margaret River

e = Riverland

Vertical bars represent the standard deviation for each mean value.

Berry weight and berries per bunch

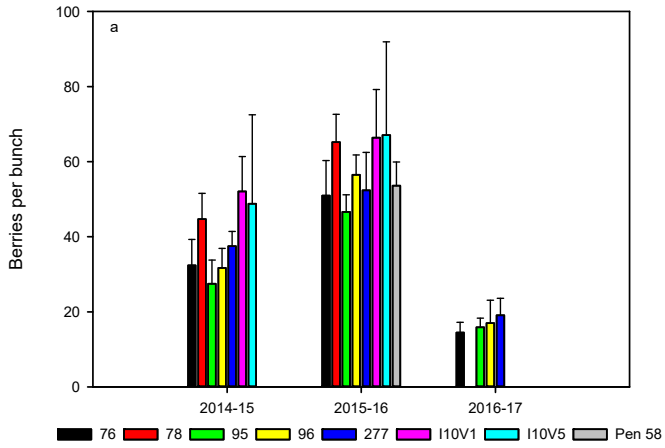
Adverse weather conditions, for example low temperatures during the flowering to set period, can have a negative effect on the number of berries per bunch which may be compensated for by an increase in berry weight. This was apparent at the Drumborg site in the 2016-17 season when low temperatures during the November flowering period (Section 7.2) resulted in a significant reduction in berries per bunch of Chardonnay compared with previous years (Figure 34a). In contrast, the 2015-16 season had relatively warm conditions during flowering and the highest berry number per bunch. I10V1 and I10V5 had the highest berry numbers per bunch in the two seasons they were assessed, and 95 the lowest berry number per bunch in two out of three seasons. Among the Bernard clones, 78 had the highest berry number per bunch in the two seasons it was assessed. The mean berry weights at the Drumborg site were reasonably similar across all three seasons (Figure 35a), even with large differences in the number of berries per bunch, and there were no consistent differences between the clones.

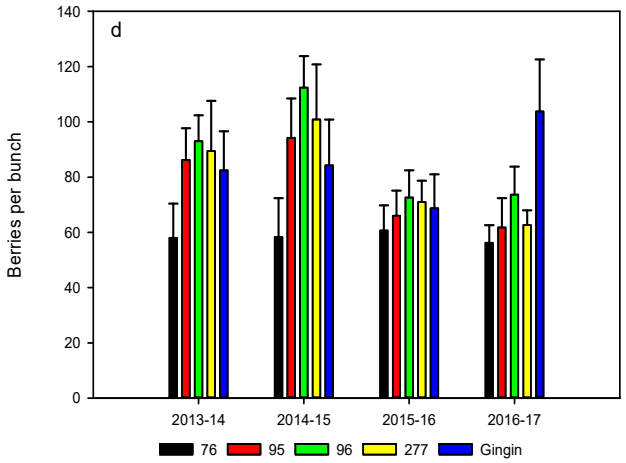
Like Drumborg, the Grampians site experienced low temperatures during flowering in 2013-14 which influenced berry number per bunch. The 2013-14 season had a lower berry number per bunch compared with the 2015-16 and 2016-17 seasons (Figure 34b). Clone 78 had the highest or second highest berry number per bunch in the three seasons it was assessed which was a similar result to Drumborg while the lowest berry number per bunch was inconsistent between the clones across the seasons. With average berry weights, the 2013-14 and 2015-16 seasons were similar and had lower berry weights than the 2014-15 and 2016-17 seasons (Figure 35b). I10V5 had the highest or second highest berry weight in all three seasons it was assessed, and B95 the lowest berry weight in three out of four seasons.

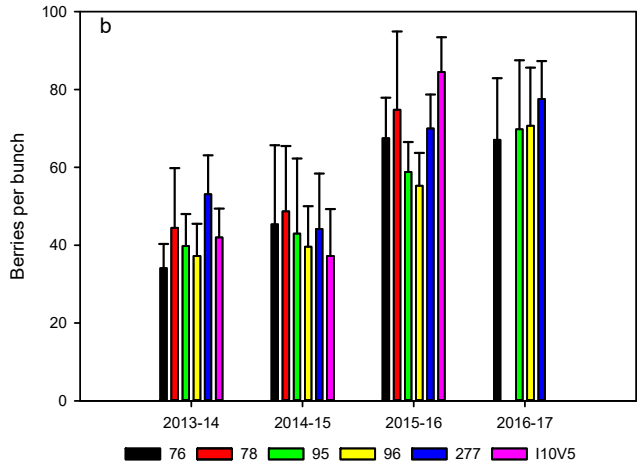
In comparison to the other sites, the clones at the Margaret River and Great Southern sites tended to have more berries per bunch (Figure 35). In Great Southern, I10V1 recorded the lowest number of berries per bunch in three of the four seasons (Figure 354c), while 96 recorded the highest number of berries per bunch in each of the four seasons. The Gingin clone had relatively variable berry number per bunch from lowest in 2016-17 to second highest in 2015-16. The sampling protocol used at the Margaret River and the Great Southern sites did not enable any statistical analysis on the berry weight data (Figure 35). The data presented from Great Southern in Figure 345 c suggests the Gingin clone had the lowest berry weight in three of the four years and clone 76 had the second lowest in two of the four years. Clone 277 was highest or second highest across all seasons.

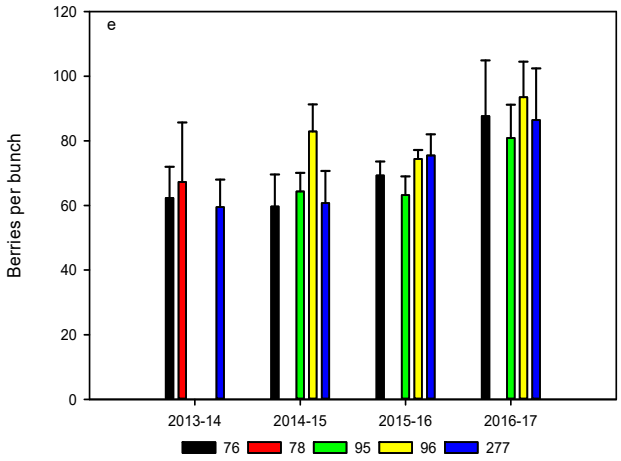
At the Margaret River site, 76 consistently had fewer berries per bunch compared with the other clones (Figure 354d) whilst 96 had the highest number of berries per bunch in three of four seasons. The Gingin clone had by far the highest number of berries per bunch in 2016-17 but was similar to the other clones in the previous seasons. Variable berry weight of the Gingin clone was apparent at the Margaret River site where it ranged from the highest berry weight in 2013-14 to by far the lowest in 2016-17 (Figure 345d). Clone 96 had the highest berry weights in three of the four seasons.

There was no consistent pattern between Chardonnay clones at the Riverland site for either the number of berries per bunch (Figure 34e) or berry weight (Figure 35e). The tendency of clone 96 for heavier bunch weight, as previously noted, appears to be a combination of both more berries per bunch and heavier berries. This combination of both more and larger berries per bunch would have resulted in more compact bunches (even though no significant differences between clones were noted; Section 7.4.1) and may account for the higher level of Botrytis infection noted at harvest for this clone, especially in 2016-17.









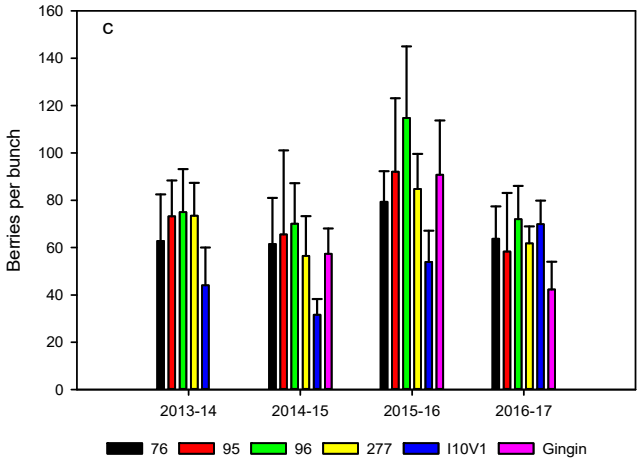


Figure 34. Berries per bunch of Chardonnay clones at each of the sites for harvest years 2014, 2015, 2016 and 2017.

a = Drumborg

b = Grampians

c = Great Southern

d = Margaret River

e = Riverland

Vertical bars represent the standard deviation for each mean value.

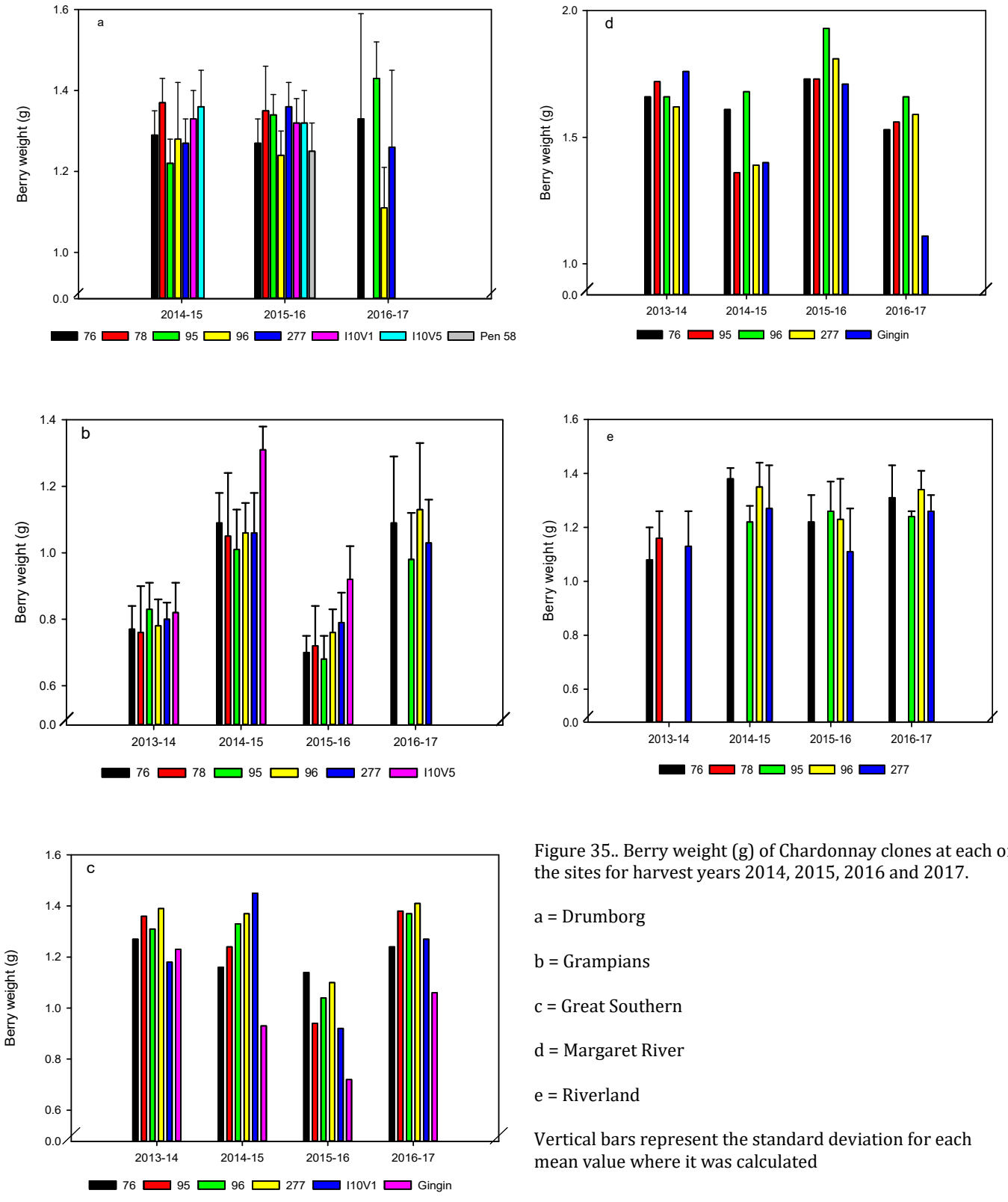


Figure 35.. Berry weight (g) of Chardonnay clones at each of the sites for harvest years 2014, 2015, 2016 and 2017.

a = Drumborg

b = Grampians

c = Great Southern

d = Margaret River

e = Riverland

Vertical bars represent the standard deviation for each mean value where it was calculated

Hen and Chicken?

In the 2013-14 season at the Grampians region site, 'hen and chicken' (millerandage) was evident across the trial block. A sample of six bunches per clone was dissected and berries less than 8mm diameter and live green ovaries were counted as 'chickens, and expressed as a proportion of total berries. Some differences between clones were evident (Figure 36) with 95 and 277 having the highest percent chickens, and the remaining four clones having similar percent chickens. The higher percent chickens in the two clones clearly did not negatively impact on yield since 95 and 277 were the two highest yielding clones in that season.

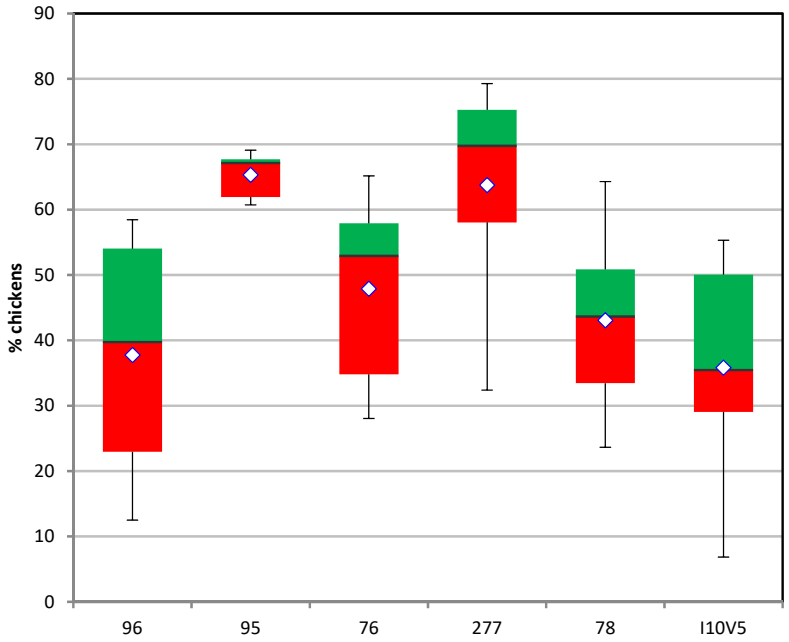


Figure 36. Percent chickens in six Chardonnay clones at the Grampians region site in 2013-14.
In the figure the white diamond is the average, the horizontal line between the red and green is the median, the lower end of red box is 1st quartile (ie 25% of the values were below this) and the upper end of the green box is 3rd quartile (ie 25% of values are above this), the lower bar is the lowest value and the upper bar is the highest value recorded.

7.5.2 Shiraz

Yield per vine, bunches per vine and bunch weight

There was a wide range in yield per vine between Shiraz clones and season at the Barossa site, with BVRC 12, PT15 and R6W being the lowest yielding clones in each of the three seasons, with BVRC 12 only yielding 1.2 Kg per vine in the low-yielding 2014-15 season (Figure 37a). These clones each had obvious Eutypa infection, with a number of dead spur positions on the bilateral cordon which resulted in fewer number of bunches per vine (Figure 38a) and lower bunch weight (Figure 39a). Across the three season BVRC 30 and 1654 maintained consistently high yields. McCarthy (1986) reported that when averaged over six harvests, BVRC 12 yielded significantly more fruit than 1654 with BVRC 30 being mid-way and not significantly different in yield to either clone in a well replicated clonal evaluation trial planted on the Nuriootpa Research Centre in the Barossa Valley . Nicholas *et al.* (1996) subsequently reported that for the other clones considered here, PT15 and BVRC 12, which were similar in yield, produced significantly higher yield per vine than R6W when averaged over three consecutive seasons. This well replicated clonal trial was also planted on the Nuriootpa Research Centre and supports the outcome reported here that R6W is a lower yielding clone.

Shiraz yields were relatively even across the three seasons at the Grampians site (Figure 37b), probably due to the very even pruning to a consistent number of buds per vine each season and bunch thinning to a target yield, as reflected in the small variation in the number of bunches per vine (Figure 38b). Clone 1654 was the highest yielding clone in all three seasons and R6W the lowest in two of the three seasons. Clone 1654 also had the highest bunch number per vine in all three seasons and PT15 the lowest in two of the three seasons, however the standard deviations suggest they were not significantly different. Clone 1654 had the highest bunch weights and R6W the lowest in all three seasons. Whiting (2003) reported no significant difference in yield between any of the six clones in this trial (excluding Bests selection) over four years. There were no significant differences between clones for bunch number per vine but R6W had a significantly lower bunch weight than 1654, PT15 and BVRC 12.

In Margaret River, PT15 ranged from the lowest yielding clone in 2013-14 to the highest yielding in the following season (Figure 37c), which was primarily driven by bunch number per vine (Figure 38c). Across the three seasons there was only a 1.7 kg per vine difference in the total weight harvested per vine (BVC12 - 12.76 kg per vine, WA selection -12.1 kg per vine) indicating that, when averaged across seasons, there appears to be little difference in the productivity of the four clones. Bunch numbers per vine in Margaret River were the lowest and bunch weights the highest when compared with the other three sites.

There was a dominant seasonal influence on yield at the Riverland site, with overall yield in 2014-15 being approximately half that of the 2013-14 and 2015-16 seasons (Figure 37d), resulting from there being approximately half the number of bunches per vine (Figure 38d). Similar to other sites where the same clones were present, 1654 was consistently high in yield, R6W low in overall yield and BVRC 12 and BVRC30 also being lower in yield for two of the three seasons. Clone R6W had consistently low bunch numbers per vine and bunch weight was high or intermediate compared to the other clones. SARDI 4 had the lowest or second lowest bunch weight over the three seasons.

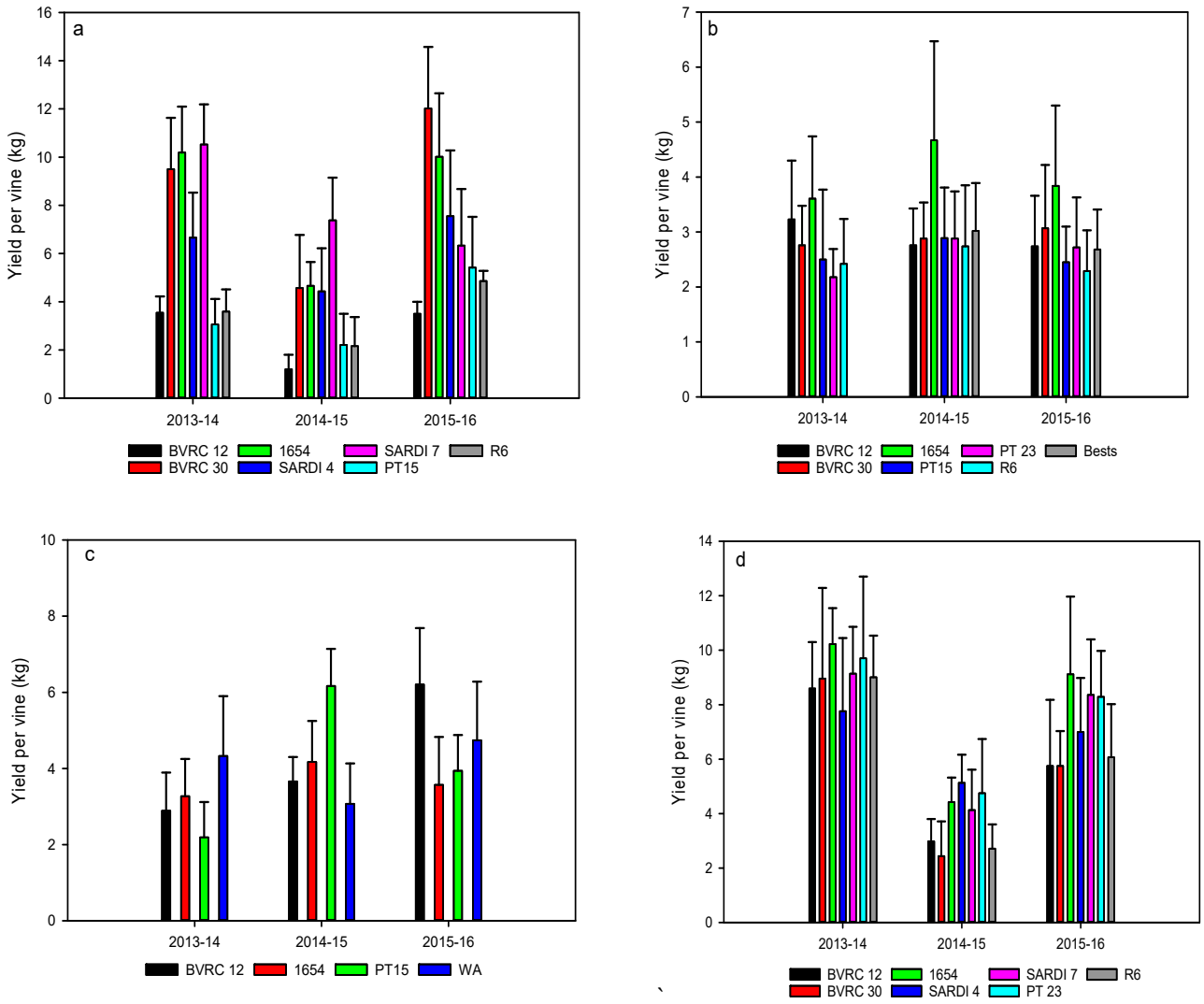


Figure 37. Yield per vine of Shiraz clones at each of the four sites for harvest years 2014, 2015 and 2016.

a = Barossa. b = Grampians, c= Margaret River, d= Riverland.
Clone R6W is abbreviated to R6
Vertical bars represent the standard deviation for each mean value.

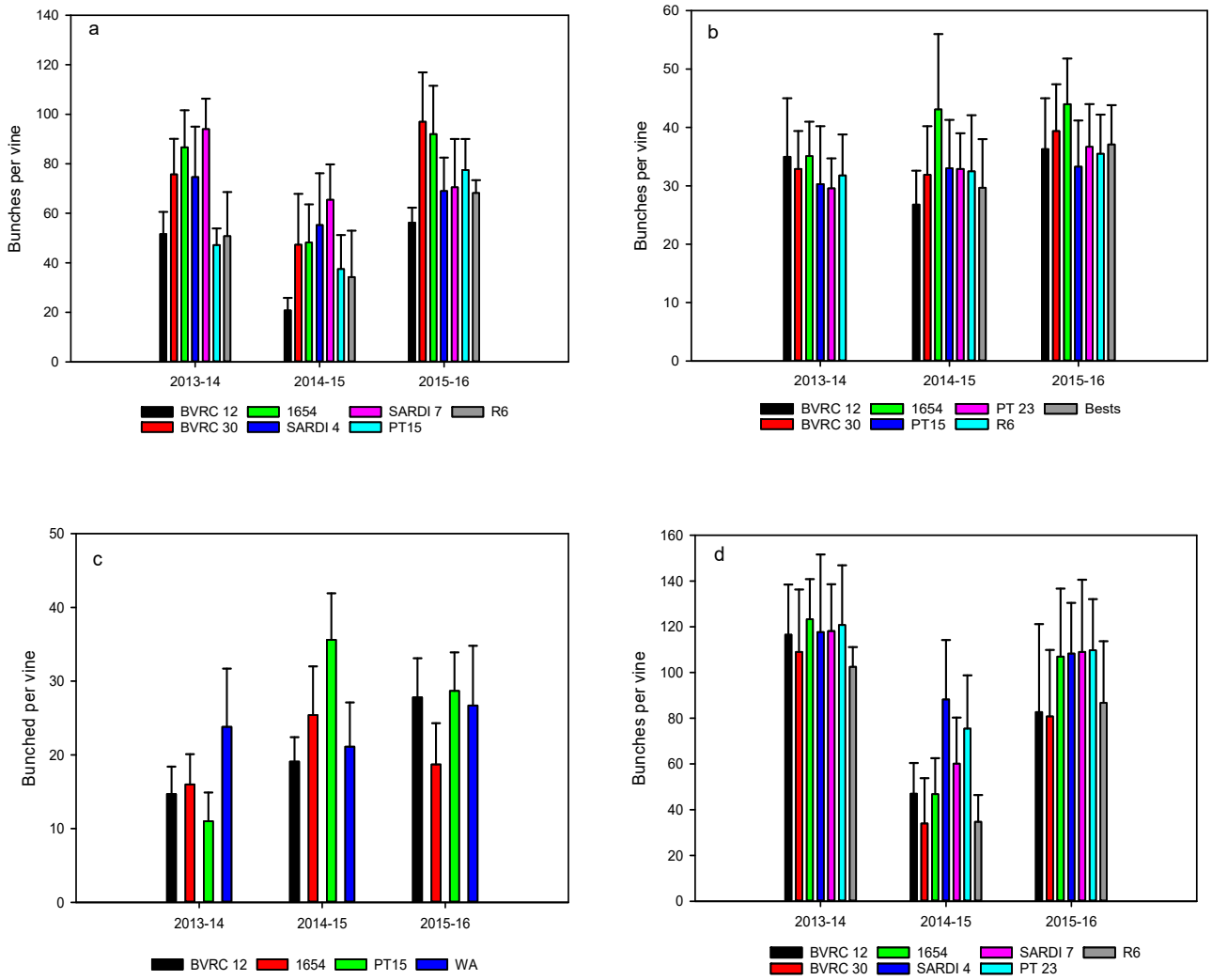


Figure 38. Number of bunches per vine of Shiraz clones at each of the four sites for harvest years 2014, 2015 and 2016.

a = Barossa. b = Grampians, c= Margaret River, d= Riverland.
Clone R6W is abbreviated to R6
Vertical bars represent the standard deviation for each mean value.

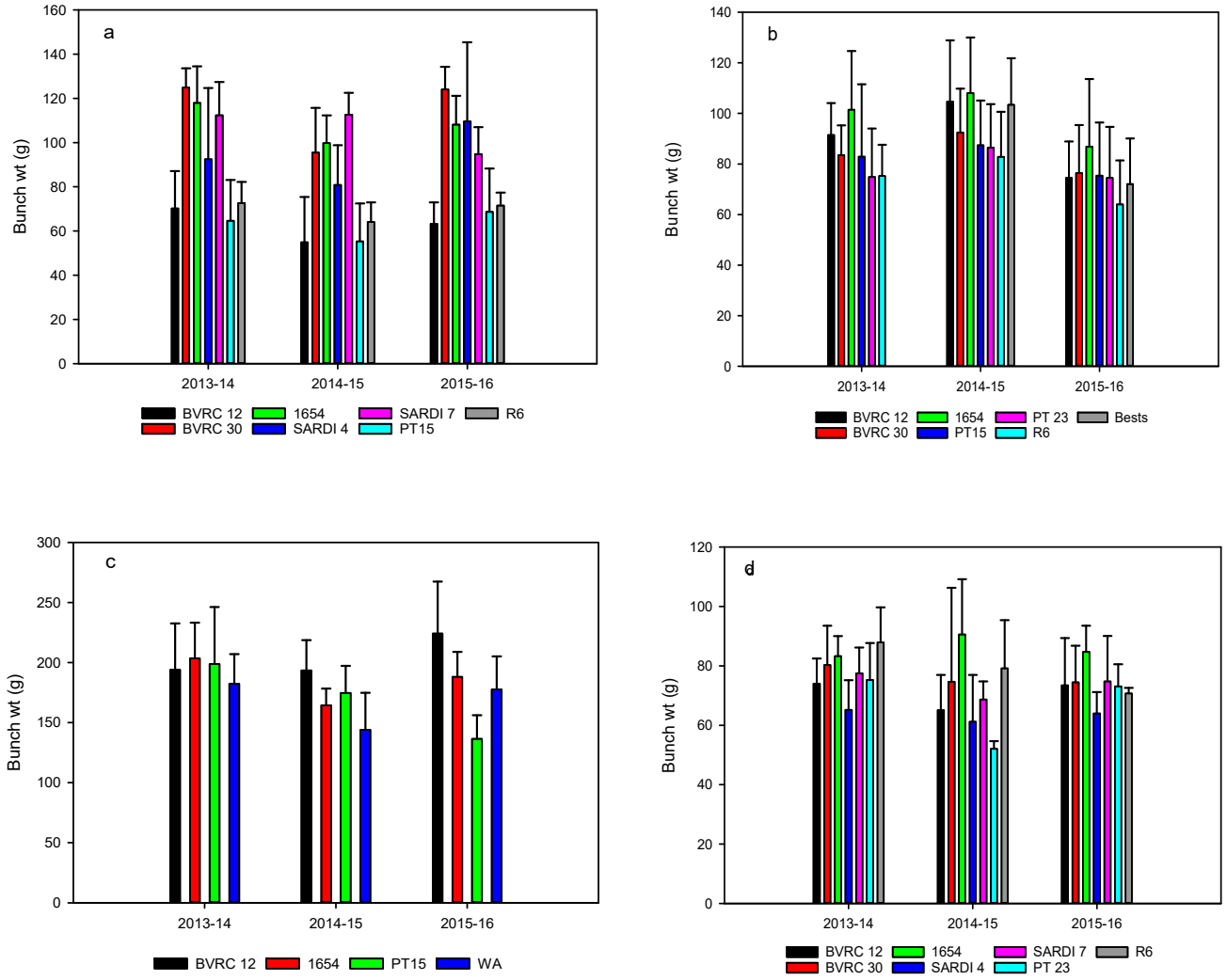


Figure 39. Bunch weight (g) per vine of Shiraz clones at each of the four sites for harvest years 2014, 2015 and 2016.

a = Barossa. b = Grampians, c= Margaret River, d= Riverland.
Clone R6W is abbreviated to R6
Vertical bars represent the standard deviation for each mean value.

Berry weight and berries per bunch

There was a wide range in berry weight at the Barossa site across the three years with a minimum of 0.52 g (PT 15 in 2013-14) to 1.16 g for SARDI 7 in 2014-15. (Figure 40a). Clones PT 15 and BVRC 12 recorded the lowest or second lowest berry weight in all years. In comparison, BVRC 30 and SARDI 7 consistently recorded some of the heaviest berries. There was no similar separation in the number of berries per bunch (Figure 41a) with the exception of R6W having the lowest number of berries per bunch in all three seasons.

Mean berry weight for Shiraz at the Grampians site was highest in the 2014-15 season (Figure 40b) and lower in the 2013-14 and 2015-16 seasons. The mean berry weight of clone 1654 was highest in two out of three seasons, and that of PT23 and R6W the lowest or second lowest in three seasons. Clone R6W had the lowest number of berries

per bunch at the Grampians site in all three seasons (Figure 41b). Berry number per bunch was greater in the 2013-14 season, and the 2015-16 season had the lowest berry number per bunch with most of the clones. Clone 1654 produced the highest berry number per bunch in all seasons. Whiting (2003) reported that PT23 had a significantly lower berry weight than 1654 and R6W had significantly less berries per bunch than BVRC 12. There were no significant differences between all other comparisons of clones.

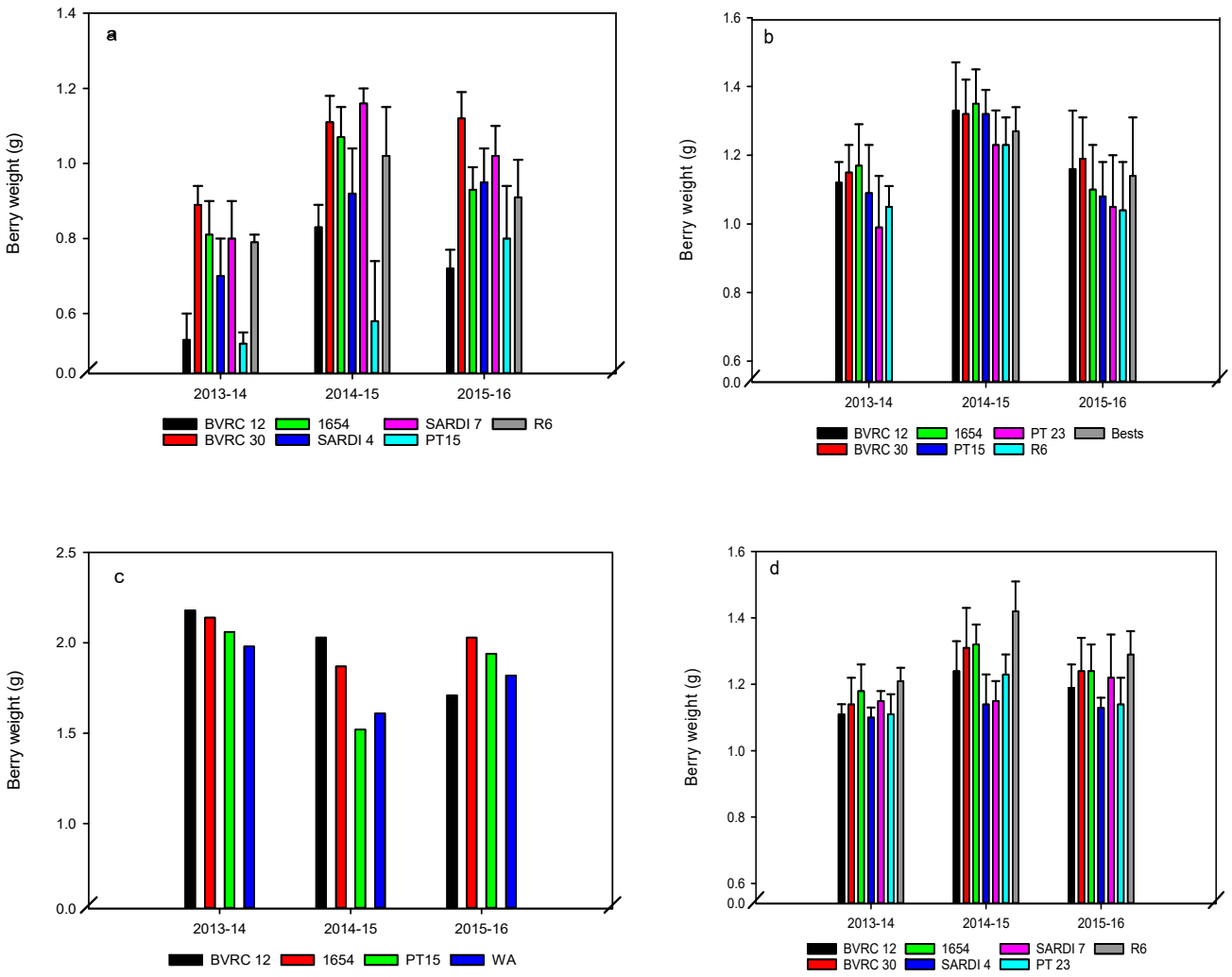


Figure 40. Berry weight (g) of Shiraz clones at each of the four sites for harvest years 2014, 2015 and 2016.

a = Barossa. b = Grampians, c= Margaret River, d= Riverland.
Clone R6W is abbreviated to R6.
Vertical bars represent the standard deviation for each mean value where calculated.

Average berry weight was heavier in Margaret River than the other three sites, with berries often being heavier than 2 g (Figure 40c). Results were not consistent, with BVRC 12 recording both the lightest and heaviest berries during

the three years. Clone 1654 produced fairly consistent berry weights and berry number per bunch across the three seasons but the ranking between clones was inconsistent. For example, BVRC 12 and PT15 ranged from the least to most berries per bunch (Figure 41c).

In the Riverland, R6W had the heaviest berries in each of the three years (Figure 40d), however probably not significantly heavier in years one and three. There was a trend for SARDI 4 to have smaller berries and the least number of berries per bunch. The fewer number of berries per bunch on R6W that was apparent in the Barossa site (and, to a lesser extent, the Grampians site) was only apparent at the Riverland site in the 2015-16 season (however that standard deviation suggests it was not significantly less than most other clones; Figure 41d). Clone 1654 had the highest number of berries per bunch in two of the three seasons.

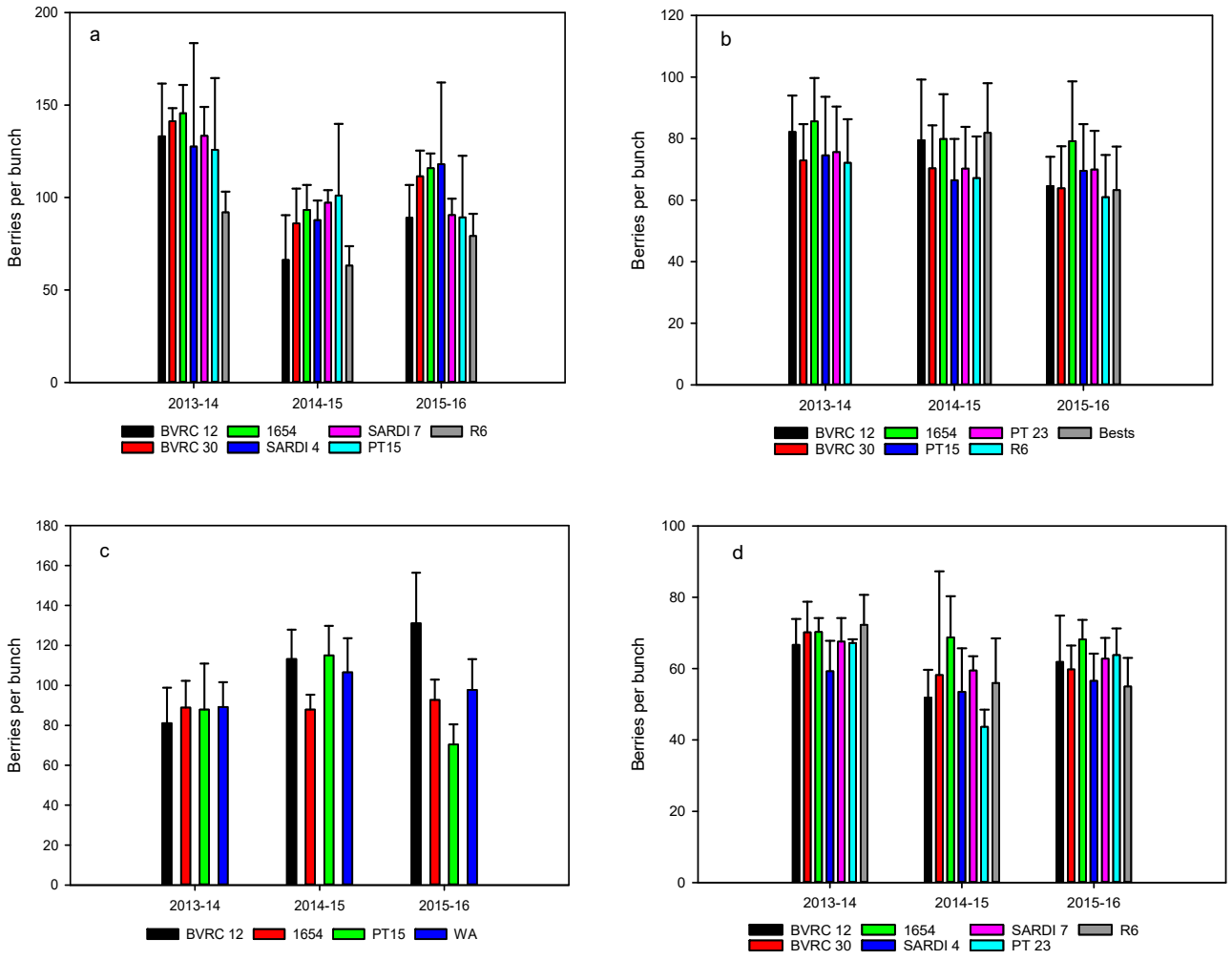


Figure 41. Berries per bunch of Shiraz clones at each of the four sites for harvest years 2014, 2015 and 2016.

a = Barossa. b = Grampians, c= Margaret River, d= Riverland.
Clone R6W is abbreviated to R6.
Vertical bars represent the standard deviation for each mean value.

7.6 Berry composition

Total soluble solids, (°Brix) titratable acid and pH was measured on juice extracted from a sample of 50 berries collected immediately before harvest in each year at each site where it was logistically possible and there was timely access to a laboratory.

7.6.1 Chardonnay

Soluble solids concentration

Balancing the goal of attaining target maturity, and the threat of Botrytis bunch rot, resulted in the maturity of some Chardonnay clones across the three years that the Drumborg site was harvested being lower than target °Brix (Figure 42a). This was not a constraint problem at the other four sites. In the two seasons that all clones were harvested, I10V5 recorded the lowest °Brix. This pattern was also apparent at the Grampians site where I10V5 recorded the lowest °Brix at all three harvests (Figure 42b).

The Gingin clone and I10V1 consistently recorded the highest °Brix in all four seasons at the Great Southern site (Figure 42c), with the four Bernard clones being lower and similar to each other. The average °Brix for the Great Southern site at harvest was similar for 2013-14, 2014-15 and 2015-16 with the final year being slightly lower. This which was due to the need to harvest fruit before unacceptable levels of Botrytis bunch rot developed. In the final (2016-17) season the Gingin clone and I10V1 were again the highest in °Brix at harvest with the Bernard clones slightly lower and similar. The pattern of the Gingin clone having higher °Brix was also apparent at the Margaret River site (Figure 42d) in three of the four seasons, and smaller differences between the four Bernard clones were observed.

The warm irrigated environment at the Riverland site results in rapid ripening of both red and white varieties and harvesting fruit before it exceeds target maturity is an annual challenge in predicting harvest date. For the three seasons that the clones were berry sampled for maturity testing there were only minor difference in ^{0}Brix between clones (Figure 42e) and, based on the standard deviation of each clone (which was small), they were probably not significantly different. There was a range of 0.3 to 0.7% alcohol in the final wines for the four years (Table 37, Table 38,

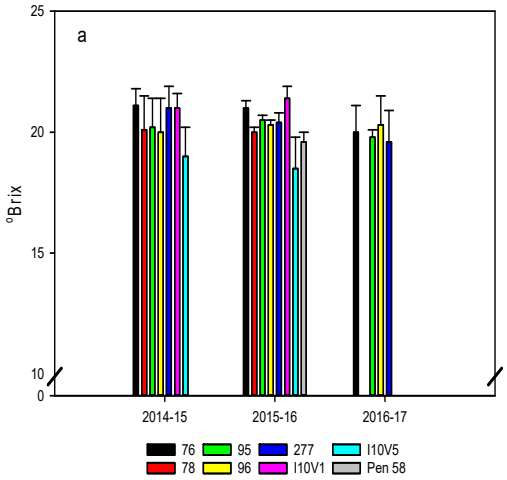
Table 39 and Table 40) which also indicates that all the clones were of similar maturity at harvest.

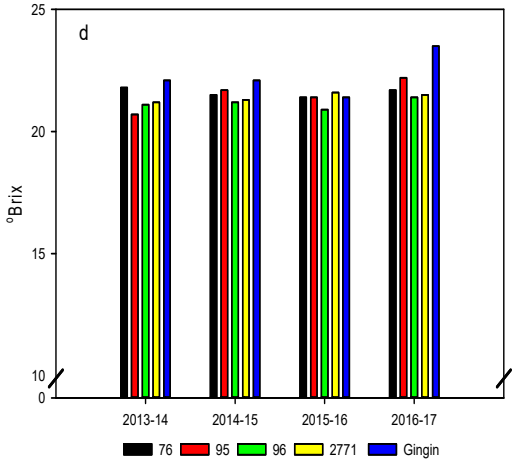
Titratable acid and pH

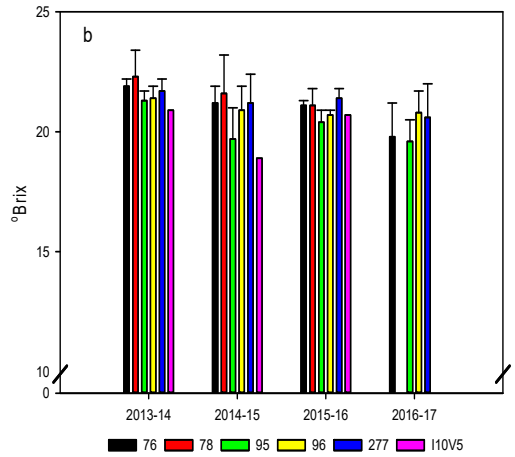
Berry juice Titratable acid (TA) and pH were not measured on Chardonnay samples collected from the Riverland site and the sampling protocol used at the Great Southern and Margaret River sites precluded any statistical analysis of the data.

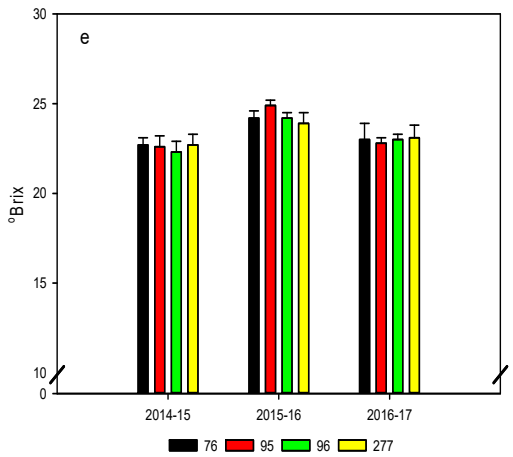
At Drumborg the clones separated into two groups for TA with 76, 78 and Pen58 being lower in TA than a higher group containing the other five clones (Figure 43a). A smaller and opposite pattern with juice pH was observed (Figure 44a), with no difference between clones based on the standard deviation values. For the two seasons that TA and pH were measured at the Grampians site there was no consistent pattern in the ranking of the clones, but there was at the two Western Australia sites.

At Margaret River the Gingin clone and 76 consistently recorded the highest TA's and low pH (Figure 43d and Figure 44d) and the trend for the Gingin clone to record high TA was repeated at the Great Southern site (Figure 44c) in two of the four seasons. Similar to Margaret River the pH of juice of 76 at Great Southern was in the lower end of the range recorded over the four seasons.









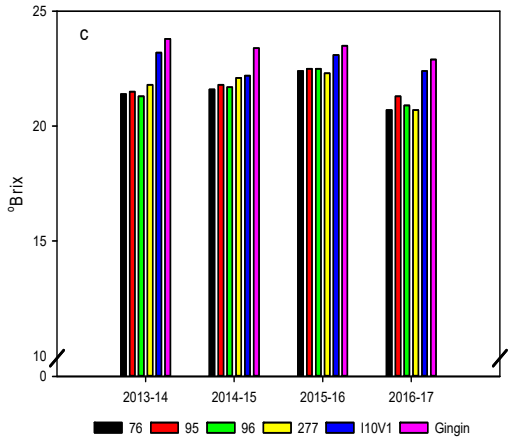


Figure 42. Total soluble soids (°Brix) of juice of Chardonnay clones at five sites for the years data were collected.

a = Drumborg

b = Grampians

c = Great Southern.

d = Margaret River

e= Riverland

Vertical bars represent the standard deviation where the sampling protcol enabled this calculation.

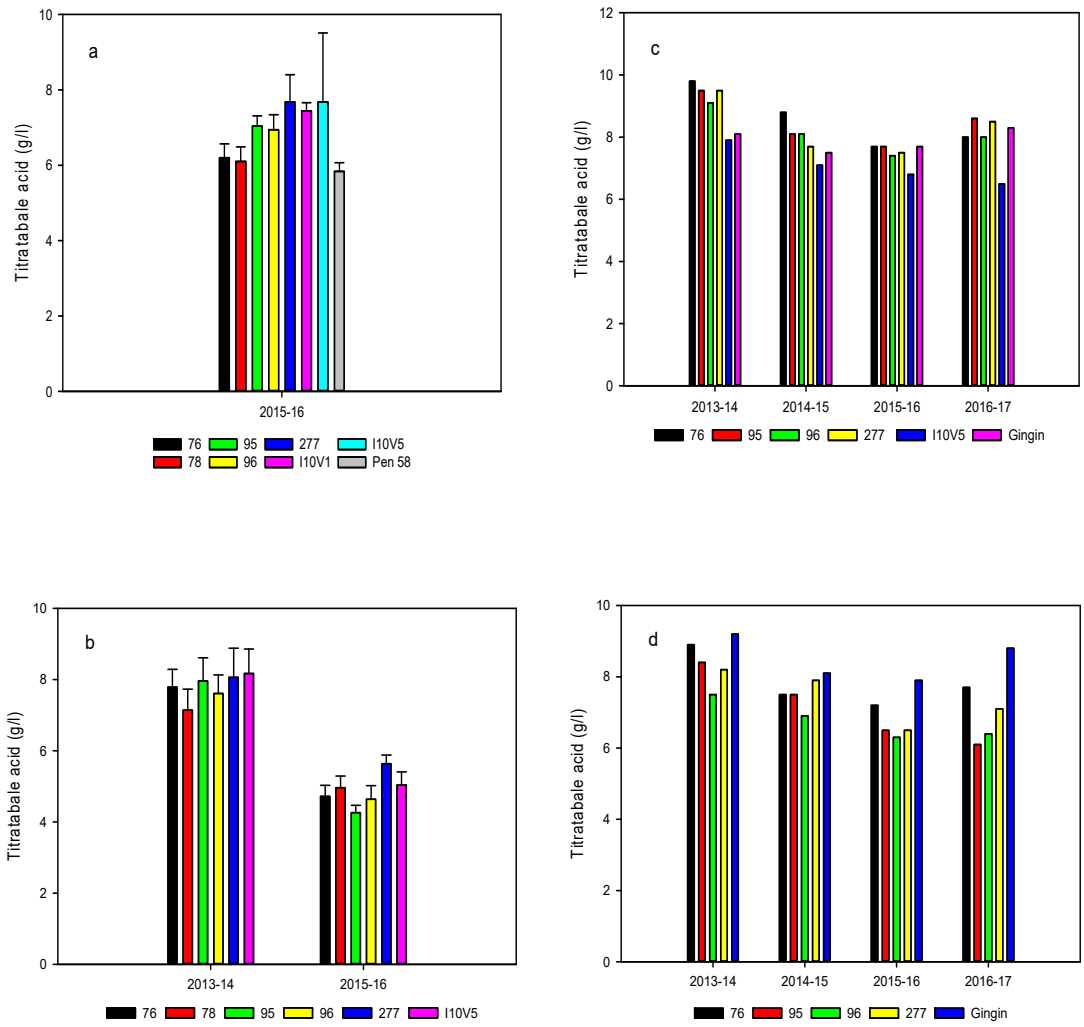


Figure 43. Titratable acid of juice of Chardonnay clones at four sites for the years data were collected.

a = Drumborg, b = Grampians, c = Great Southern, d = Margaret River.
Vertical bars represent the standard deviation where the sampling protcol enabled this calculation.

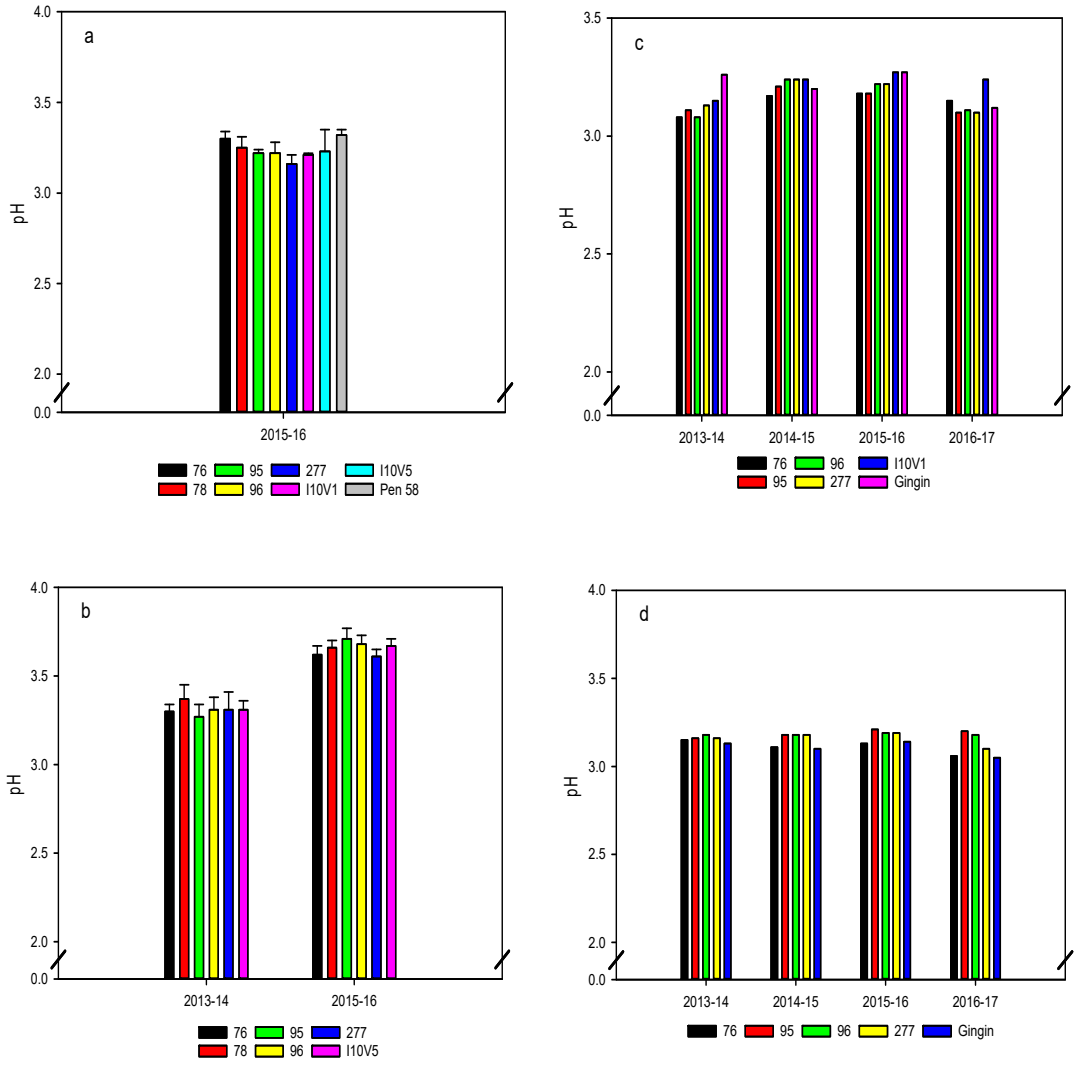


Figure 44. pH of juice Chardonnay clones at four sites for the years data were collected.

a = Drumborg, b = Grampians, c = Great Southern, d = Margaret River
Vertical bars represent the standard deviation where the sampling protcol enabled this calculation

The higher TA of the Gingin clone at the two WA sites is also evident in the scatter plot of the pooled °Brix and TA data (Figure 45). While the Gingin clone recorded the highest °Brix of all clones, sites and years it also had the highest TA. Clone 76 and I10V1 also recorded favourable ratios suggesting that the Gingin, 76 and I10V1 clones may be more suitable for sparkling wine base than perhaps 78 and I10V5.

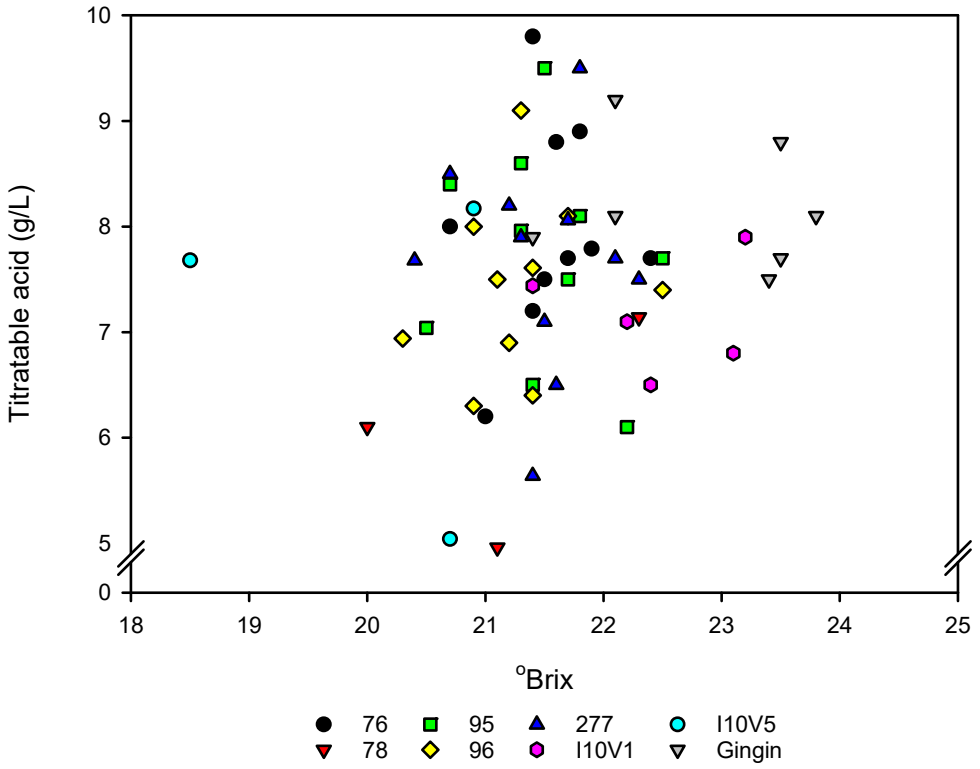


Figure 45. Scatter plot of the pooled oBrix and Titratable acid data for all clones, sites and years data was available.

7.6.2 Shiraz

Soluble solids concentration

While there were large differences in yield (Figure 37a) previously reported between Shiraz clones and between years at the Barossa site, this was not reflected in °Brix (Figure 46a) when all clones were berry sampled on the same day prior to harvest. The warm-hot conditions in 2014-15 resulted in rapid ripening of the low-yield crop and °Brix of fruit was higher than the target when it was logistically possible to harvest and deliver fruit for small lot winemaking. Similar weather conditions in the Riverland in 2014-15 and a low crop also resulted in rapid ripening with fruit being higher than the target °Brix (Figure 46d) by the time it was harvested. Similar to the Barossa, the large difference in yield between clones was not reflected in difference in °Brix.

The higher yield of 1654 previously reported at the Grampians site (Figure 37b) resulted in lower °Brix (Figure 46b) when sampled on the same day. The lower yielding clones tended to have higher °Brix although the magnitude of the standard deviation associated with these measures suggests that these differences are not significant. The lower °Brix of 1654 at harvest was reflected in the % alcohol of the finished wine for the 2016 and 2017 vintages (Table 41 and Table 42).

While the sampling protocol used at the Margaret River site precluded calculation of any statistics, there was no consistent pattern in °Brix at harvest between the clones across the three years. The influence of yield on °Brix observed at the Grampians site was also apparent in Margaret River where, for example, in 2015-16 BVRC 12 recorded the highest yield (Figure 37c) and the lowest °Brix (Figure 46c) while 1654, had lower yield and higher °Brix immediately prior to harvest. In comparison, in 2013-14, while the WA selection was the highest yielding clone it was not the lowest in °Brix and PT15, which was lower yielding, was not the highest in °Brix. The percent alcohol in the finished wines was a better indicator of maturity at harvest as a result of a larger and more representative harvest sample and these data (

Table 401, Table 41 and Table 423) reveal a range of 0.5, 1.4 and 2.1 % alcohol in the finished wines in 2013-14, 2014-15 and 2015-16 respectively, suggesting there were differences in berry maturity at harvest.

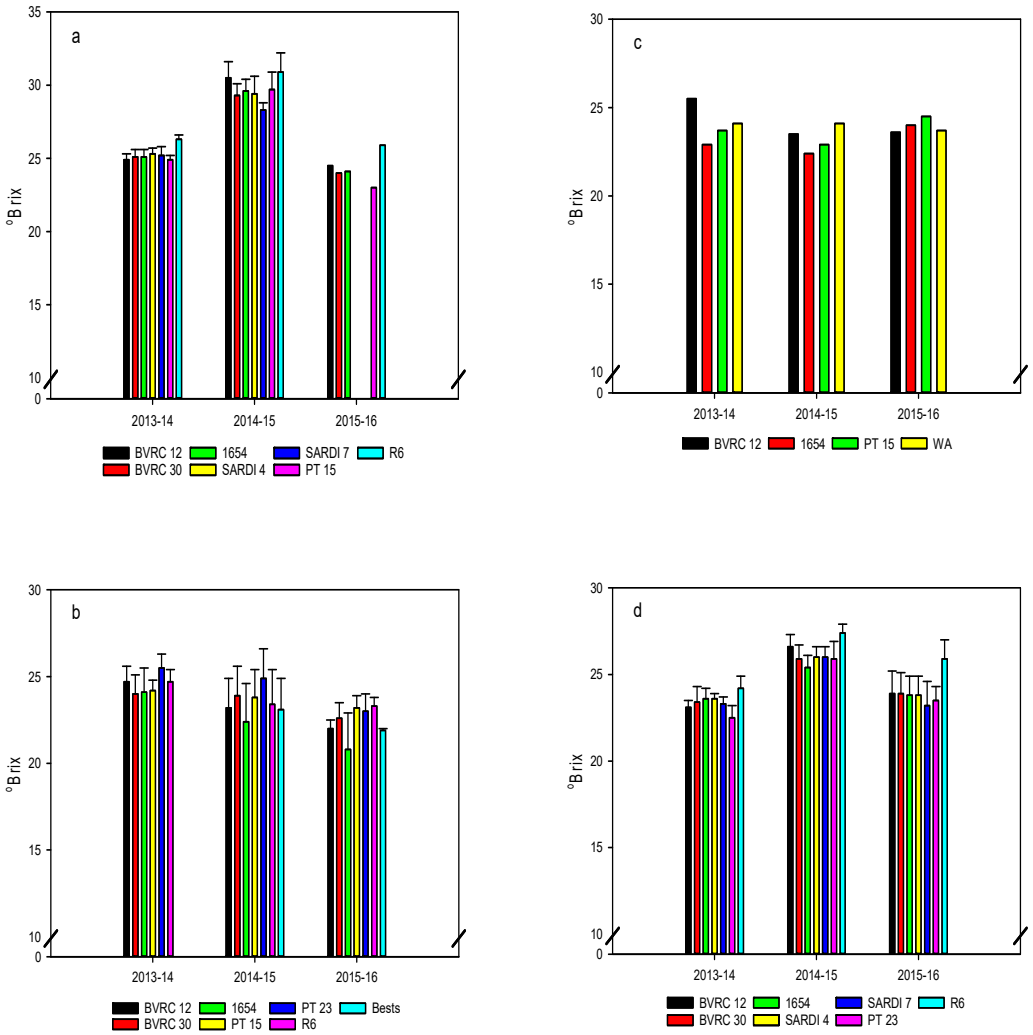


Figure 46. Total souble solids (°Brix) of juice of Shiraz clones at four sites for three years.

a = Barossa, b = Grampians, c = Margaret River, d = Riverland.
Clone R6W is abbreviated to R6.
Vertical bars represent the standard deviation where the sampling protcol enabled this calculation

Titratable acid

The standard deviation in titratable acid (TA) between Shiraz clones at the Grampians sites (Figure 47a) for the two years data were collected suggests there was no difference in TA between clones. The lower values recorded in 2015-16 are a reflection of differences in maturity and growing conditions. TA's at the Margaret River site (Figure 47b) were similar to the Grampians and there was no apparent difference between clones, for example in 2013-14 BVRC 30 recorded the highest TA and the lowest in 2015-16.

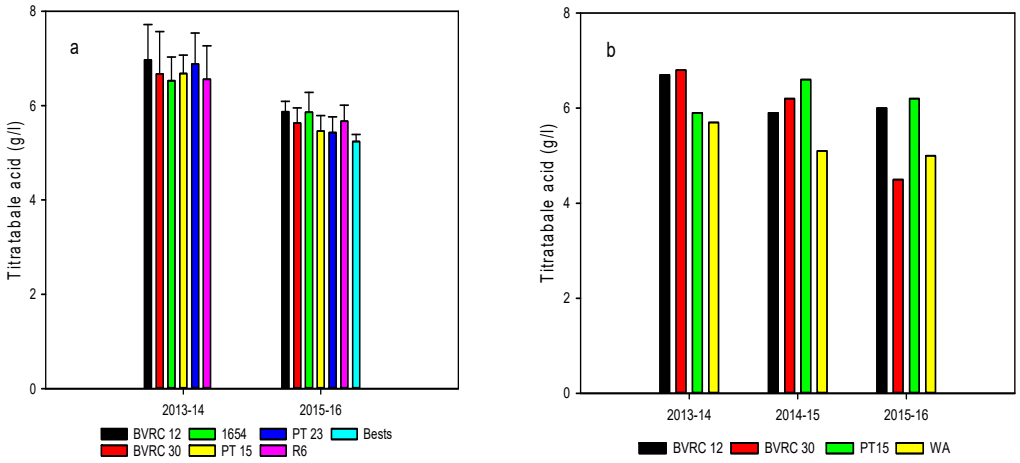


Figure 47. Titratable acid (g/L) of juice of Shiraz clones at two sites for two or three years.

a = Grampians, b = Margaret River
Clone R6W is abbreviated to R6.
Vertical bars represent the standard deviation where the sampling protcol enabled this calculation

pH

pH data for Shiraz clones was only collected for two years at the Grampians and Riverland sites and for three years at Margaret River. There was no clear pattern in pH between clones at the Margaret River site. The Riverland site recorded the highest pH's of the three regions where, while SARDI 4 and SARDI 7 were lower in pH, there were no differences between clones (Figure 48c). pH in 2015-16 was slightly higher than 2013-14 in the Riverland, which was the opposite of the Grampians site (Figure 48a). As juice pH is normally inversely related to °Brix, the differences reported between years is a reflection of the minor differences in maturity at sampling time between years.

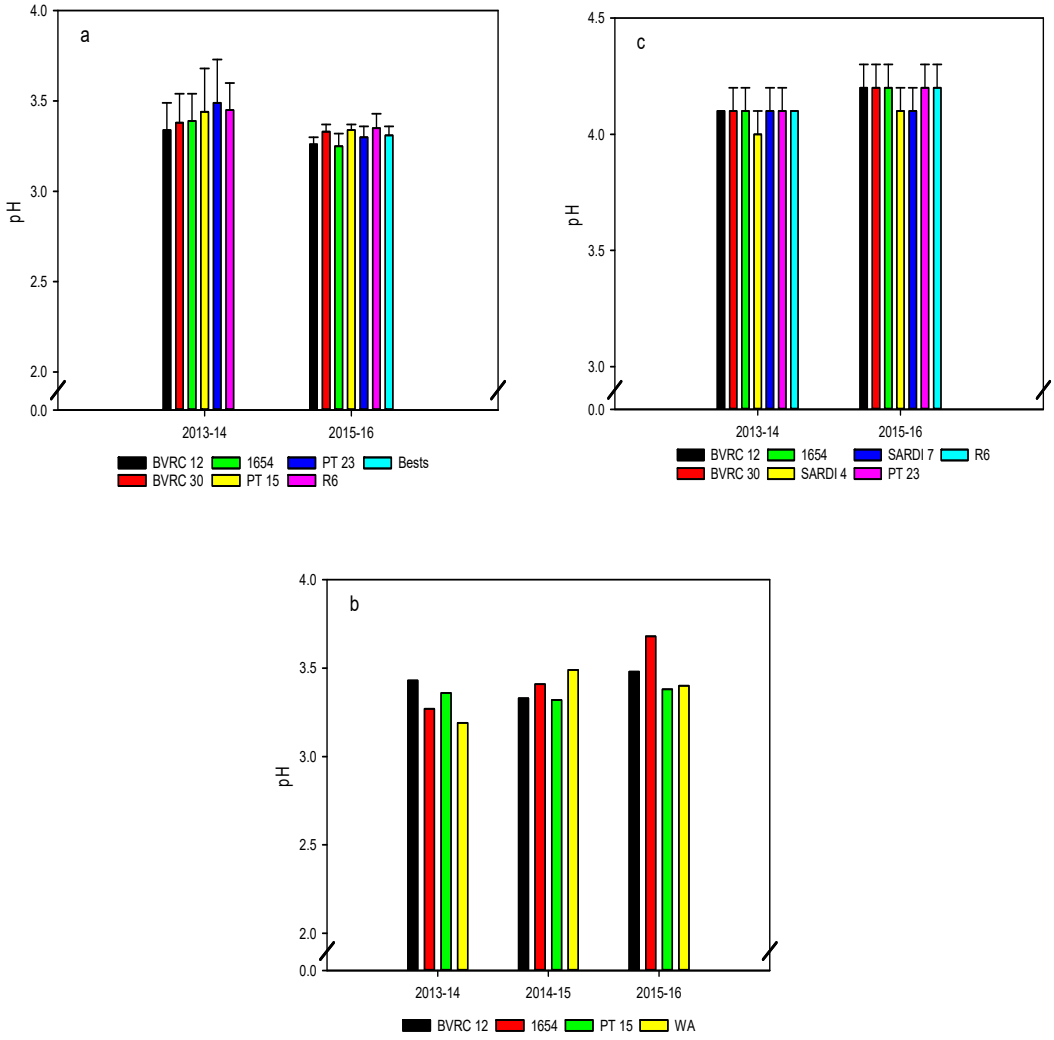


Figure 48. pH of juice of Shiraz clones at three sites for two or three years.

a = Grampians. b = Margaret River, c = Riverland.
Clone R6W is abbreviated to R6.
Vertical bars represent the standard deviation where the sampling protcol enabled this calculation.

7.7 Wine analysis at bottling

In each year AWRI undertook the analysis of the wines at bottling. Alcohol, glucose and fructose, pH, TA at pH 7 and 8.2, Malic acid, volatile acid, Free SO_2 and Total SO_2 were measured and these data are presented in Appendix 2.

7.8 Wine sensory analysis

7.8.1 Statistical methodology

a) For the statistical analysis of all clones of each variety in all regions and in each year the entire data set was used (each sensory panel member was considered a replicate). This approach revealed any confounding interactions which were absent in all but one data set. The sensory traits that were significantly different were then used for the Principal Component Analysis and plots using the mean score of the fermentation replicates.

b) For regional comparisons of sensory attributes, the mean score for all clones and fermentation replicates was used for statistical analysis and the sensory attributes that were significantly different between regions were used for the Principal Component Analysis and plots. This data set was also used to construct radar plots of sensory scores at the regional level and within regions with significant and non-significantly different sensory attributes included.

The different methodologies between a) and b) (i.e. the analysis of averaged or raw data) resulted in small differences in the number of sensory attributes that were considered significantly different even though the reported values were the same.

7.8.2 Sensory analysis of 2014 Chardonnay

7.8.2.1 Regional comparisons

There were no Chardonnay wines made from the Drumborg site for vintage 2014 (V14) due to cold weather during flower in late 2013 which resulted in very low grape yields.

The Principal Component Analysis (PCA) biplot for pooled data by region resulted in the remaining regions falling in three quadrats (Figure 49), indicating an impact of region on Chardonnay sensory attributes. Margaret River and Great Southern wines appeared in the same quadrat and were rated high in acid, astringency and citrus flavour. Riverland wines had high overall fruit flavour and stonefruit flavour, and a degree of hotness. The Grampians wines were rated high in in yellow colour, tropical fruit aroma, box hedge aroma, passionfruit aroma and sweaty /cheesy aroma.

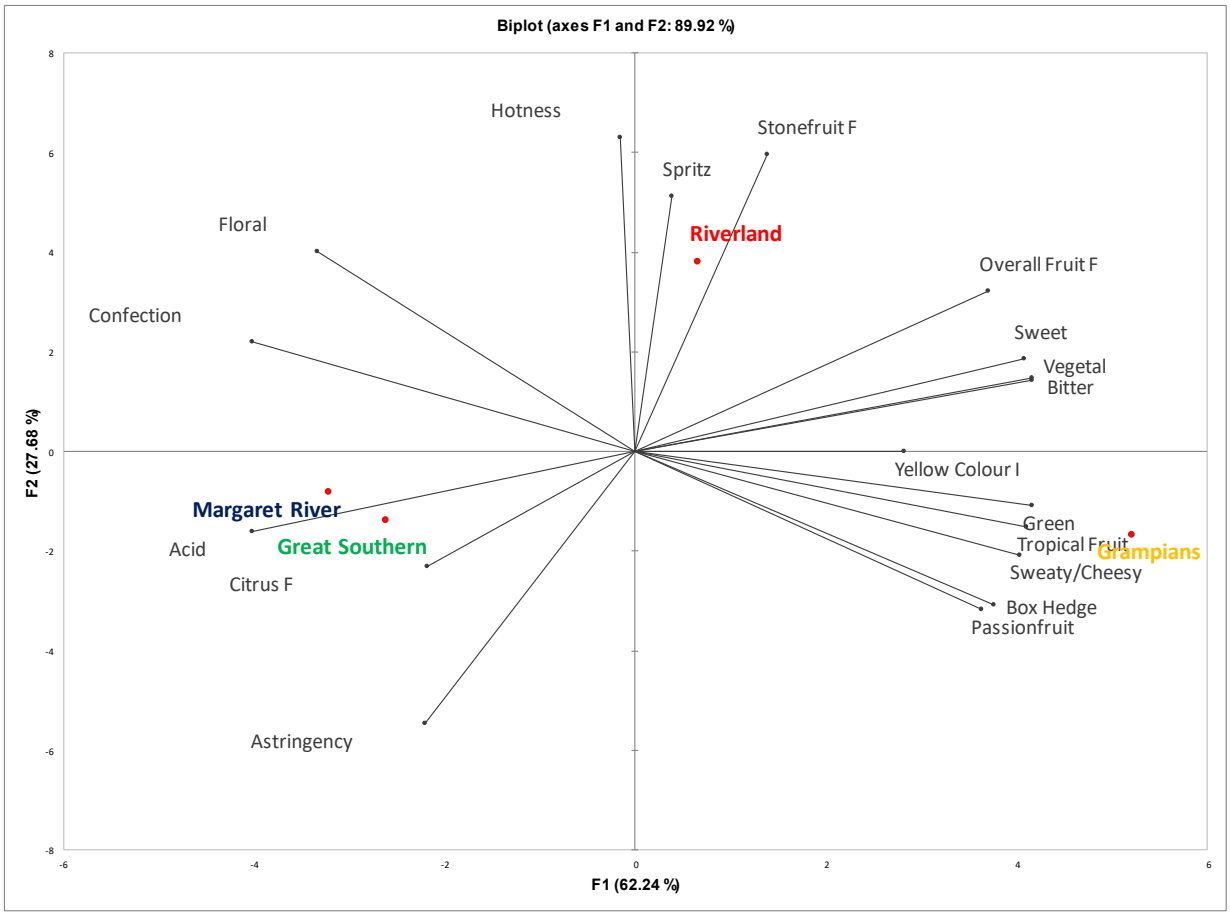


Figure 49 . Scores and loadings bi-plot for PCA of attributes for 2014 Chardonnay wines pooled for each region, showing F1 and F2.

For each region the mean score of each attribute for all clones and for both winemaking replicates and tasting sessions were used to generate least significant differences. From this conservative analysis of variance there were significant differences among 20 of the 28 attributes. Pineapple aroma, overall fruit aroma, stonefruit aroma, citrus aroma, herbal aroma, flint aroma, overall fruit flavour and hotness were not significantly different. The highest scores (>4 = greatest intensity) were allotted to astringency and acidity, and some of the lowest scores (<1 = lowest intensity) were allotted to spritz and box hedge aroma.

The radar plot of the mean scores of all attributes for each region (Figure 50) highlighted that the Grampians wines scored highest in passionfruit, green sweaty/cheesy, and box hedge aromas, pungent, bitter taste, fruit after taste and tropical fruit flavours. Great Southern wines had the highest citrus flavour, astringency and acid while the Margaret River wines had the highest confection and floral aromas. For the Riverland wines stonefruit flavour, spritz and sweetness were significantly higher than wines from one or more of the other regions.

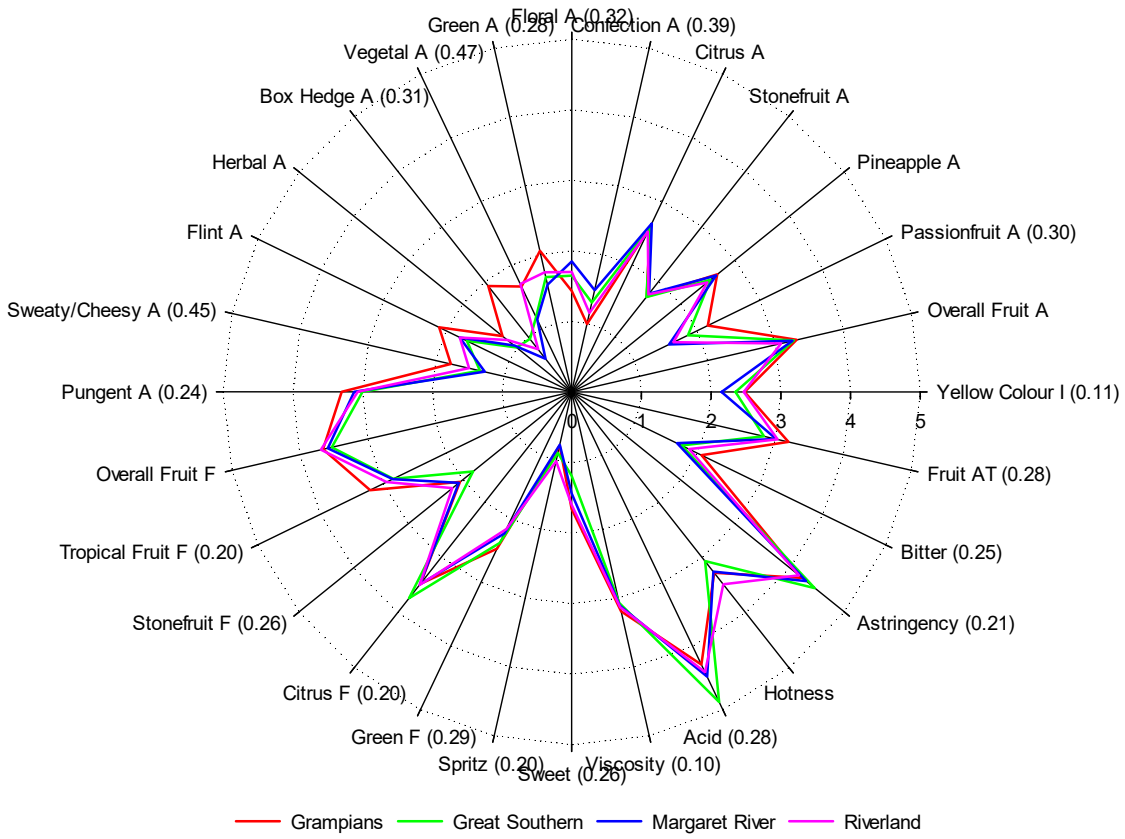


Figure 50 Radar plot of mean sensory scores for V14 Chardonnay wines for all clones in each region. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

For the PCA plots of all clones in each region (Figure 51), F1 and F2 only accounted for 55.5% of the variation in the data set. Similar to Figure 49, most samples in the PCA's were grouped more by region than by clone, with the exception being the Riverland samples, which were relatively evenly distributed through the PCA plot (Figure 51). The wines plotted to the left of the figure were rated higher in floral and confection, while those to the right were rated lower in these attributes and higher in box hedge aroma, passionfruit aroma, vegetal aroma and sweaty/cheesy aroma. The separation along F2 was mainly due to acid related attributes, with acid, astringency and citrus flavour being higher for those wines plotted to the upper half of the figure, mainly the wines with high titratable acidity from the Margaret River and Great Southern regions.

The Margaret River and Great Southern wines tended to be rated lower in the attributes tropical fruit aroma, passionfruit aroma, box hedge aroma and green flavour, while being rated higher in floral aroma, confection aroma, acid and citrus flavour. Grampians samples were relatively high in box hedge aroma, passionfruit aroma, sweaty/cheesy aroma and vegetal aroma, and lower in floral and confection aromas. Riverland samples were well separated over the PCA plot, with clones 96 and 95 rated higher in sweet, tropical fruit aroma, bitterness, yellow colour, stonefruit flavour and overall fruit flavour, while clones 78 and 76 were rated higher in floral and confection aromas, and 277 rated highest for the Riverland samples in citrus flavour and acid. Clone 78 vines were removed from the Riverland field site by Yalumba after harvest as some winemakers considered it possessed excessive "*Muscat character*".

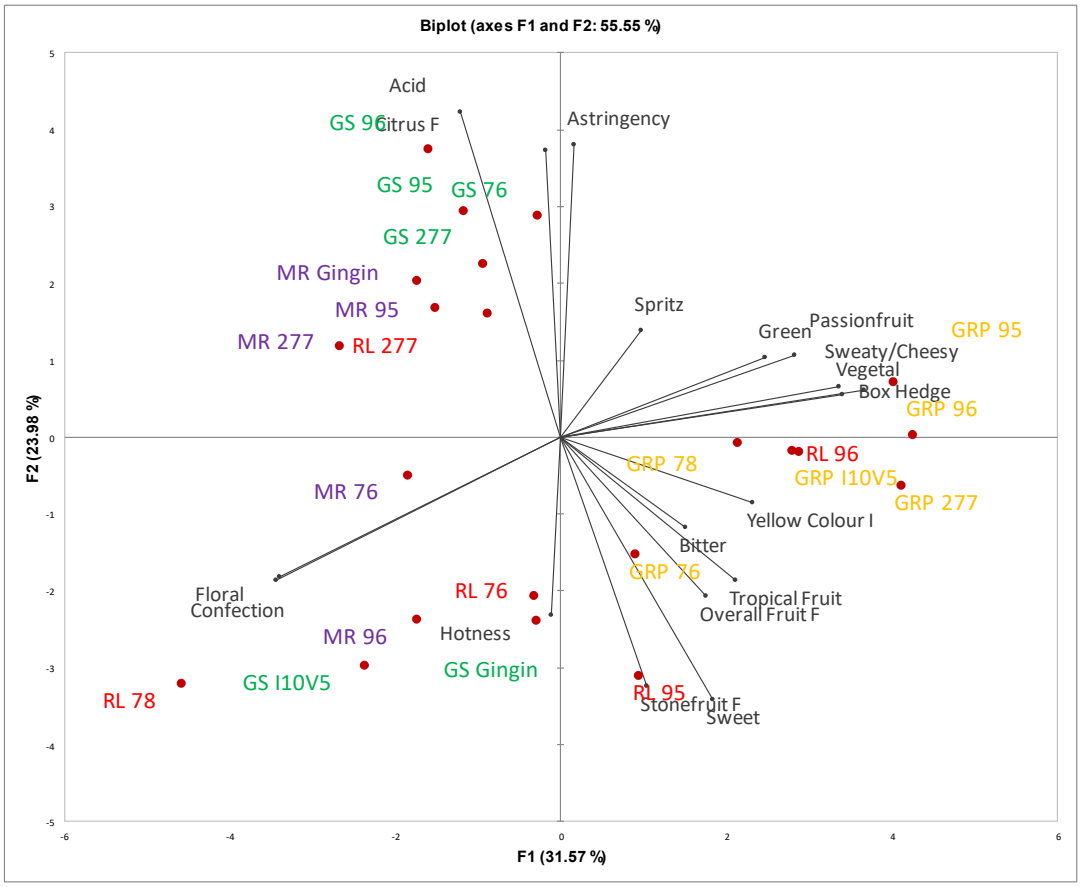


Figure 51. Scores and loadings bi-plot for PCA of attributes and treatments for 2014 Chardonnay clonal wines, showing F1 and F2.

GRP= Grampians, GS = Great Southern, MR = Margaret River, RL = Riverland

7.8.2.2 Within-region comparisons

Radar plots of each Chardonnay clone grouped by region highlight the differences reported in Figure 51.

Grampians

At the Grampians site (Figure 52) there were significant differences between clones for 19 of the 28 attributes. Only attributes with significant differences between clones will be examined further. With overall fruit aroma and flavour the clones I10V5, 76, 96 and 277 scored higher than 78 and 95. Clone 76 was higher in confection and floral aromas, tropical fruit flavours and hotness, while relatively lower in box hedge and sweaty/cheesy aromas, and vegetal aroma score. Clone 78 had a relatively low score for hotness, passionfruit aroma and stonefruit aroma. Clone 95 scored relatively high for hotness, whilst 96 scored higher for passionfruit aroma and tropical fruit flavour. Clone 277 scored high in stonefruit aroma, and I10V5 scored higher in passionfruit aroma and tropical fruit flavour but lower in hotness, and sweaty/cheesy and vegetal aromas.

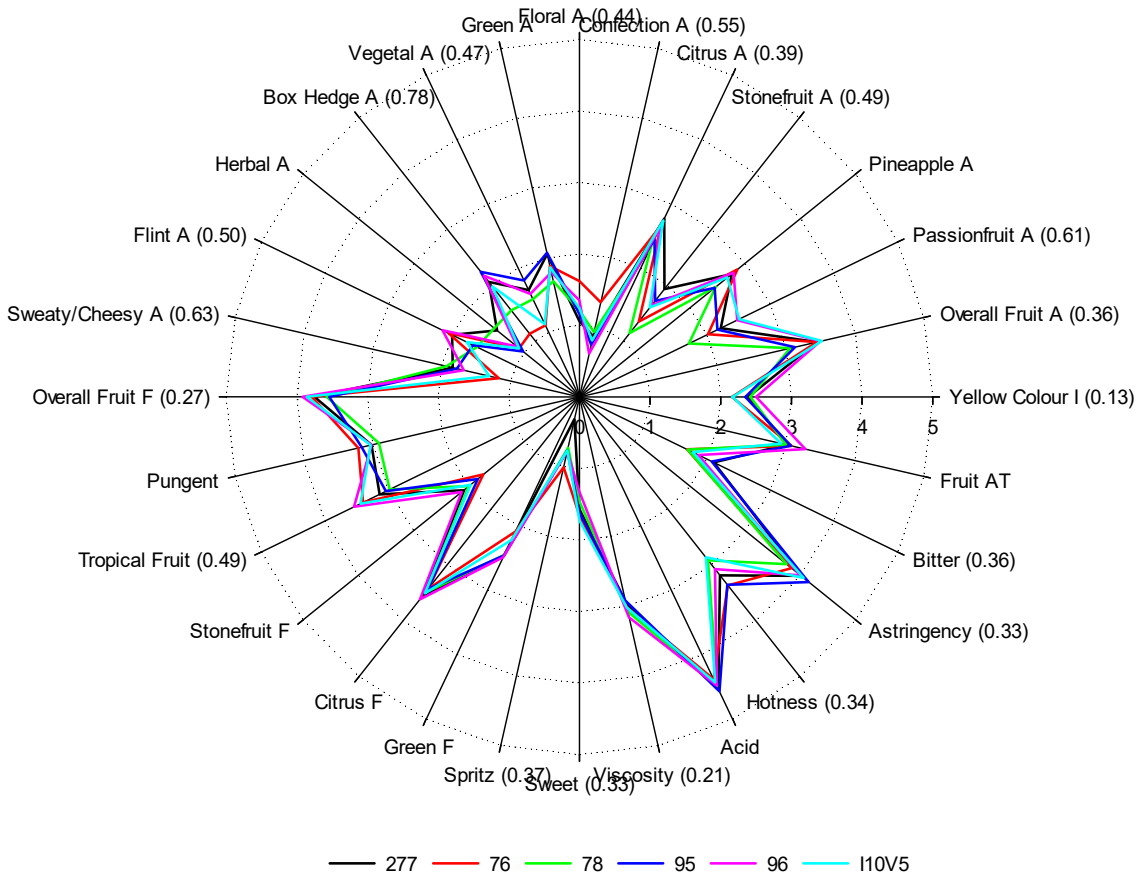


Figure 52. Radar plot of sensory attributes of V14 Chardonnay clonal wines from the Grampians. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

Great Southern

In the Great Southern wines there were significant differences between clones for 13 of the 28 attributes (Figure 53). There were no significant differences between clones for overall fruit aroma or fruit aftertaste, but there were differences in overall fruit flavour, with the Gingin clone having the highest score and 95 and 277 the lowest scores. Clone 76 was high in box hedge aroma and astringency, and 277 was also high in box hedge aroma. Clone 95 scored relatively high in spritz and astringency, and low in hotness and tropical fruit flavour. Clone 96 scored higher in green flavour and low in sweetness, hotness and stonefruit flavour. Clone I10V5 was higher in sweetness, hotness, tropical fruit and stonefruit flavours, but lower in box hedge aroma, green flavour and astringency. The Gingin clone scored higher in yellow colour, stonefruit flavour, pungency and hotness. There was a clear separation in acid taste, with the Gingin and I10V5 wines both being significantly lower than the other four clones.

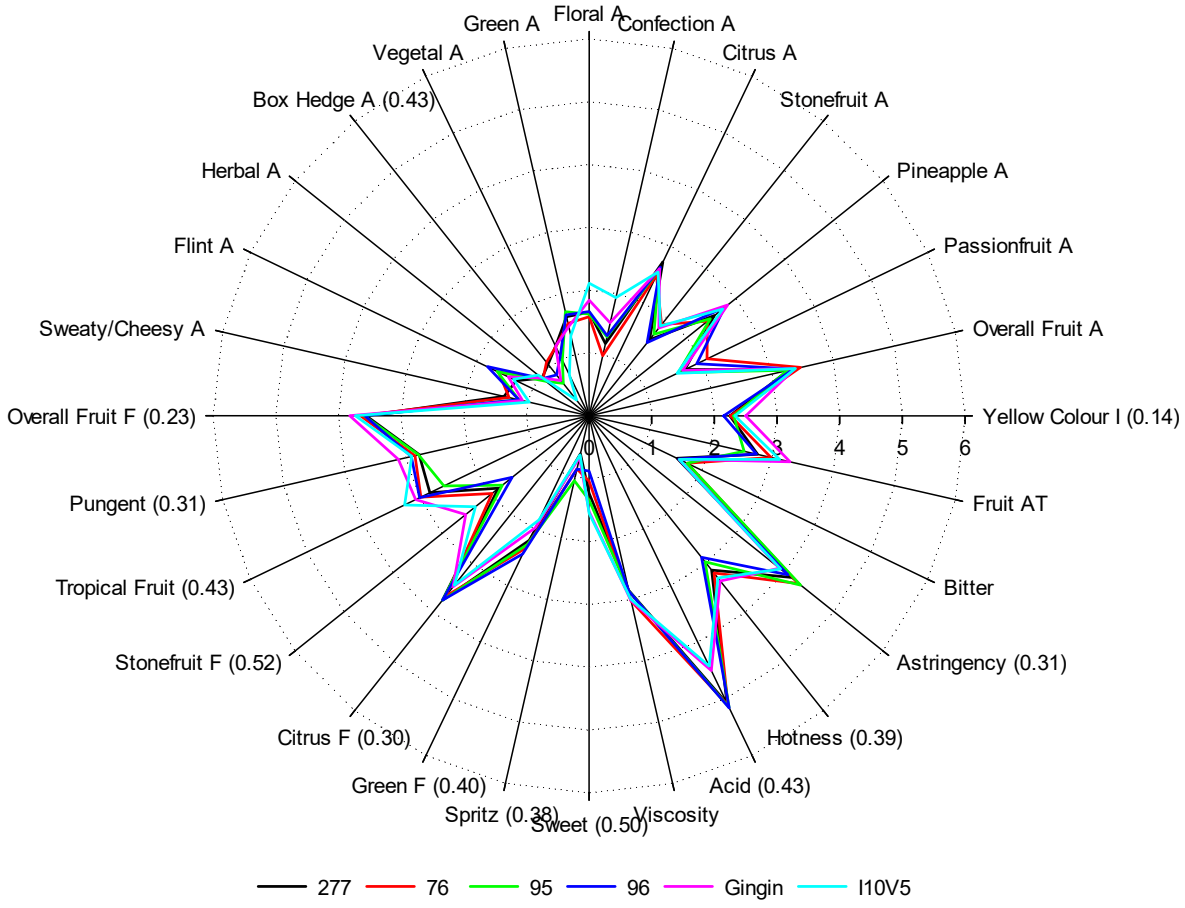


Figure 53. Radar plot of sensory attributes of V14 Chardonnay clonal wines from the Great Southern. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

Margaret River

For Margaret River wines there were only 11 attributes with significant differences between clones, out of the 28 assessed (Figure 54). There were no significant differences between clones for overall fruit aroma and fruit aftertaste, but there were differences in overall fruit flavour with 76 and 96 having higher scores and 277 the lowest. Clone 76 was relatively high in tropical fruit flavour while 277 scored higher for hotness and astringency, and low for tropical fruit flavour. Clone 95 scored highly for spritz and low for hotness, while 96 scored well for citrus aroma and tropical fruit flavour, but low for acidity, astringency and spritz. The Gingin clone scored higher for yellow colour and green aroma, but low for citrus aroma.

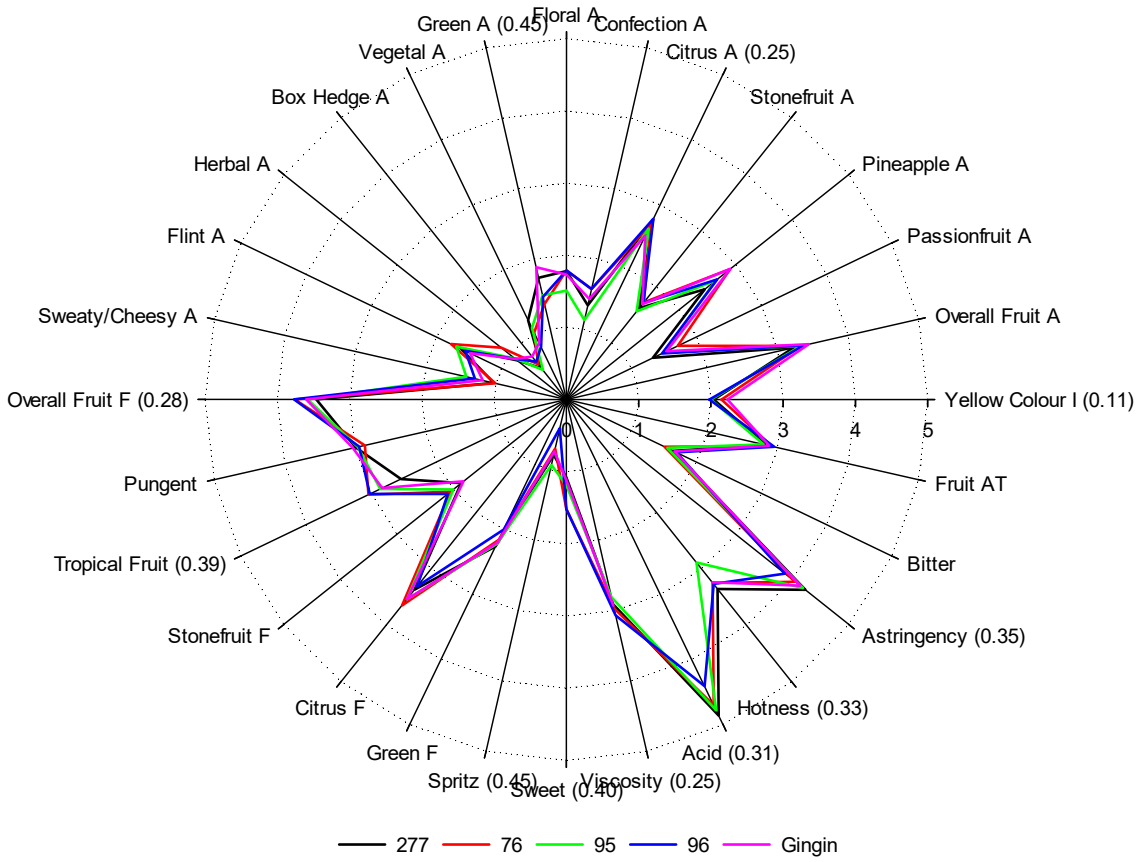


Figure 54. Radar plot of sensory attributes of V14 Chardonnay clonal wines from Margaret River. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

Riverland

In the Riverland, 16 of the 28 attributes showed significant differences between Chardonnay clones (Figure 55). With overall fruit aroma, 78 had the highest score and 277 the lowest, and for overall fruit flavour 76 and 96 scored highest and 78 the lowest. There were no significant differences between fruit aftertaste. Clone 76 had high yellow colour and low scores for sweaty/cheesy aroma, spritz and bitterness. Clone 78 scored higher for citrus, pineapple, confection and floral aromas, and had low scores for vegetal, box hedge and sweaty/cheesy aromas (all contributing to its highest overall fruit aroma score), as well as low scores for acidity, astringency, spritz and yellow colour. Clone 95 scored high for citrus and sweaty/cheesy aromas, and bitterness, and low for astringency, while 96 scored high for vegetal, box hedge and sweaty/cheesy aromas, sweetness and spritz, and low for confection and floral aromas, and bitterness. Clone 277 scored high for acid and astringency, and low for pineapple aroma and sweetness.

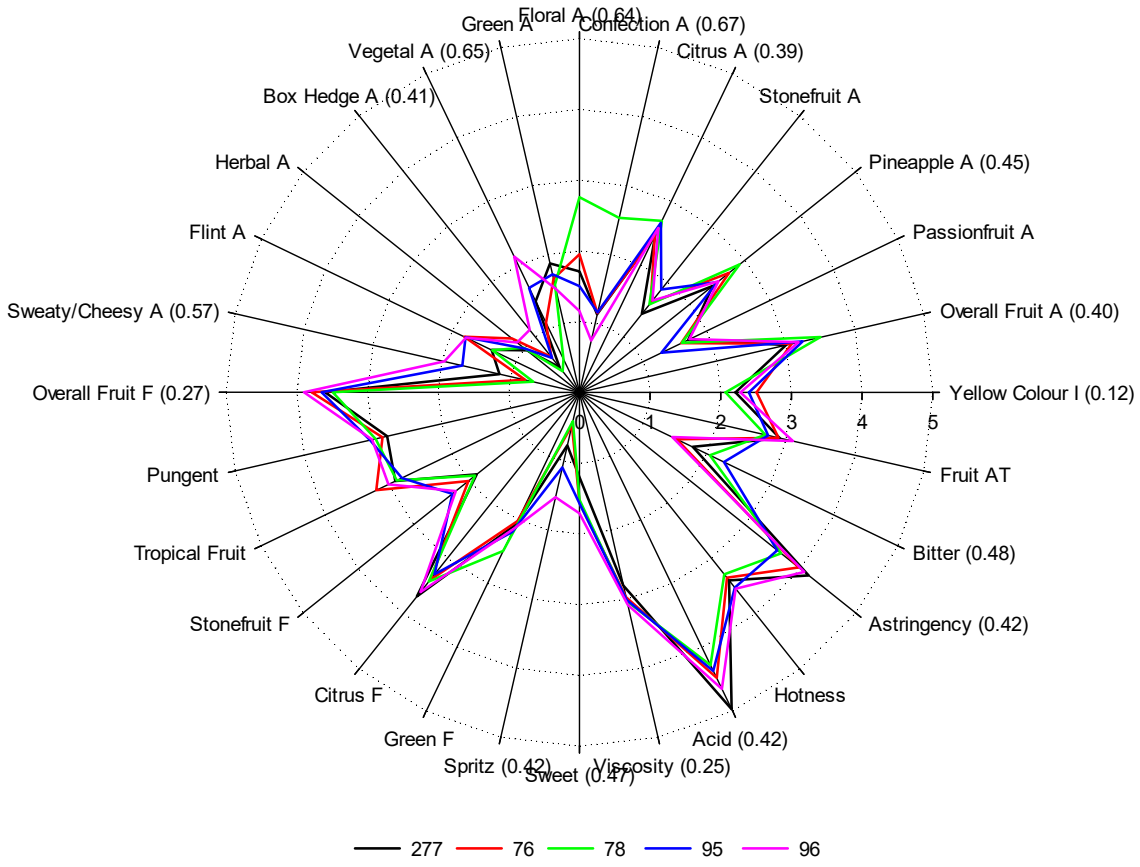


Figure 55 Radar plot of sensory attributes of V14 Chardonnay clonal wines from the Riverland. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

7.8.3 Sensory analysis of 2015 Chardonnay

7.8.3.1 Regional comparisons

Some of the wines from the Grampians site were deemed unsuitable for sensory assessment, due to oxidation as a result of low free SO_2 in wines prior to bottling, with the result that only three clones from this site were submitted for sensory analysis.

Wines from the Drumborg and Grampians sites were grouped in one quadrant (Figure 56) described by box hedge aroma, green flavour, flint aroma and flavour, bitterness and acid. The Riverland wines were associated with sweaty/cheesy, savoury/meaty and vegetal aromas, and oily, viscosity and hotness attributes. Margaret River and Great Southern wines in the same quadrat and were characterised by fruit aftertaste, floral, tropical, citrus, confection, stonefruit and overall fruit aromas, and stonefruit, tropical fruit, confection and overall fruit flavours. F1 and F2 accounted for 79% of the variability, which was not as strong as the correlation in V14 (90%).

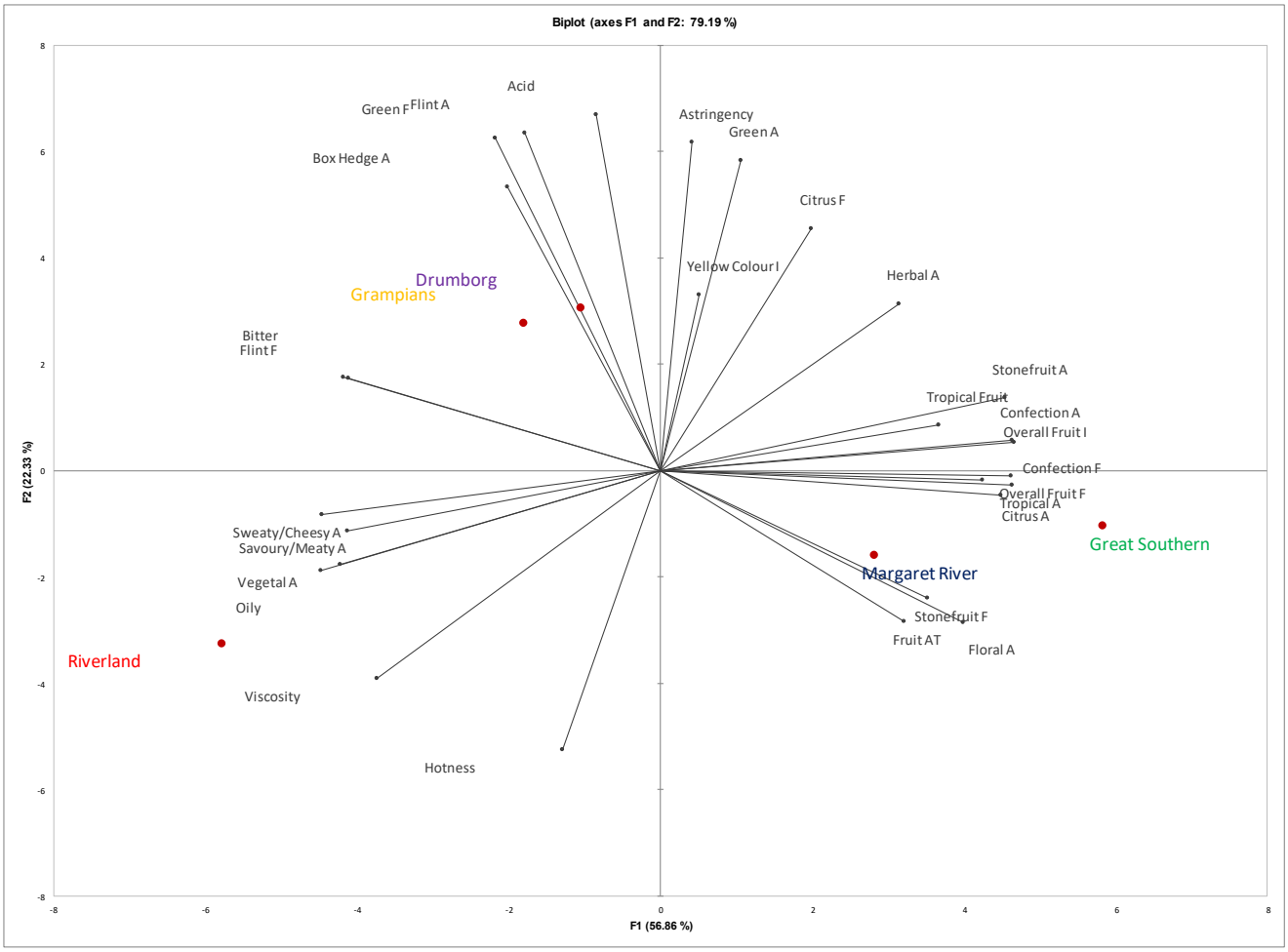


Figure 56. Scores and loadings bi-plot for PCA of attributes 2015 Chardonnay clonal wines pooled by region showing, showing F1 and F2.

The mean score of each attribute for all clones for both winemaking replicates and tasting sessions for each region were used to generate Least Significant Differences for each attribute. From this conservative analysis of variance there were significant differences among the 23 of the 29 attributes. Flint and pungent aromas, and tropical fruit flavour, viscosity, bitter and fruit aftertaste were the wine attributes not significantly different.

Overall there was less separation between regions for the V15 Chardonnay wines than for V14, although for most attributes there was significant separation between the highest and lowest scores. The radar plot of the mean data for regions highlighted the higher scores for acid and astringency (Figure 57) which was similar to V14 wines. However the V15 wines scored higher in the traits stonefruit and overall fruit aromas and flavours, and lower in sweaty/cheesy and pungent aromas, yellow colour, fruit aftertaste and viscosity than in V14.

Wines from the Great Southern had high scores (although not always significantly higher than all regions) for the aroma traits tropical, stonefruit, citrus, confection, floral and herbal, and the flavours stonefruit and confection. Wines from Margaret River also scored well for many of these aroma attributes while the Riverland wines were highest in vegetal, sweaty/cheesy and savoury/meaty aromas, and hotness, and low in fruity aromas. Drumborg wines were highest in citrus and green flavours, acidity and astringency, and lowest in stonefruit flavour. Grampians wines were highest in green, flint and box hedge aromas, and lowest in floral aroma and hotness.

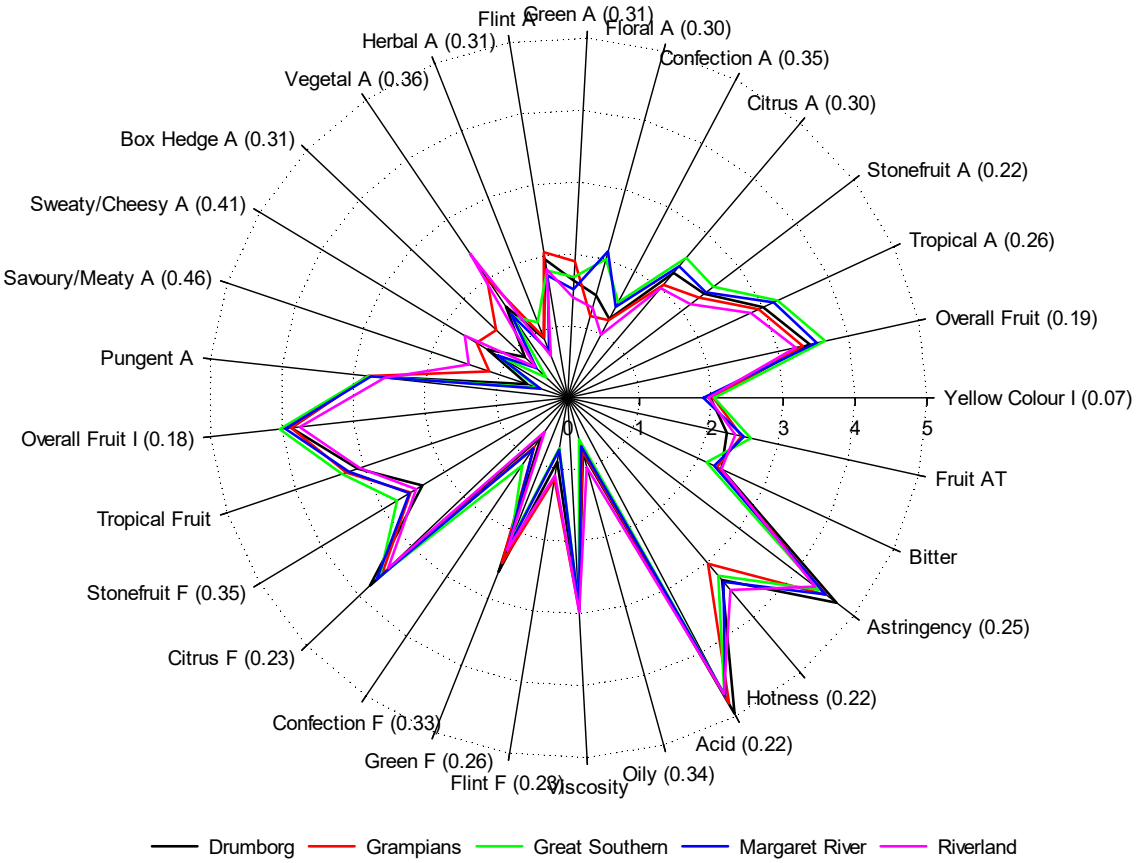


Figure 57. Radar plot of meaned sensory scores for V15 Chardonnay wines for all clones in each region. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

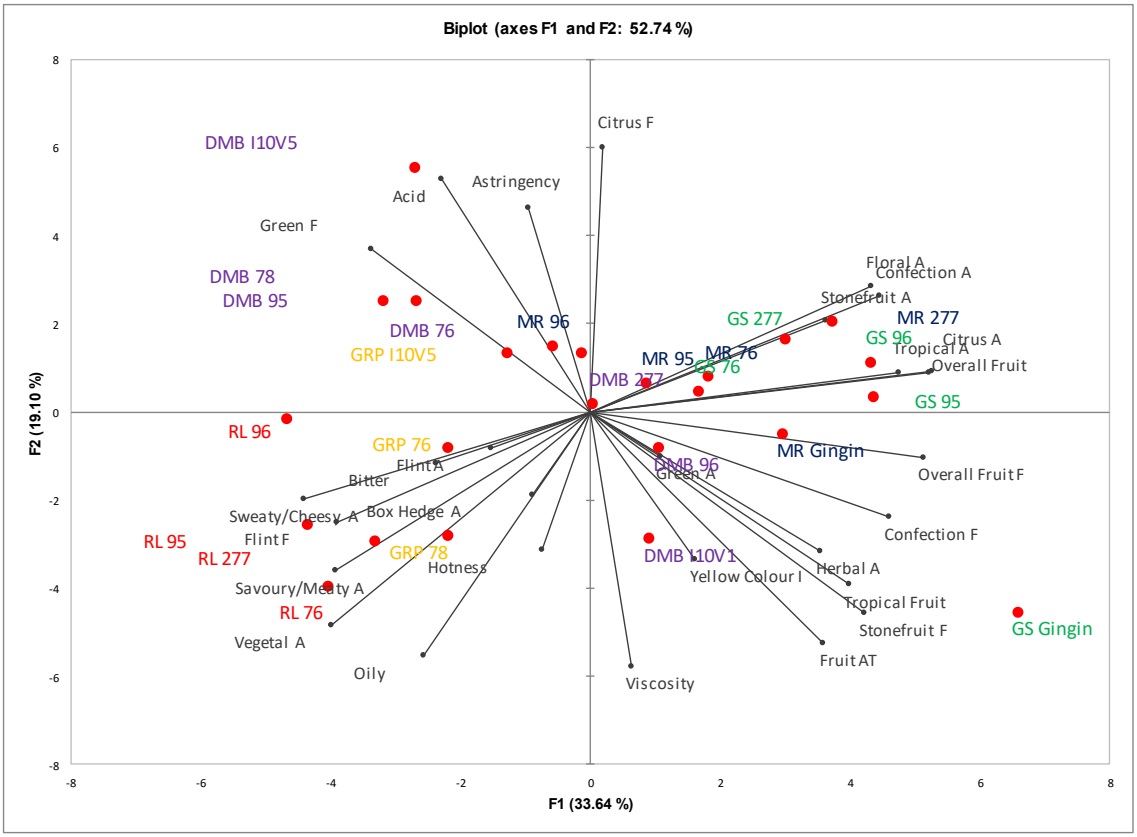


Figure 58. Scores and loadings bi-plot for PCA of attributes and treatments for 2015 Chardonnay clonal wines, showing F1 and F2.
DMB = Drumborg, GRP = Grampians, GS = Great Southern, MR = Margaret River, RL = Riverland

From the analysis of variance of all clones in each region, there were significant differences ($P<0.05$) among the 24 wines for 28 of the 29 attributes. The non-significant attribute was pungent aroma. F1 and F2 for the PCA plots of all clones in all the regions (Figure 58) only accounted for 52% of the variability. The Margaret River and Great Southern samples were mostly grouped reasonably close together in one half of the plot, and tended to be rated higher in overall fruit flavour and aroma, floral, confection, tropical fruit, stonefruit and citrus aromas, and confection flavour. The Gingin clone from both sites separated into the lower right-hand quadrat with relatively higher fruit flavours.

The Drumborg wines were spread along a diagonal axis from the upper left to lower right quadrat with some clones scoring higher in green flavour, acidity and astringency, and others higher in yellow colour, viscosity, stonefruit, tropical fruit and confection flavours, and green and herbal aromas. The three Grampians wines were spread across two quadrats with a range of non-fruity aromas and flavours. The four Riverland wines were grouped in one quadrat displaying high scores in flint, sweaty/cheesy, box hedge, savoury/meaty and vegetal aromas, flint flavour, and bitter, hot and oily attributes.

7.8.3.2 Within region comparisons

Drumborg

In the Drumborg wines there were 23 attributes where there were significant differences between clones (Figure 59). For overall fruit aroma, clones I10V1 and 96 scored the highest and 95 and 78 the lowest. For overall fruit flavour I10V1 scored highest and I10V5 the lowest, whilst for fruit aftertaste

I10V1 scored the highest, and I10V5 and 95 the lowest. This result may have been due to a spread of maturities at harvest with I10V1 having the highest alcohol content of 13.2% (Table 37) and I10V5 the lowest (11.5%).

Within each clone, 76 had the lowest citrus flavour, 78 scored high on astringency and bitter, and low on tropical aroma, 95 scored high for hotness and low for tropical aroma, 96 scored high for yellow colour, citrus, herbal and pungent aromas, and for tropical fruit and stonefruit flavours, whilst 277 scored high in stonefruit flavour and hotness, and low for flint flavour. Clones 78 and 95 were rated high in acid taste while 76 and I10V1 were the lowest. Clone I10V1 scored highest in 13 of the 23 attributes and lowest only in savoury/meaty aroma. Clone I10V5 scored lowest in 14 of the 23 attributes and only highest with savoury/meaty aroma and citrus flavour.

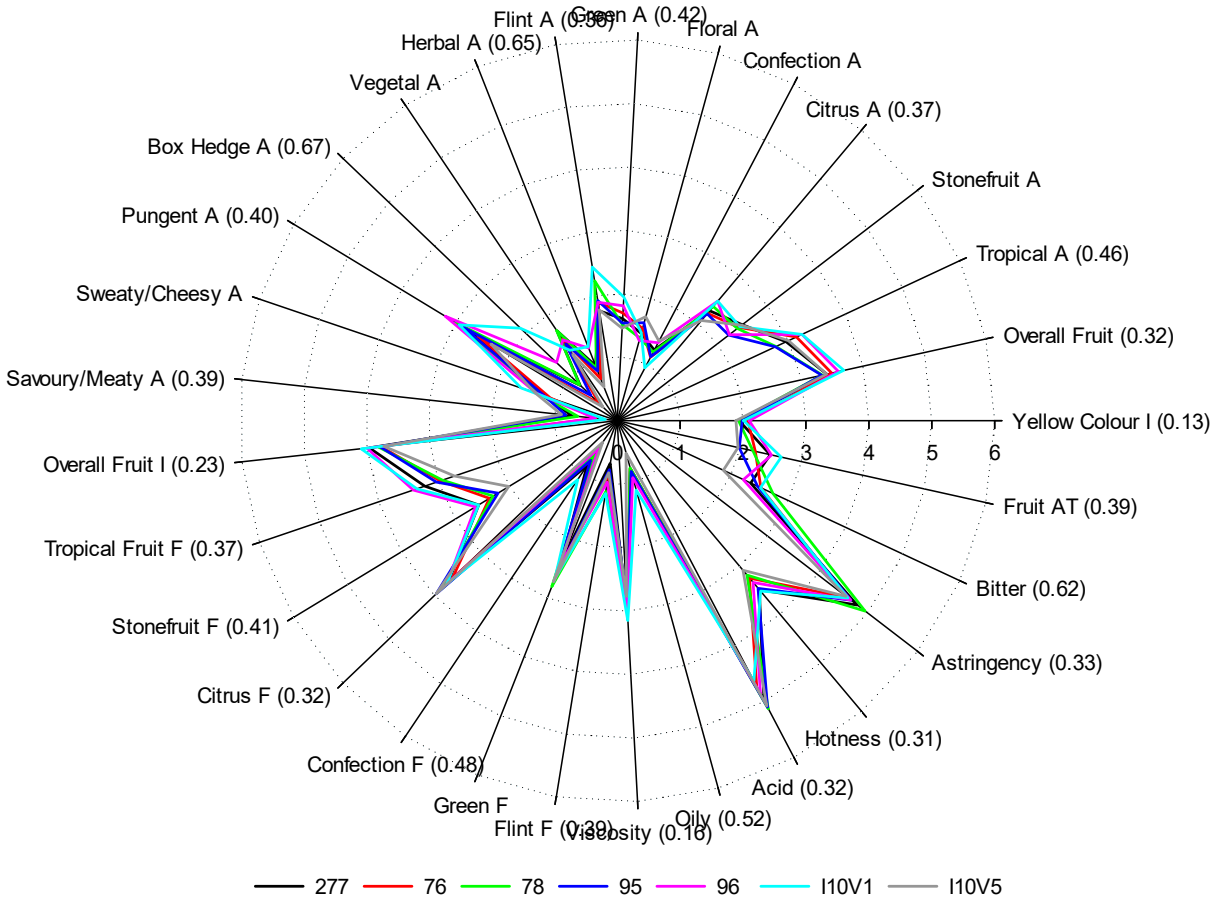


Figure 59. Radar plot of sensory attributes of V15 Chardonnay clonal wines from Drumborg. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

Grampians

The limited number of Grampians clonal wines (three of six) for statistical analysis resulted in only 7 of the 29 attributes being significantly different (Figure 60). There were no significant differences between clones for overall fruit aroma and flavour or fruit aftertaste. For five of these attributes there was only statistical separation between the highest and lowest score. Overall, 76 scored high for stonefruit and savoury/meaty aromas, and flint flavour, and low for box hedge aroma, 78 scored highest for yellow colour and lowest for stonefruit and citrus aromas, and astringency, and I10V5 scored highest for box hedge aroma and citrus flavour, and lowest for savoury/meaty aroma.

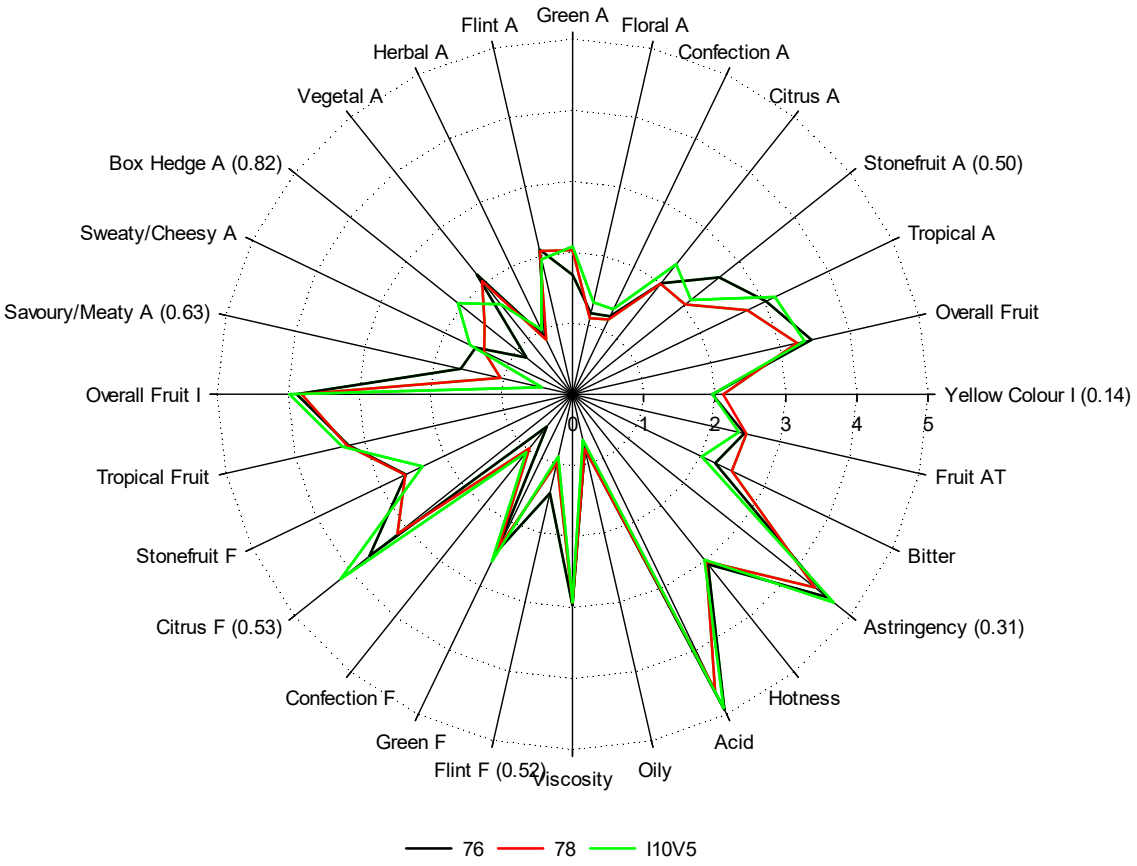


Figure 60. Radar plot of sensory attributes of V15 Chardonnay clonal wines from the Grampians. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

Great Southern

Fifteen of the 29 attributes from the Great Southern Chardonnay wines showed significant differences between clones (Figure 61). There were no significant differences between clones for overall fruit aroma and flavour, but for fruit aftertaste the Gingin clone scored highest and 277 the lowest. Across the clones 76 scored high in box hedge and savoury/meaty aromas, and low in floral aroma and oily taste, 95 scored high for tropical aroma, 96 scored low for yellow colour, tropical and savoury/meaty aromas, and stonefruit and flint flavours, and 277 scored high for floral aroma, flint flavour and astringency, and low for herbal aroma. The Gingin clone was highest in yellow colour, herbal and savoury/meaty aromas, stonefruit flavour, viscosity and oily taste, and low in box hedge and sweaty/cheesy aromas, citrus flavour, acid and astringency. This result in Great Southern may have been the result of slightly riper fruit at harvest and higher wine alcohol (Table 37) in the Gingin wines.

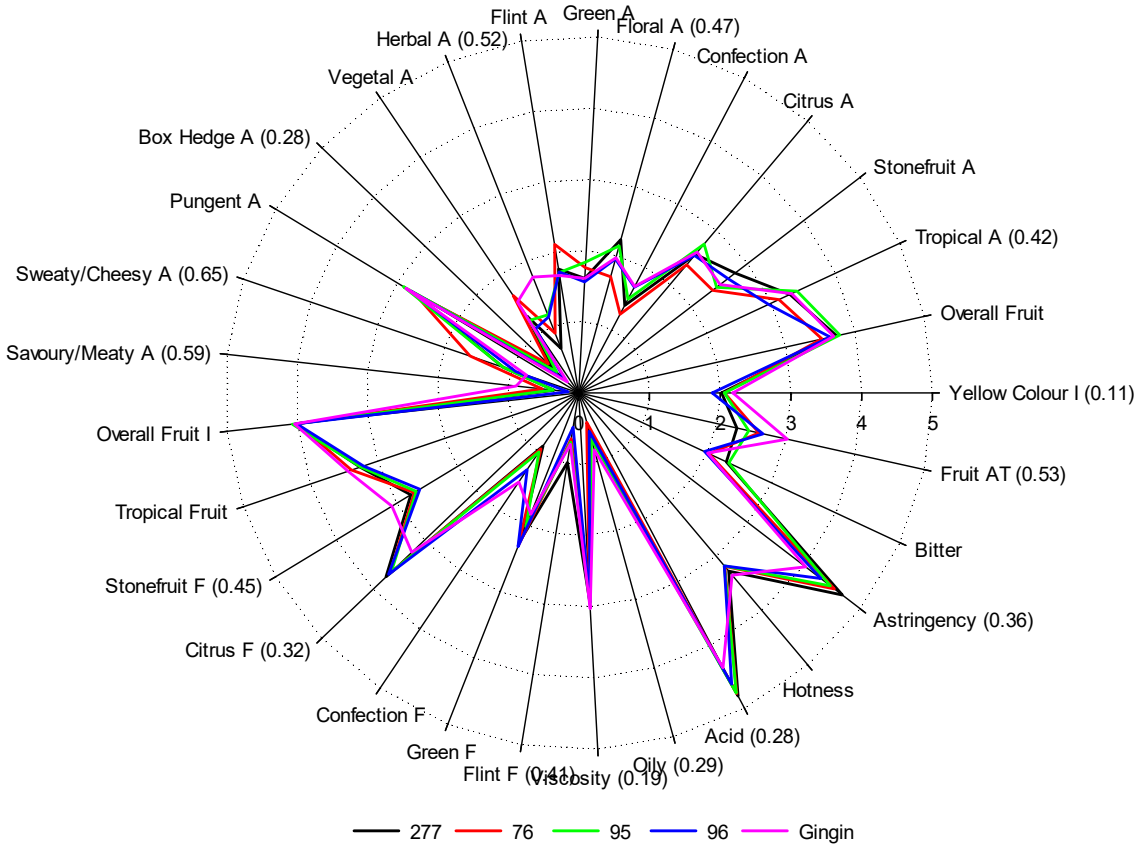


Figure 61. Radar plot of sensory attributes of V15 Chardonnay clonal wines from the Great Southern. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

Margaret River

Ten of the 29 attributes were significantly different for Margaret River clonal wines in V15 (Figure 62), however only wine yellow colour intensity of 277 was significantly different to all other clones. Clone 277 also recorded the highest scores for tropical and floral aroma and citrus flavour and the lowest scores for the possible negative attributes of green, sweaty/cheesy and savoury/meaty aroma and hotness. In contrast, the Gingin wine recorded the highest score for hotness, but was also high in overall fruit aroma, stonefruit, citrus and box hedge aroma. Clone 96 received the lowest scores for some of the positive aroma attributes and high scores for some of the possible negative attributes.

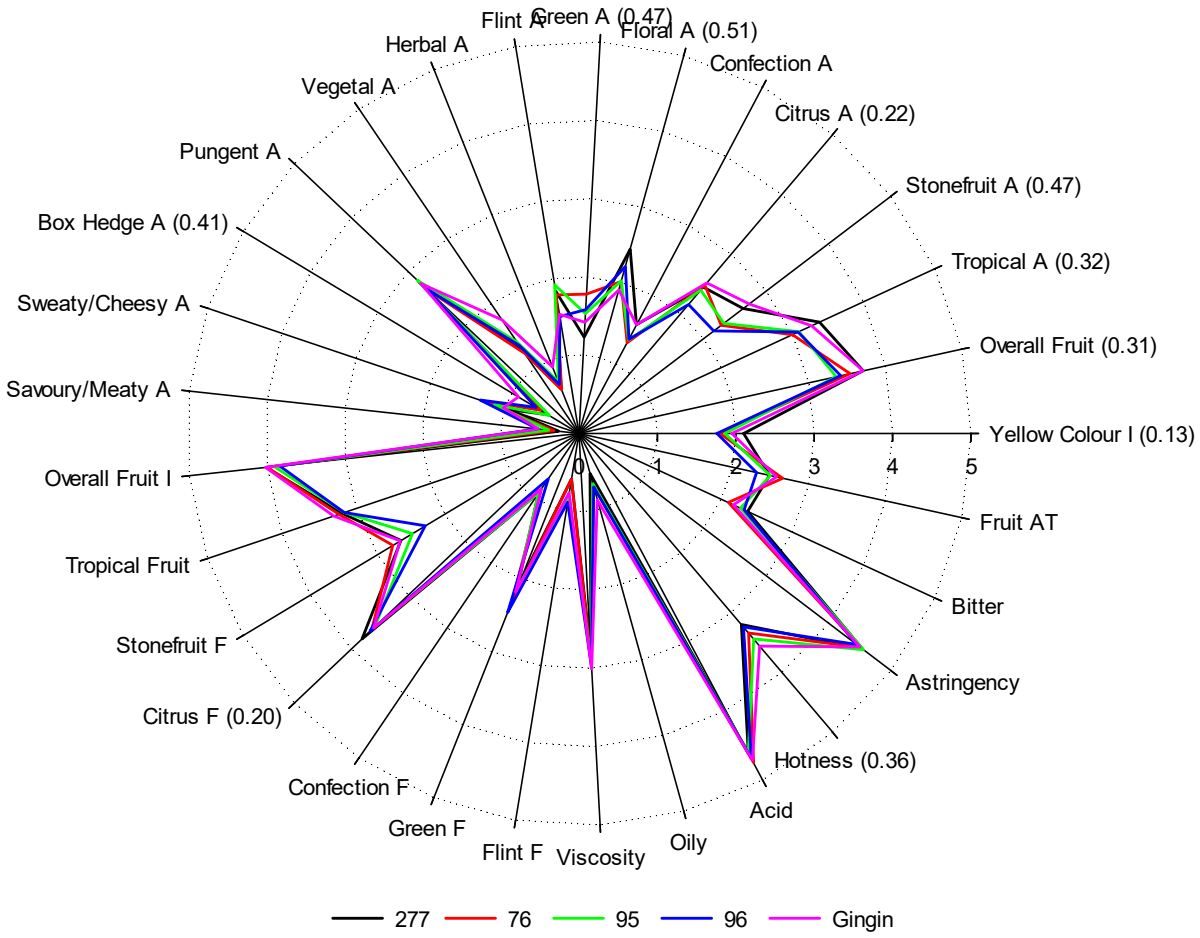


Figure 62. Radar plot of sensory attributes of V15 Chardonnay clonal wines from Margaret River. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

Riverland

For the Riverland wines in V15 clone, only 9 of the 29 attributes showed significant differences between the Chardonnay clones (Figure 63). There were no significant differences between clones for overall fruit aroma and flavour or fruit aftertaste. Clone 76 had the highest scores for attributes such as vegetal and pungent aroma, oily taste, yellow colour and hotness. Clone 95 scored high for flint aroma and low for confection and floral aromas. Clone 96 recorded the lowest scores for vegetal, pungent and savoury/meaty aromas and the highest score for confection aroma. Clone 277 scored highest for floral and savoury/meaty aromas, and lowest scores for flint aroma and hotness.

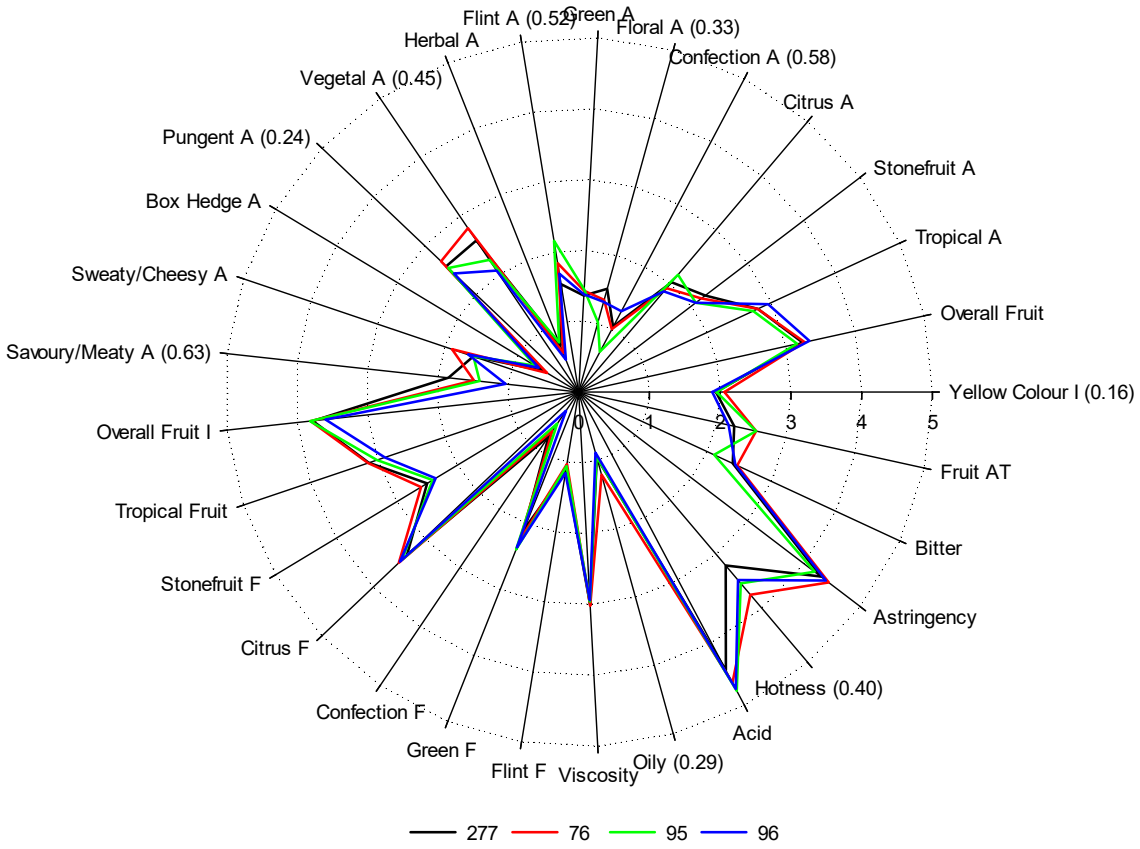


Figure 63. Radar plot of sensory attributes of V15 Chardonnay clonal wines from the Riverland. Least Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

7.8.4 Sensory analysis of 2016 Chardonnay

7.8.4.1 Regional comparisons

Principal Component Analysis (PCA) was performed using the significant sensory attributes (26 of the 30 attributes) and for the meaned data for each region. F1 and F2 accounted for approximately 93% of the variation (Figure 64). Fresh green, chemical, and pungent aromas, and bitter taste were the non-significant attributes between regions. Fruit from Drumborg and Margaret River was slightly lower in maturity at harvest and this resulted in slightly lower percent alcohol in the finished wines (Table 38).

The Grampians, Great Southern, Margaret River and Riverland regions all plotted to the right of Figure 64 and were rated higher in all the fruity attributes, while Drumborg wines, which were plotted to the left of the PCA, were rated higher in the non-fruit attributes such as rotten fruit & vegetable, drain, sweaty/cheesy and flint aromas, and green flavour. The Drumborg samples also had the lowest pHs, highest TAs and lowest alcohols of the sample set, possibly explaining the panellist's high ratings for acid, astringency and citrus flavour and low ratings for the fruity attributes.

For each region the mean score of each attribute for all clones for both winemaking replicates and tasting sessions for each region were used to generate Least Significant Differences for each attribute. From this conservative analysis of variance there were significant differences among the 26 of the 30 attributes. Green, pungent and chemical aromas, and bitter taste were the wine attributes not significantly different.

The radar plot of the mean data for regions highlights higher scores for acid and astringency, which was similar to previous years. However the V16 wines scored higher in the traits stonefruit, citrus, pungent and overall fruit aromas, and stonefruit and overall fruit flavours, and hotness and yellow colour, and lower in citrus flavour and hotness than in previous seasons.

The Drumborg wines were significantly different from all other regions for 17 of the 26 significant attributes and highlight the marked overall difference in these wines compared with those from the other three regions. The Drumborg samples scored highly for the attributes acid, astringency, green flavour, and the aromas of drain, rotten fruit & vegetable and sweaty/cheesy, and the wines had low scores for many of fruity aromas and flavours, although Drumborg did score the lowest in the negative trait of hot/burning aftertaste. In summary these characteristics suggest the while the Drumborg fruit was "sugar ripe" it was lacking in "flavour ripeness".

Among the other regions, there were few highest and lowest scores apart from Great Southern scoring high in confection and banana aromas, and tropical and confection flavours, and Riverland scoring high in oily taste and hot/burning aftertaste, and low in acid and astringency.

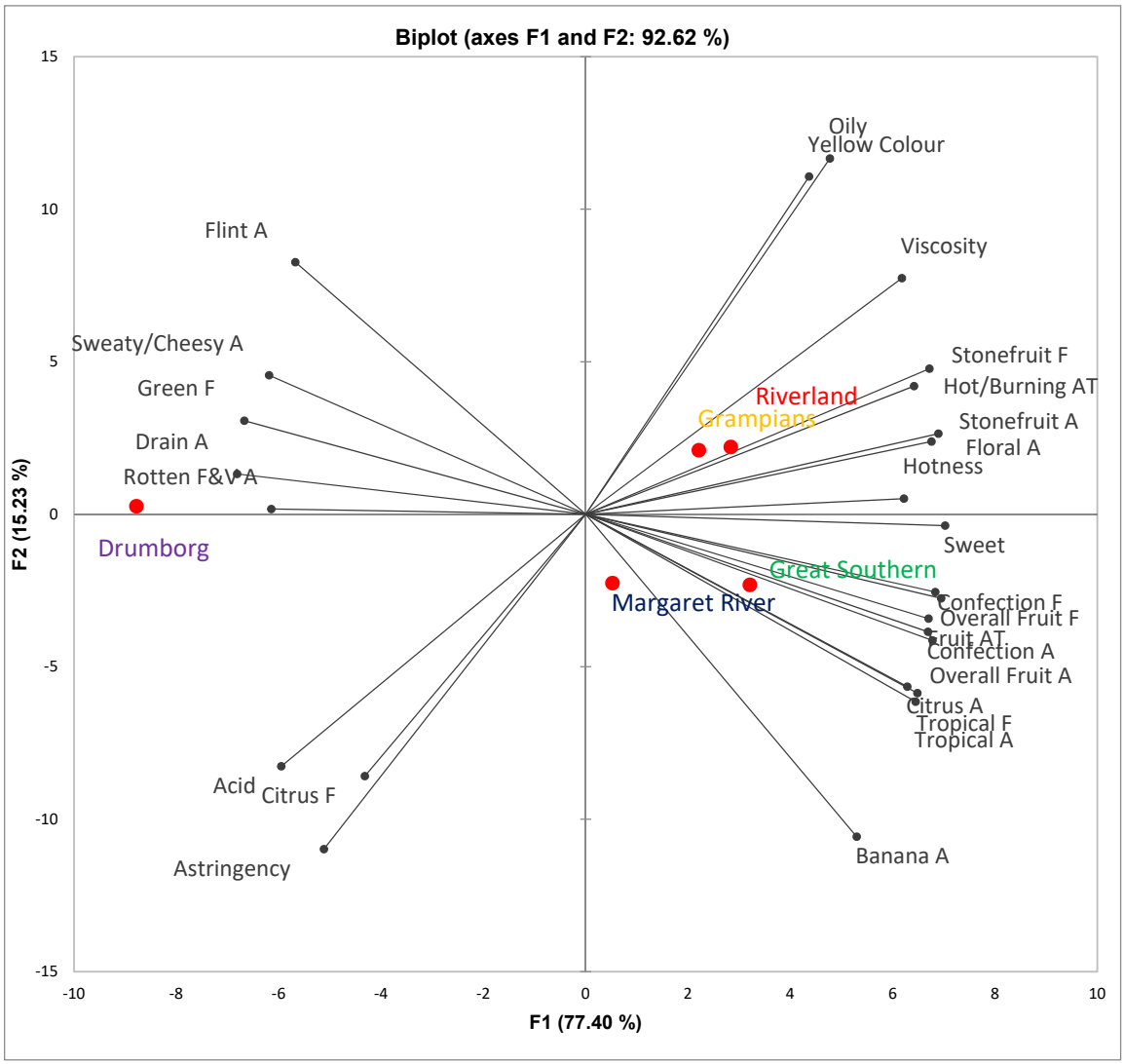


Figure 64. Scores and loadings bi-plot for PCA of attributes for 2016 Chardonnay wines pooled by region showing F1 and F2.

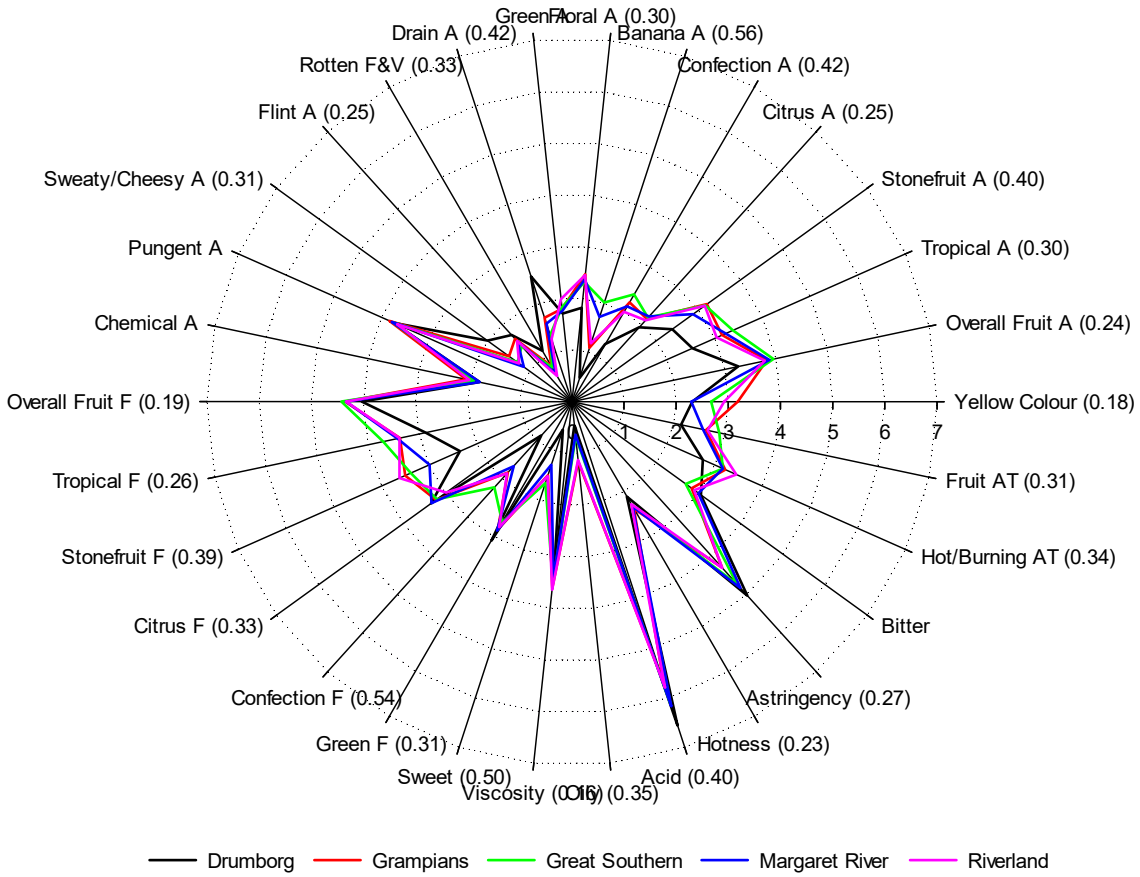


Figure 65. Radar plot of meaned sensory scores for V16 Chardonnay wines for all clones in each region. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

The PCA plot of all clones in each region (Figure 66) resulted in separation of regions similar to the analysis described above, with Margaret River, Great Southern, Grampians and the Riverland being in the right hand side of the F1 axis and all the Drumborg clones on the left. Within each region there was more separation between clonal wines along the F2 axis, especially for the Drumborg wines.

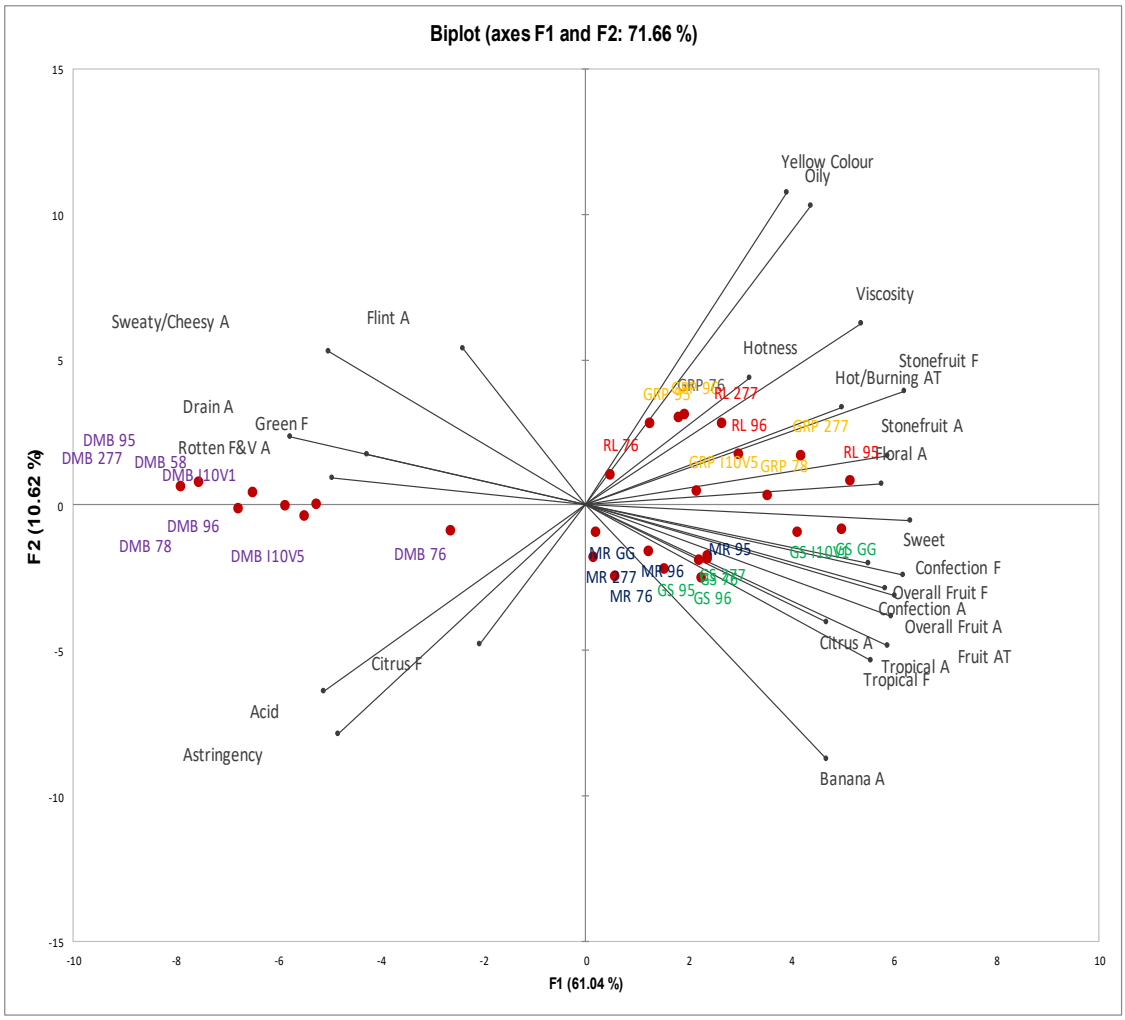


Figure 66. Scores and loadings bi-plot for PCA of attributes and treatments for 2016 Chardonnay clonal wines, showing F1 and F2.
DMB = Drumborg, GRP = Grampians, GS = Great Southern, MR= Margaret River, RL = Riverland

7.8.4.2 Within-region variation

The high number of attributes that were significantly different at the regional level as a result of the Drumborg Chardonnay wines (described above), was also apparent in the within-region analysis, with the clones at Drumborg being significantly different for 24 of the 30 traits (Figure 67). In comparison, 17 traits were different between clones at the Grampians site (Figure 68), 9 for the Great Southern (Figure 69), 10 at Margaret River (Figure 70), and 11 in the Riverland (Figure 71).

Drumborg

There were significant differences between clones for the majority of traits in the Drumborg wines. Looking at overall fruit aroma, 277 or I10V5 scored highest and P58 lowest, for overall fruit flavour 76 scored highest and 95 lowest, and for fruit aftertaste 76 again scored highest and P58 the lowest. Using the comparison of the highest (13.1%) and lowest (11.5) % alcohol in wines (76 and I10V5 respectively) there was significant separation in only 4 of the 24 traits (tropical flavour, hot/burning aftertaste, hotness and sweet taste) with 76 recording higher. A similar comparison between the 2 sets of wine that were similar in % alcohol - 76 and I10V1 (13.1 and 13.0%) and 78 and 95 (12.2%) also did not reveal any consistent trends.

Assessing each clone, P58 had high chemical aroma, 78 had high scores for drain and sweaty/cheesy aromas, and I10V1 scored high in flint aroma and astringency. Clone 76 scored high in tropical and stonefruit flavours, and sweetness, hotness and hot/burning aftertaste, and low in rotten fruit and vegetable and sweaty/chest aromas, and bitter taste. Clone 95 scored high for bitter taste, and low for stonefruit and banana aromas, tropical and stonefruit flavours, and acidity. Clone 96 scored highest in citrus flavour, and low in drain and chemical aromas. Clone 277 or I10V5 scored highest in stonefruit, confection and green aromas, and low in citrus flavour and hot/burning aftertaste.

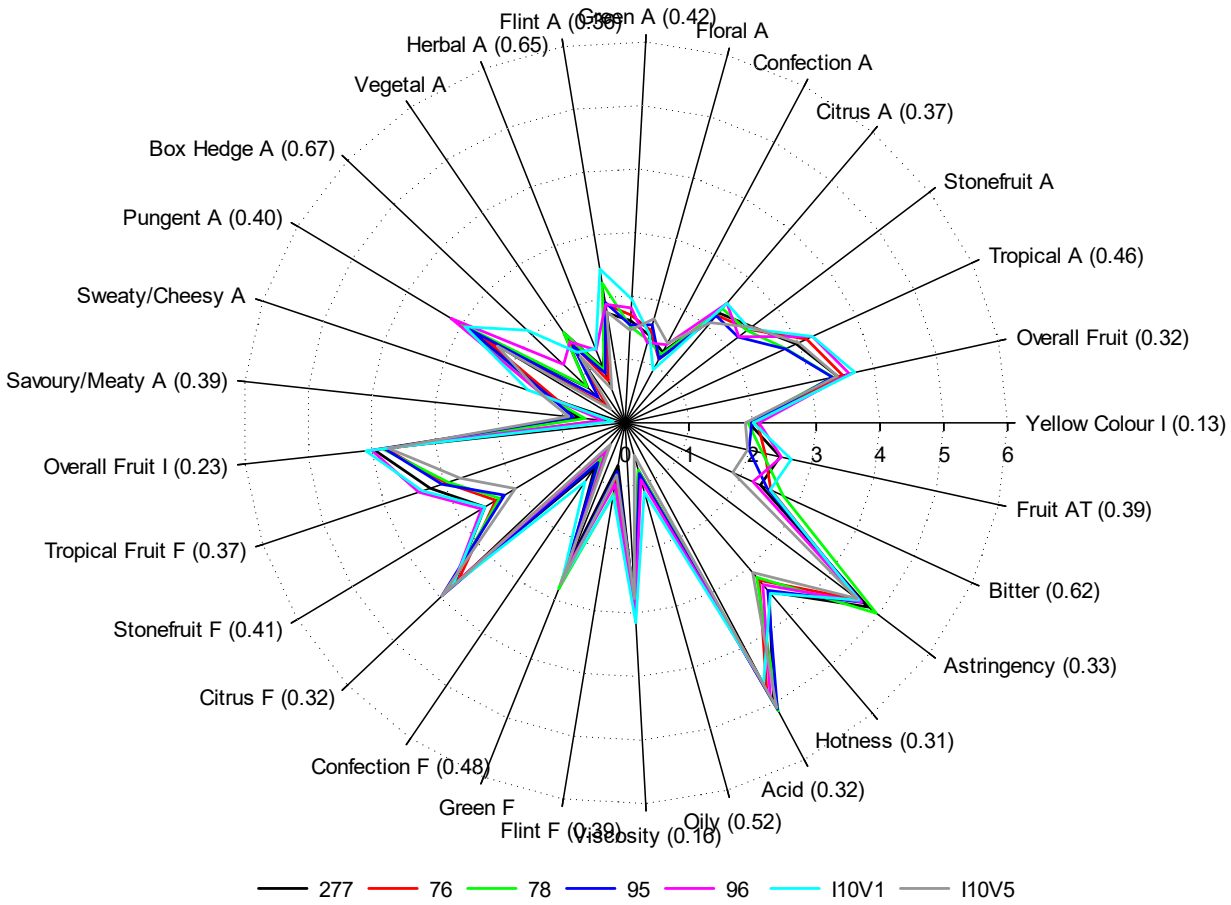


Figure 67. Radar plot of sensory attributes of V16 Chardonnay clonal wines from Drumborg. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

Grampians

There were significant differences between Chardonnay clones for 17 attributes out of 30 assessed (Figure 68). There were no significant differences between clones with overall fruit aroma, but for overall fruit flavour there were two groups, with 78, 95 and 96 scoring higher than 277, 76 and I10V5. For fruit aftertaste 78 scored highest and 95 and 96 the lowest.

Clone I10V5 recorded the lowest score for 7 of the 17 significant traits which may have been the result of the fruit being less mature than the other clones, as reflected in the low alcohol (12.9%) for this clone. However, only the yellow colour intensity of the I10V5 was significantly lower than all other clones; while the other 6 traits could not being distinguished statistically from some of other clones at this site. Of the other four clones, there were 2 sets of similar % alcohols with –277 and 95 in one set (14, 14.1 %) and 76 and 78 (13.4, 13.5%) in the other. However, similarly to the wines from Drumborg, although there were some significant differences, there was no clear and consistent conclusion to be made, apart from that there were differences.

Across the clones, 76 scored high for hotness, bitter taste and hot/burning aftertaste, and low for tropical and citrus aromas, and tropical fruit flavour; 78 scored high for tropical, citrus and green aromas, and tropical flavour, and low for bitter taste; 95 scored high for flint and sweaty/cheesy aromas, and low for banana aroma and oily taste; 96 scored high for sweaty/cheesy aroma, oily taste and hot/burning aftertaste, and low for confection, banana and green aromas; 277 scored high for confection and banana aromas, and low for green aroma and hot/burning aftertaste; and I10V5 scored low for yellow colour, flint aroma, hotness and hot/burning aftertaste.

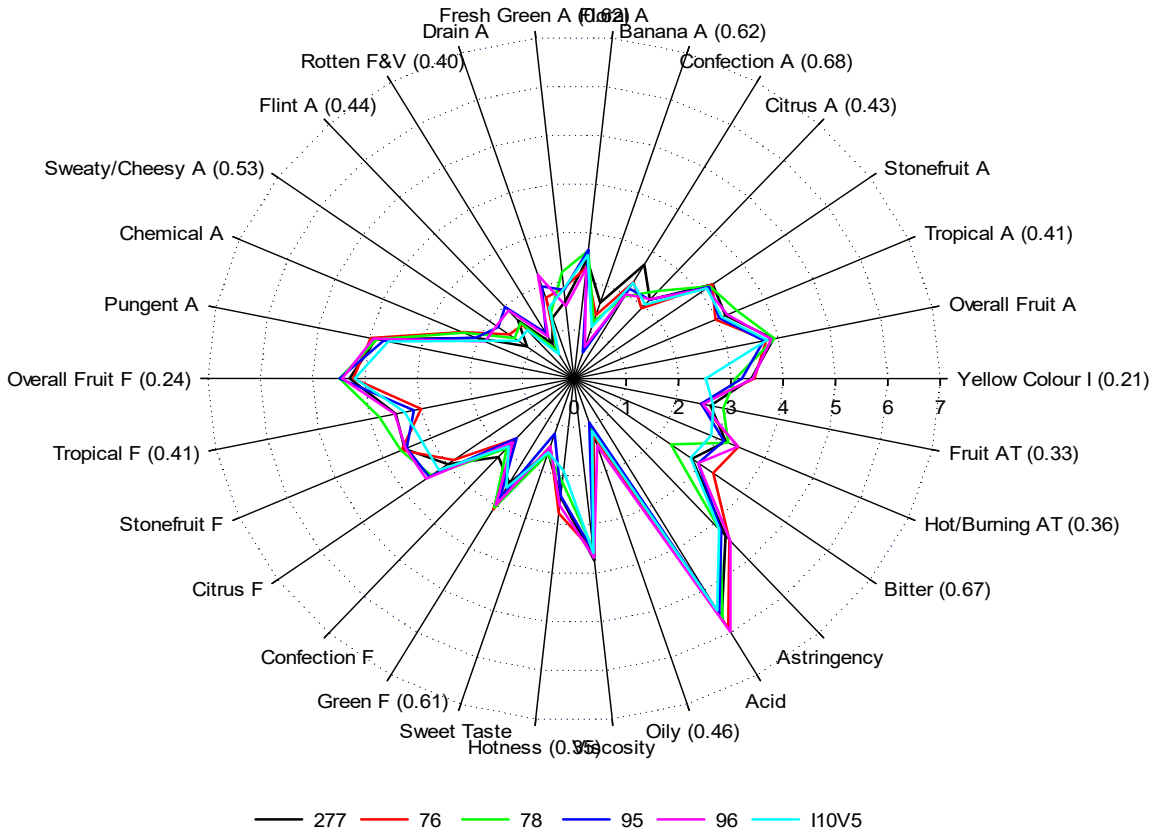


Figure 68. Radar plot of sensory attributes of V16 Chardonnay clonal wines from the Grampians. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

Great Southern

There were 9 attributes out of 30 where there were significant differences between Chardonnay clones (Figure 68) For overall fruit aroma, flavour and aftertaste there were no significant differences between clones. For each clone, 76 had high yellow colour and low hot/burning aftertaste; 95 scored high for banana and chemical aromas, and low for oily aftertaste; 96 had a score for acid and a low score for stonefruit flavour; 277 scored high in citrus flavour and oily taste and low for yellow colour; Gingin scored high for yellow colour, stonefruit flavour and hot/burning aftertaste, and low for chemical aroma; and I10V1 scored high for stonefruit flavour and low for banana aroma and acidity. As previously reported for the 2014 and 2015 seasons and regions where there were significant differences between clones for certain attributes, it was usually only between the highest and lowest score for each attribute.

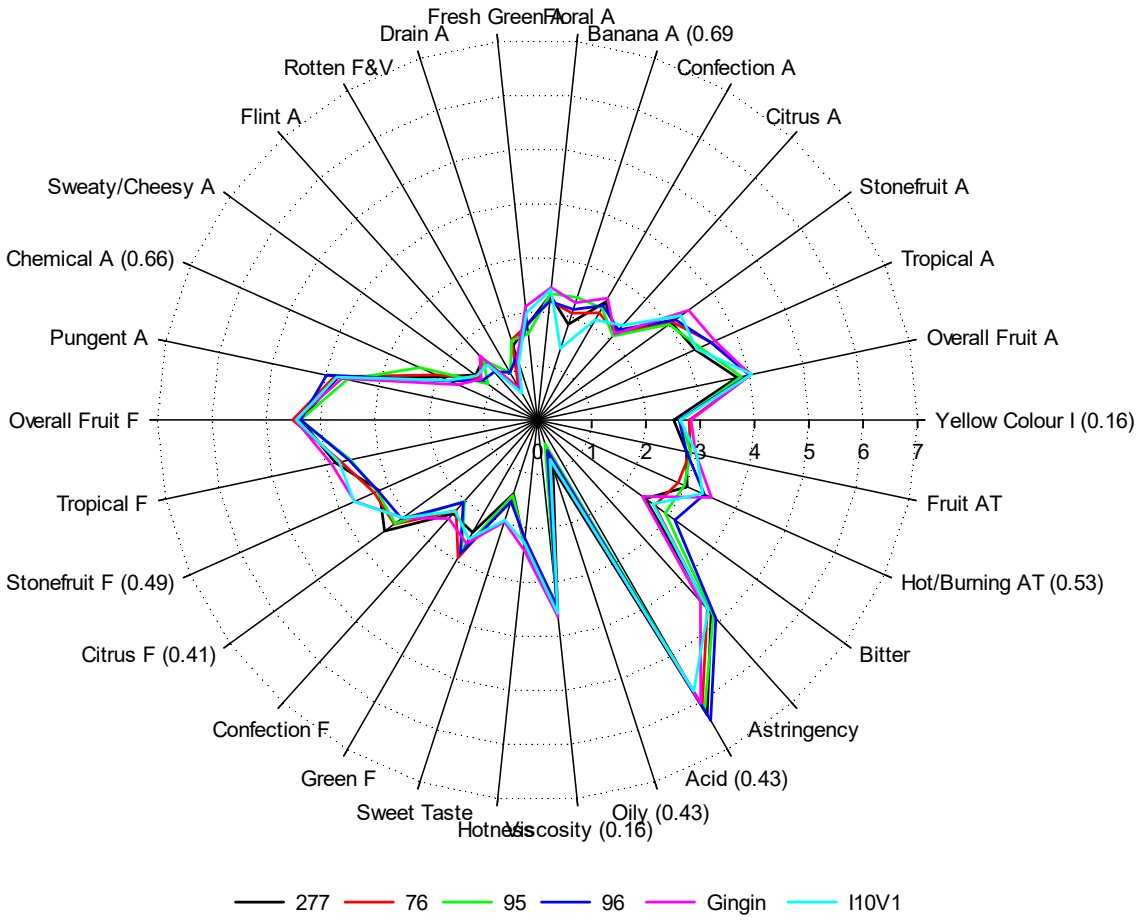


Figure 69. Radar plot of sensory attributes of V16 Chardonnay clonal wines from the Great Southern. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

Margaret River

In this region, significant differences between Chardonnay clones were evident in 10 of the 30 attributes (Figure 70). There were no significant differences between clones for overall fruit aroma, flavour or aftertaste. Across the clones, 76 scored high for citrus and drain aromas, and low for oily and bitter taste; 95 scored high for banana aroma and low for yellow colour, drain and sweaty/cheesy aromas, and acidity; 96 scored high for confection and pungent aromas, and oily and bitter taste; 277 scored high for bitter taste; and Gingin scored high for yellow colour, sweaty/cheesy aroma and acidity, and low for citrus, confection, banana and pungent aromas.

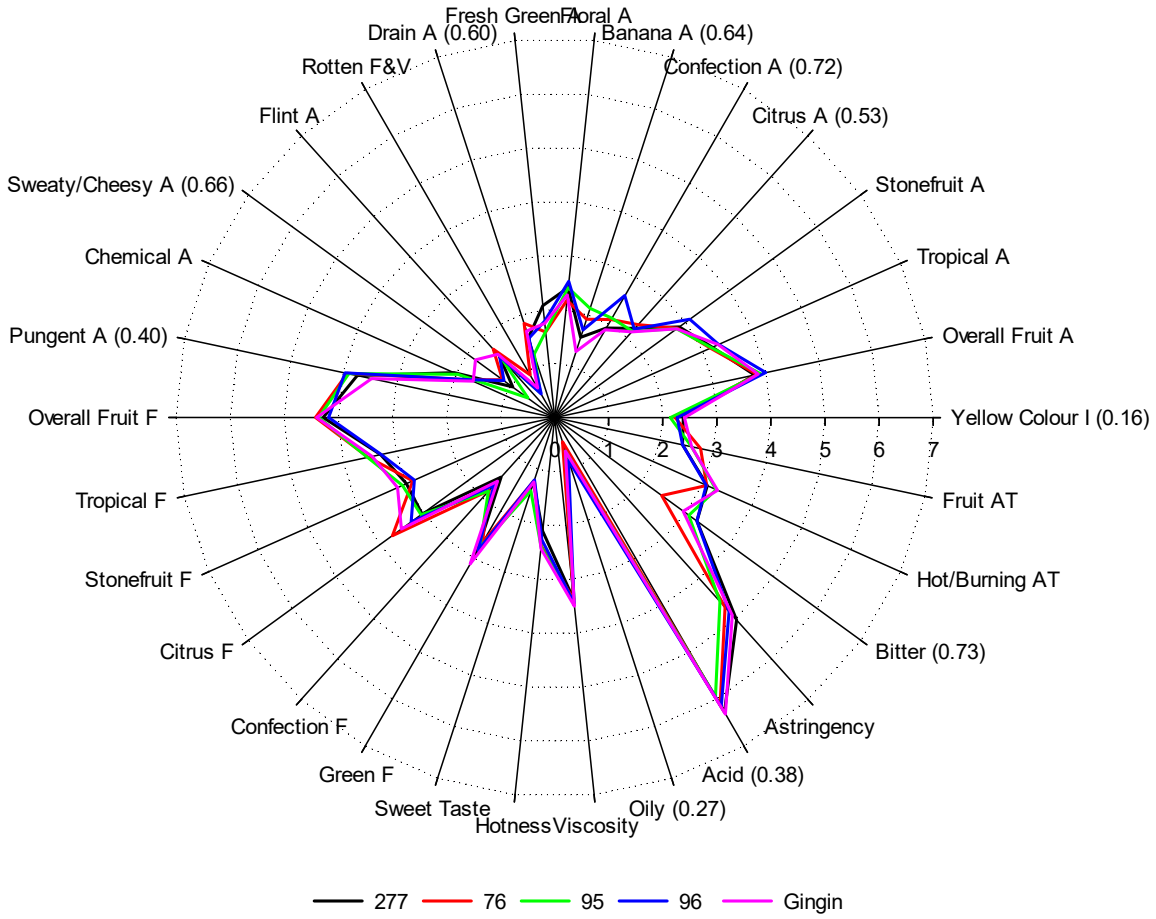


Figure 70. Radar plot of sensory attributes of V16 Chardonnay clonal wines from Margaret River. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

Riverland

At the Riverland site there were significant differences between clones for 11 of the 30 attributes (Figure 71). There were no significant differences between clones for overall fruit flavour but for both overall fruit aroma and fruit aftertaste, clone 95 scored highest and 76 scored lowest. These scores are reflected in the individual attributes for these clones with 95 scoring highest in tropical, stonefruit, citrus and banana aromas, stonefruit and confection flavours, and viscosity, whereas 76 scored the lowest in most of these attributes, including yellow colour. Of the other two clones, 96 scored highest in citrus flavour and lowest in banana aroma, and 277 scored lowest in citrus flavour. Clone 95 was slightly higher in % alcohol than 76 (14.05 vs 13.75). However, this small difference in harvest maturity is unlikely to account for the number of significant differences between the two clones which suggests a clonal influence at this site.

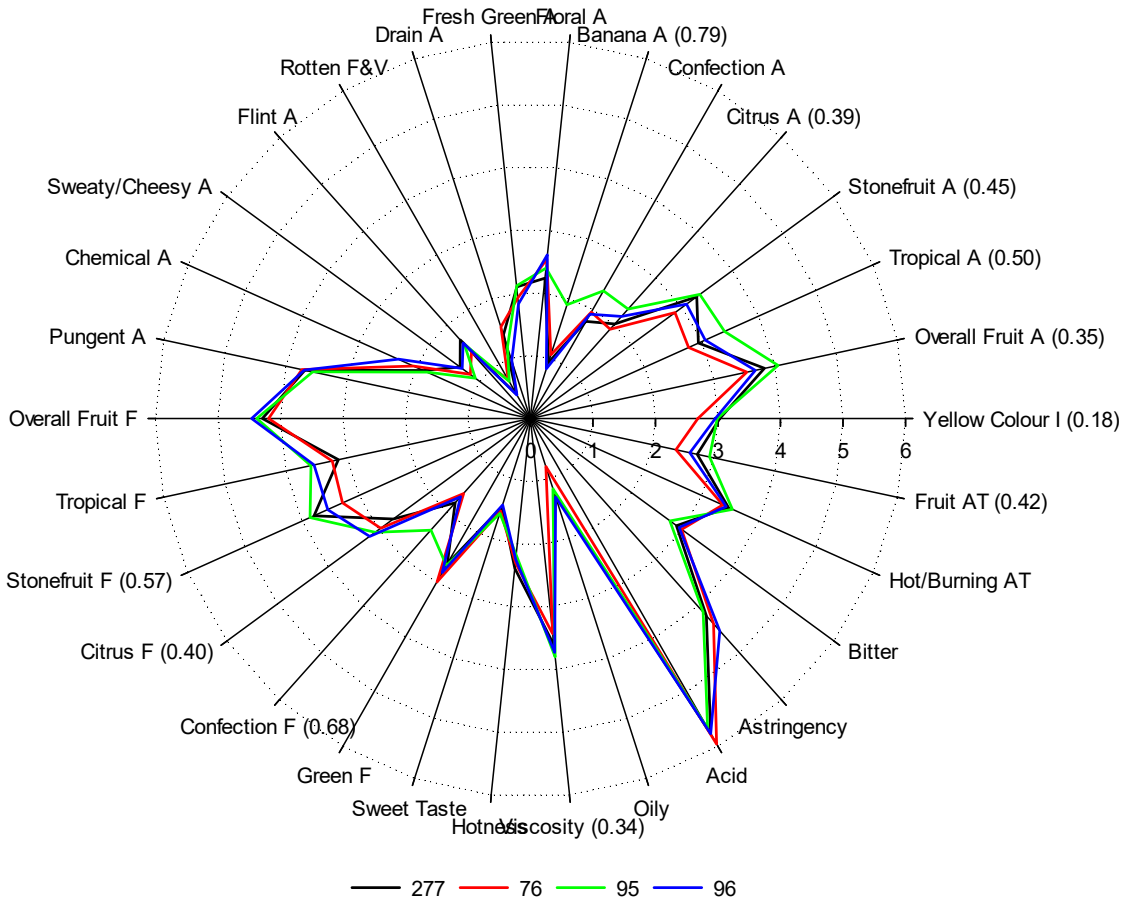


Figure 71. Radar plot of sensory attributes of V16 Chardonnay clonal wines from the Riverland. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

7.8.5 Sensory analysis of 2017 Chardonnay

7.8.5.1 Regional comparisons

In the 2017 vintage, only four of the Bernard clones were harvested for winemaking at the Grampians, Drumborg and Riverland sites. In Great Southern the four Bernard clones, the Gingin clone and I10V1 were included. In Margaret River the Bernard clones and Gingin clone were included. There was a variation in the wine alcohol concentration between sites, with the mean of the Drumborg wines at 11.9% compared to 13.6% for the Riverland wines. As in previous seasons, the optimal harvest time at Drumborg was difficult to achieve, as it was a compromise between reaching adequate maturity and preceding harvesting operations in the commercial vineyard. There was a higher incidence of bunch rot in some regions in V17, and similar to Drumborg, this influenced harvest date; while no fruit was rejected for winemaking there was some concern about winemaking outcomes. Drumborg again experienced poor conditions for bunch initiation in the previous season and during fruit set in the current season, resulting in fewer and smaller bunches and leading to low yields.

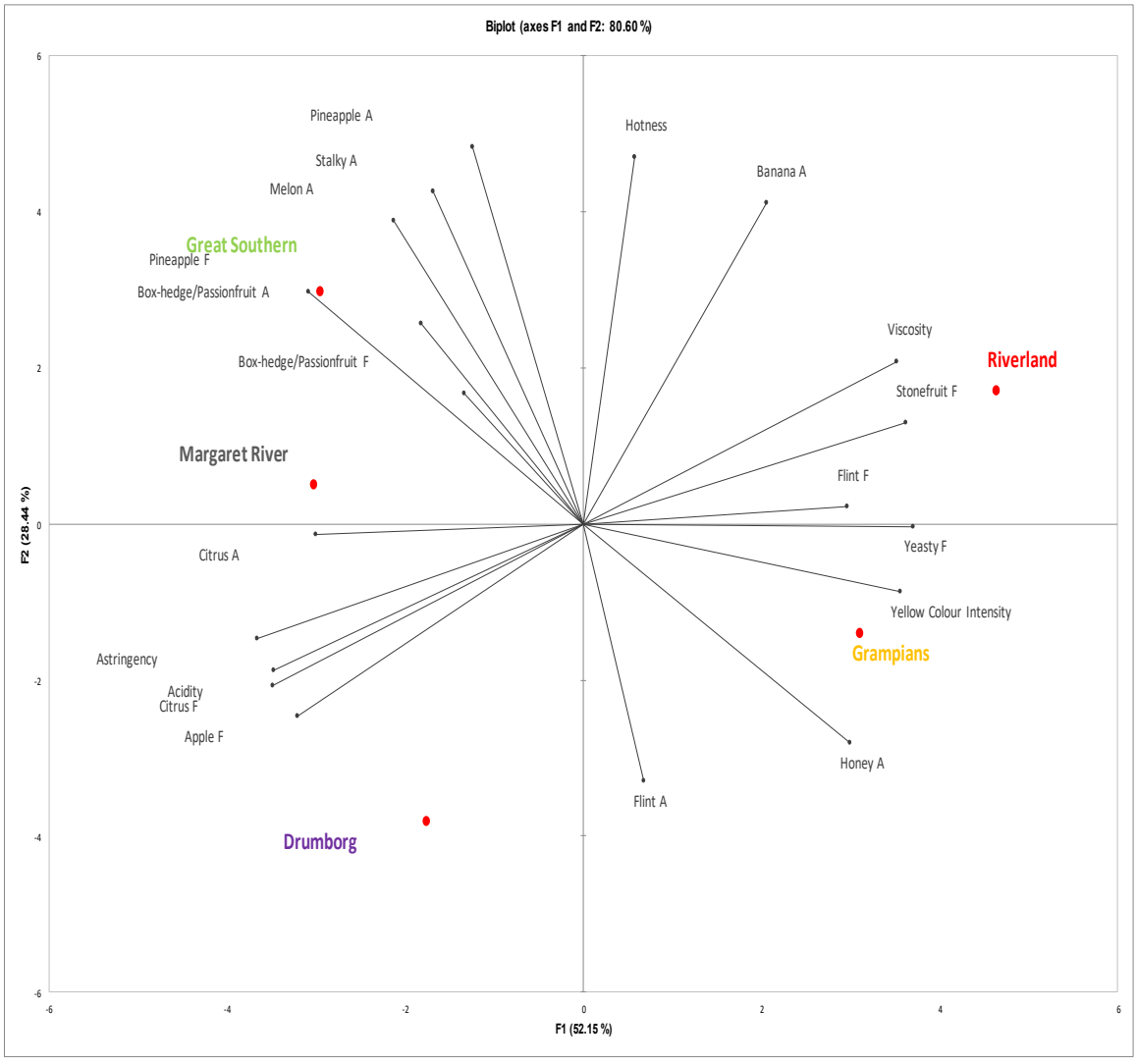


Figure 72. Scores and loadings bi-plot for PCA of attributes and treatments for 2017 Chardonnay pooled for each region showing F1 and F2

Using the 20 attributes with significant differences between wines, the PCA of the meaned scores for each region resulted in clear separation of the regions with the Riverland, Grampians and Drumborg each in separate quadrats and the Great Southern and Margaret River grouped in the upper left hand quadrat (Figure 72). F1 and F2 accounted for 80.6% of the variability. In contrast to the previous seasons there was no assessment of overall fruit aroma or flavour. Riverland wines were associated with descriptors such as stonefruit, yeasty and flint flavours, viscosity and yellow colour. Grampians wines were associated honey aroma and yeasty flavour and yellow colour intensity. Descriptors such as flint aroma, apple and citrus flavours, astringency and acidity applied to Drumborg wines while Margaret River wines had box-hedge/passionfruit flavour and aroma, and citrus aroma. Wines from the Great Southern region were described as high in pineapple flavour and box-hedge/passionfruit flavour and aroma, and melon, stalky & pineapple aromas.

The mean score of each attribute for all clones for both winemaking replicates and tasting sessions for each region was used to generate Least Significant Differences for each attribute. From this conservative analysis of variance there were significant differences among the 26 of the 31 attributes (Figure 73). Melon, floral and coconut aroma, stalky flavour and fruit aftertaste were the five non-significant attributes.

The high scores for yellow colour intensity for the Riverland and Grampians wines are also apparent in the radar plot of sensory attributes (Figure 73). Drumborg wines scored highest for acidity and apple and stonefruit flavor, and lowest for hotness, bitter taste, viscosity, and pineapple and banana aromas. The Grampians wines were also high in honey and flint aromas, and flint and yeasty flavours, and low in pineapple flavor. The elevated box hedge/passionfruit and pineapple aromas and flavours of the Great Southern wines is clear, along with high scores for stalky and pungent aromas, and citrus flavor, and low scores for cheesy aroma and yeasty flavour. The Margaret River wines were high in citrus and cheesy aromas, and low in yellow colour, stonefruit and honey aromas, citrus, box hedge/passionfruit, stonefruit and flint flavours, and viscosity. The Riverland wines were also high in banana and stonefruit aromas, melon flavor, viscosity, bitterness and hotness. There were seven wine attributes (yellow colour intensity, pineapple aroma and flavour, stonefruit flavour, acidity, astringency, and viscosity) that separated into three or more statistically similar groups, however there did not appear to be any consistent regional pattern.

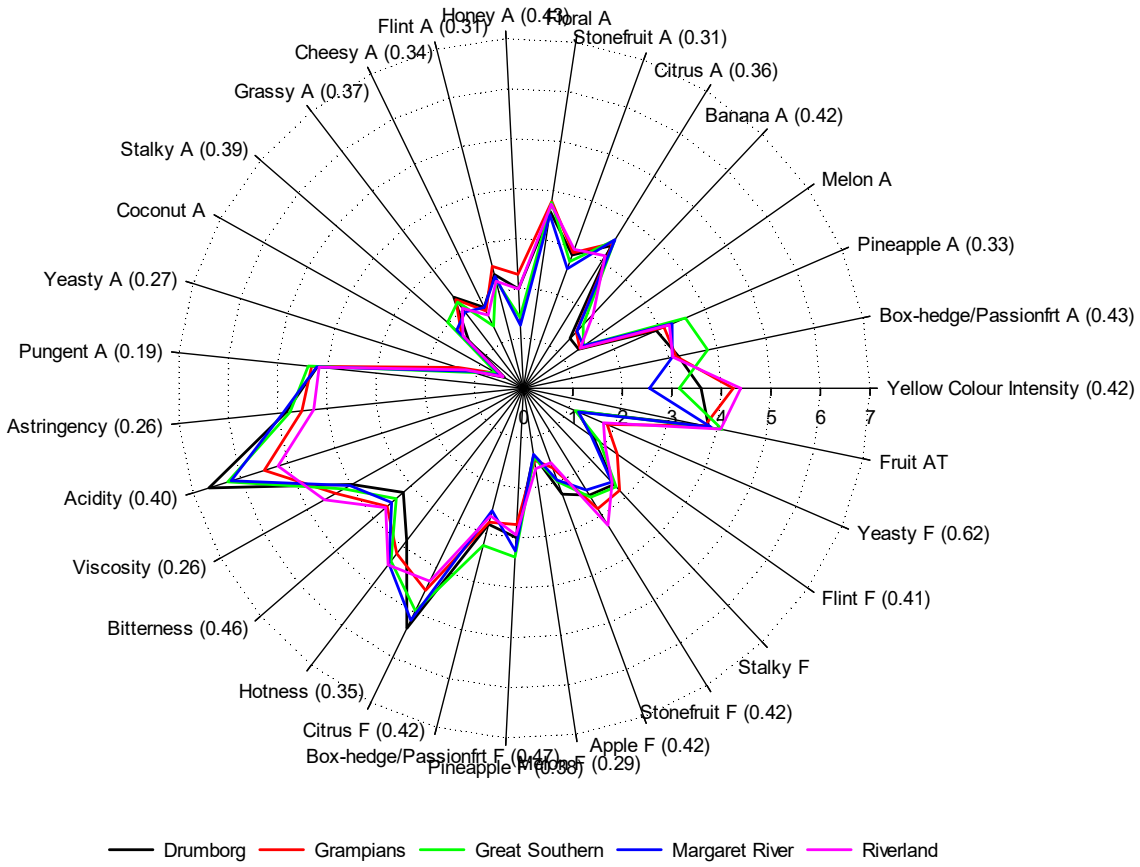


Figure 73. Radar plot of meaned sensory scores for V17 Chardonnay wines for all clones in each region. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

The PCA plots of all clones in each region revealed a similar separation into regions; but there was a spread between the clones from each region within the quadrats (Figure 74). The F1 and F2 only accounted for approximately 57% of the variation across the data set. Generally, wines plotted to the right of the figure were rated highly in citrus, box hedge/passionfruit and stalky aromas, citrus, box hedge/passionfruit, pineapple and apple flavours, astringency and acidity. Conversely, wines plotted to the left of the figure rated lower in these attributes, and highly in the attributes yellow colour intensity, honey aroma, viscosity, stone fruit, flint and yeasty flavours. Vertical separation on F2 was determined by the intensity of attributes pineapple, banana and melon aromas and hotness. The apple and citrus flavours, acidity and astringency of Drumborg wines are probably a reflection of these grape parcels being less ripe than fruit from the other regions.

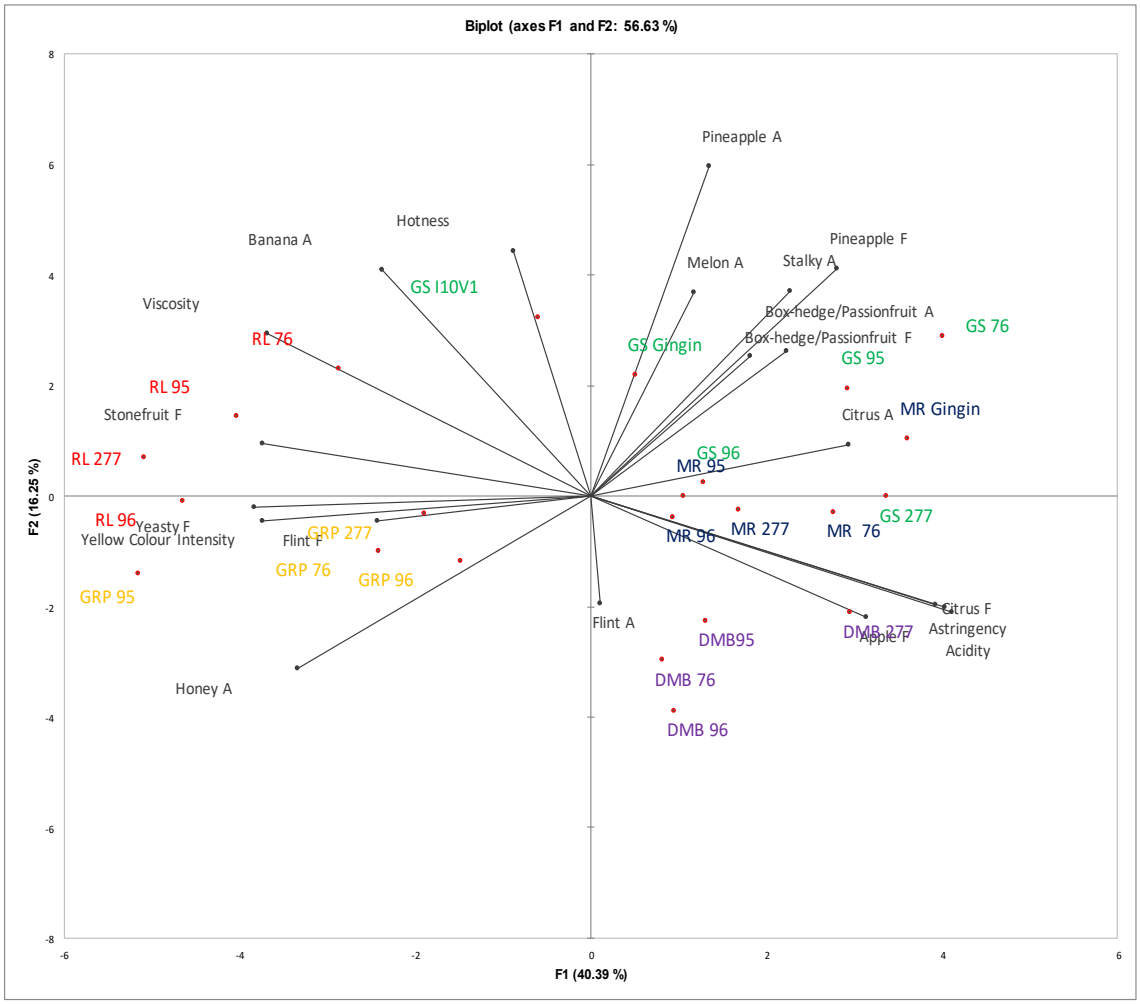


Figure 74. Scores and loadings bi-plot for PCA of attributes and treatments for 2017 Chardonnay clonal wines, showing F1 and F2.
DMB = Drumborg, GRP = Grampians, GS = Great Southern, MR = Margaret River, RL = Riverland

7.8.5.2 Within-region variation

The lack of consistent statistical separation described above may have been due to the significant judge-by-wine interaction effects, reflecting some lack of consensus between the judges. For example, for the same attribute, judge's scores ranged from 0 to 7-8, resulting in only eight of the 30 wine attributes being significantly different for Margaret River (Figure 78) and Riverland wines (Figure 79). Great Southern clonal wines (Figure 77) recorded the largest number of significantly different attributes (16). Across all the regions and clones the Gingin clone in Margaret River was the only wine that did not score a significantly lower value for any attribute. There were only 3 cases where any clone was significantly different from all others within each region. These were Margaret River 95 astringency (low) (Figure 78), Drumborg 277 yellow colour intensity (low) (Figure 75) and Grampians 95 citrus flavour (low) (Figure 76).

Drumborg

At Drumborg, 9 of the 30 attributes revealed significant differences between clones (Figure 75). Only clear lowest or highest scores within those attributes are noted here. Clone 76 had highest yellow colour and grassy aroma, and lowest astringency; 95 had lowest honey aroma; 96 had highest honey aroma and lowest scores for bitterness, box hedge/passionfruit, melon, citrus and grassy aromas, and box hedge/passionfruit flavour; and 277 scored highest in melon, citrus and box hedge/passionfruit aromas, box hedge/passionfruit flavour and astringency, and lowest yellow colour.

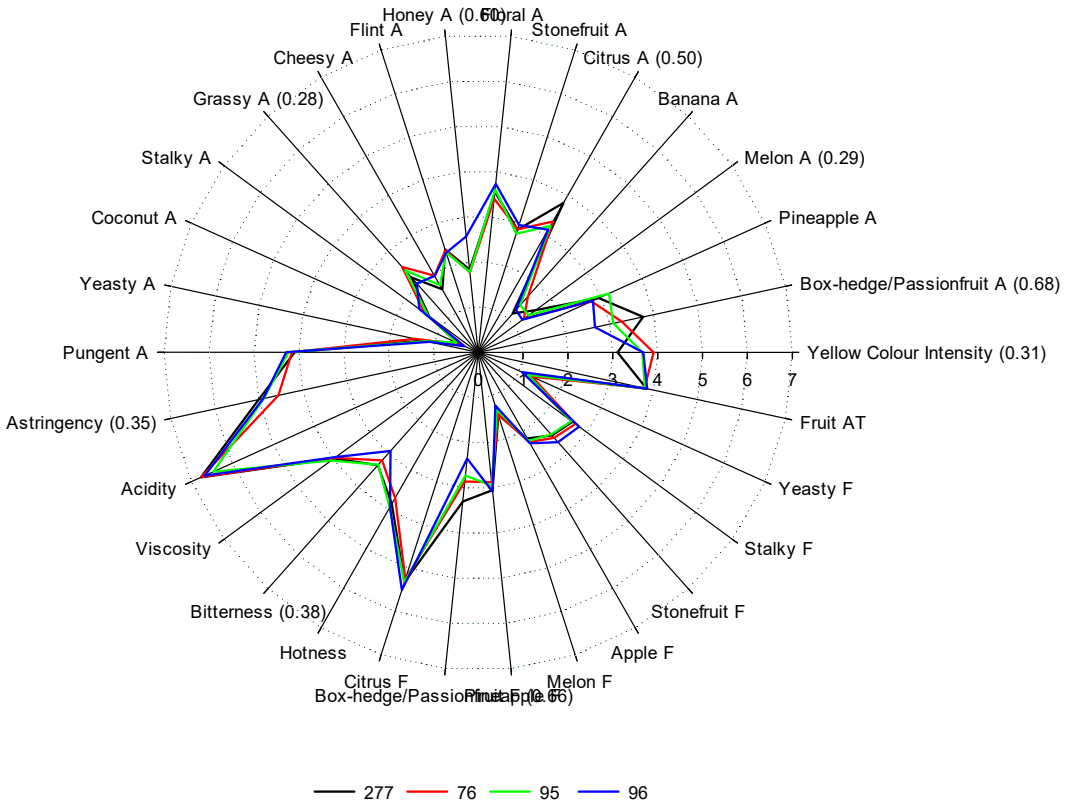


Figure 75. Radar plot of sensory attributes of V17 Chardonnay clonal wines from Drumborg
Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

Grampians

In the Grampians site, 10 of the 30 attributes showed significant differences between clones (Figure 76). For each clone, 76 has the highest score for stonefruit aroma; 95 had the highest score for honey aroma and viscosity, and lowest for citrus, box hedge/passionfruit and apple flavours and acidity; 96 had the highest score for grassy aroma, apple flavor and acidity, and lowest score for yellow colour; and 277 had the highest score for pineapple aroma, box hedge/passionfruit flavor and yellow colour, and the lowest for stonefruit and grassy aromas.

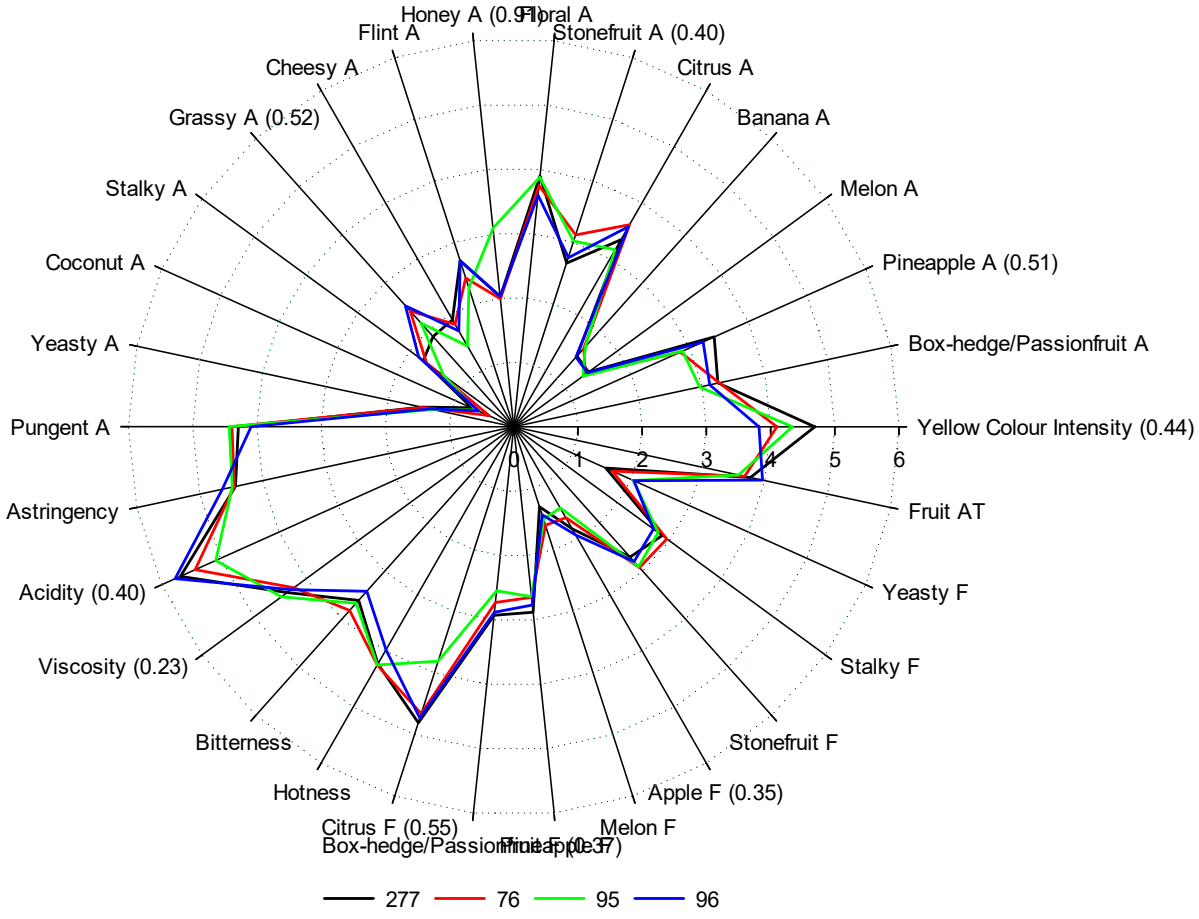


Figure 76. Radar plot of sensory attributes of V17 Chardonnay clonal wines from the Grampians. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

Great Southern

In the Great Southern region (Figure 77), 76 had highest scores for pineapple and melon aroma, and lowest scores for honey aroma, pungency and bitterness; 95 had highest box hedge/passionfruit flavor and pungency; 96 had highest scores for stalky, stonefruit and apple flavours and acidity, and low scores for pineapple aroma, melon flavor and yellow colour; 277 was high for citrus flavor and bitterness, and low with banana aroma, stonefruit and pineapple flavor, and yellow colour; Gingin scored highest in yellow colour and bitterness, and low in apple flavor, and I10V1 scored highest in banana and honey aromas, and melon, apple and stonefruit flavours, and lowest in acidity, and box hedge/passionfruit and citrus flavours. The Great Southern was the only region where there was significant difference in hotness between the clones with the Gingin clone recording the highest score and 76 the lowest.

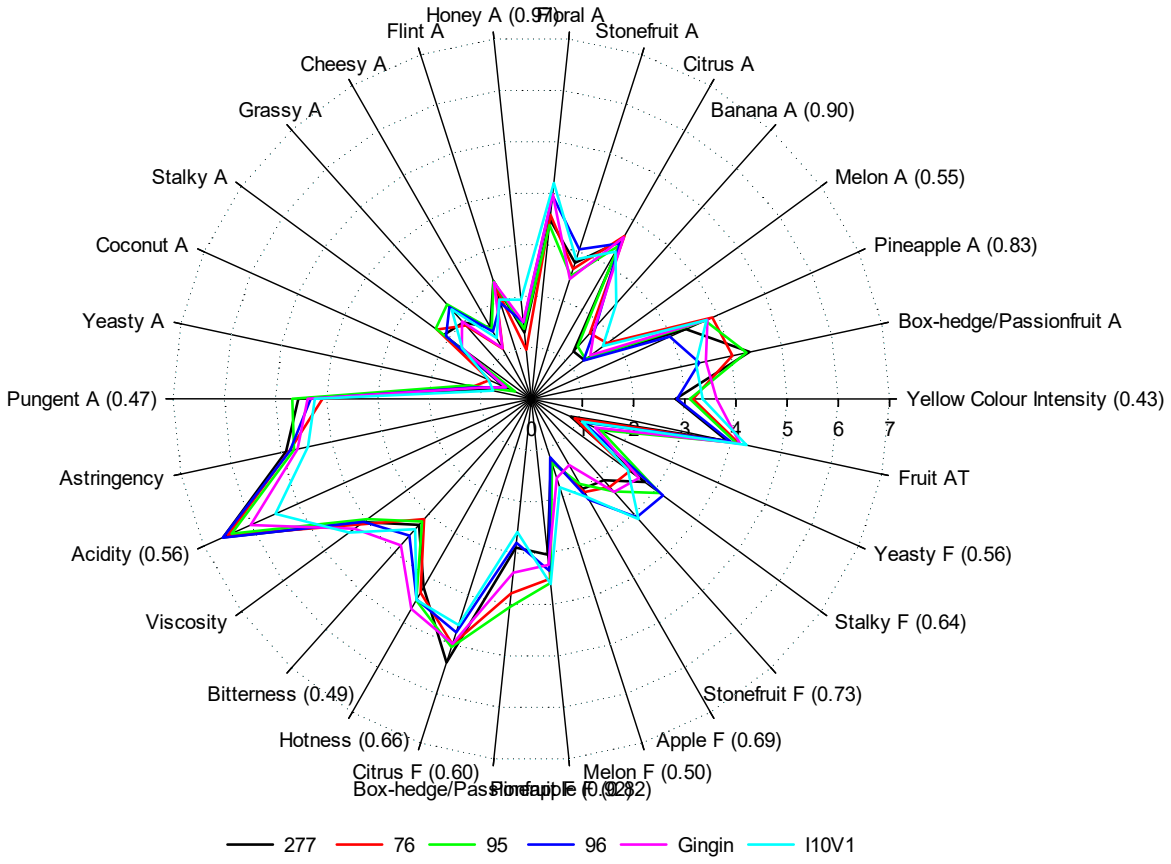


Figure 77. Radar plot of sensory attributes of V17 Chardonnay clonal wines from the Great Southern. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

Margaret River

The high and low attributes for each clone in the Margaret River region were: 76 scored high in acidity; 95 scored high in floral aroma and low in box hedge/passionfruit flavor, astringency and acidity; 96 was highest in flint aroma and yeasty flavor, and lowest in citrus and floral aromas; 277 was lowest in box hedge/passionfruit aroma; and Gingin scored highest in box hedge/passionfruit aroma and flavor, citrus aroma, astringency and acidity, and lowest in yeasty flavours.

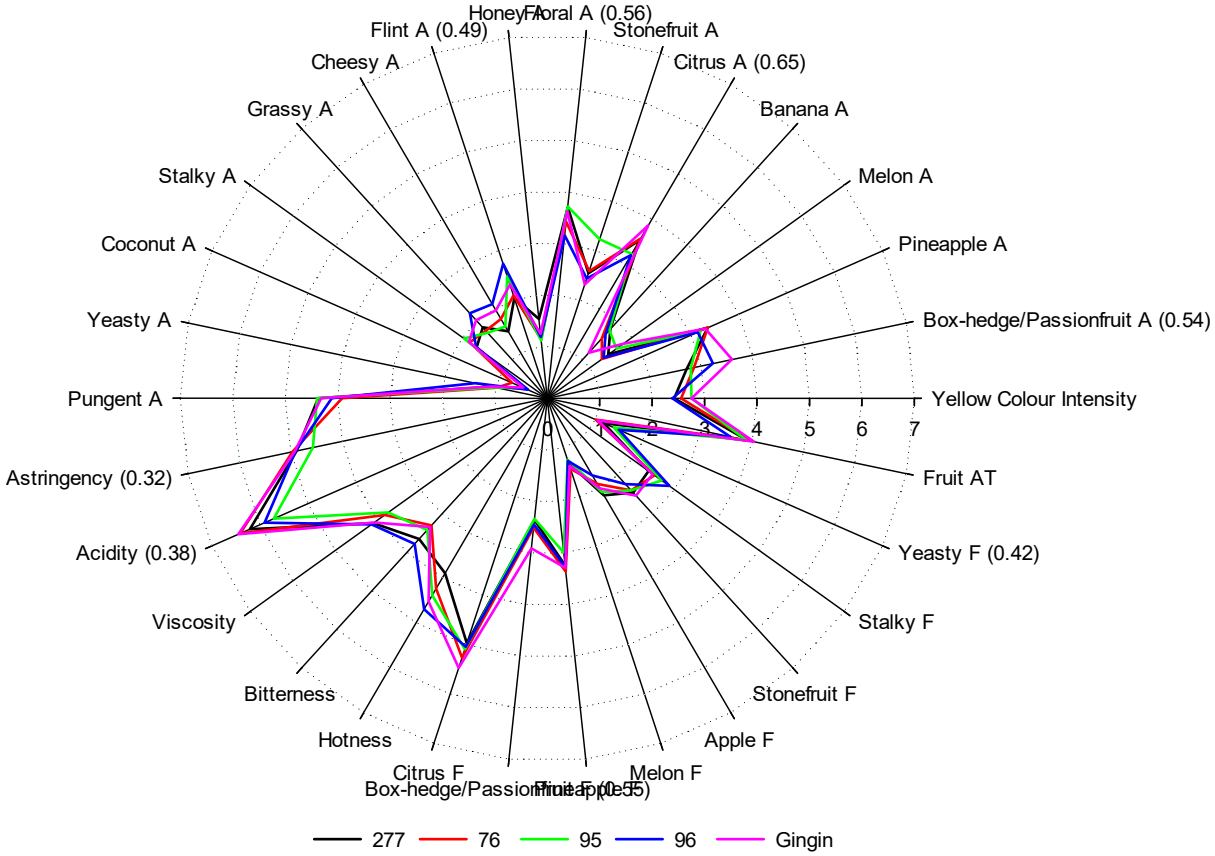


Figure 78. Radar plot of sensory attributes of V17 Chardonnay clonal wines from Margaret River. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

Riverland

Finally, in the Riverland region, the highest and lowest significant scores for each Chardonnay clone were: 76 highest scores in acidity (Figure 79) , citrus flavour and stalky, pineapple and citrus aromas, and low in stonefruit flavour; 95 was high in the attributes of yellow colour, pineapple aroma and citrus flavour, and low in citrus aroma; 96 scored highest in stonefruit flavour, and lowest in pineapple aroma, citrus flavour, acidity and yellow colour; and 277 scored highest in yellow colour and lowest in citrus aroma.

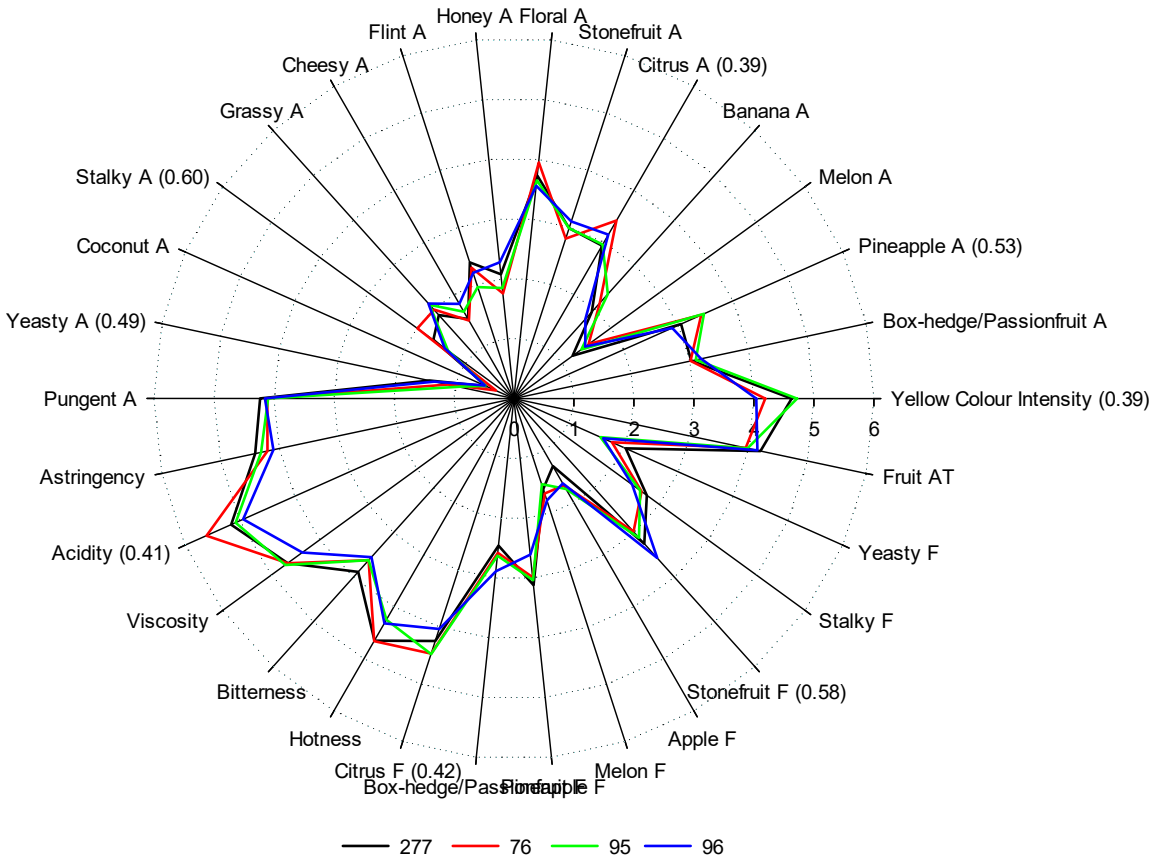


Figure 79. Radar plot of sensory attributes of V17 Chardonnay clonal wines from the Riverland. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different.

In summary; there were significant differences in a number of attributes between clonal wines in each of the five regions, and while the impact of the clones was not consistent, the V17 results demonstrated that based on the structured sensory evaluation the differences between clones are a resource that can be exploited by winemakers.

7.8.3 Sensory analysis of 2014 Shiraz

7.8.3.1 Regional comparison

PCA of the scores from the four regions separated them into three distinct groups (Figure 80) with Shiraz wines from the Grampians and Margaret River being more similar than the Barossa and Riverland wines, which were in different quadrants of the PCA plot. The Riverland wines tended to have higher alcohol (mean of 15.6 %) (

Table 401) than the other regions, i.e. overall "riper" fruit, and this may account for these wines being separated from the other regions being rated higher in brown colour, bitter, hotness, pungent, boiled egg and green aroma, several of these being perceived as negative attributes. F1 and F2 account for a total of 83.9% of the variation in the data set. The Barossa wines were 1% lower in alcohol than the Riverland wines but generally rated higher in overall fruit aroma and flavour, dark fruit aroma and flavour, opacity, sweet spice, vanilla and sweet. The Grampians samples (14.3 % alcohol) tended to be rated lower in these attributes, however were relatively high in red fruit aroma and confection. The Margaret River wines (14.8% alcohol) were similarly rated higher in red fruit and confection. While the Barossa and Margaret River wines were the closest in % alcohol they were either side of the F1 axis, highlighting the impact of the regional climate on wine sensory attributes.

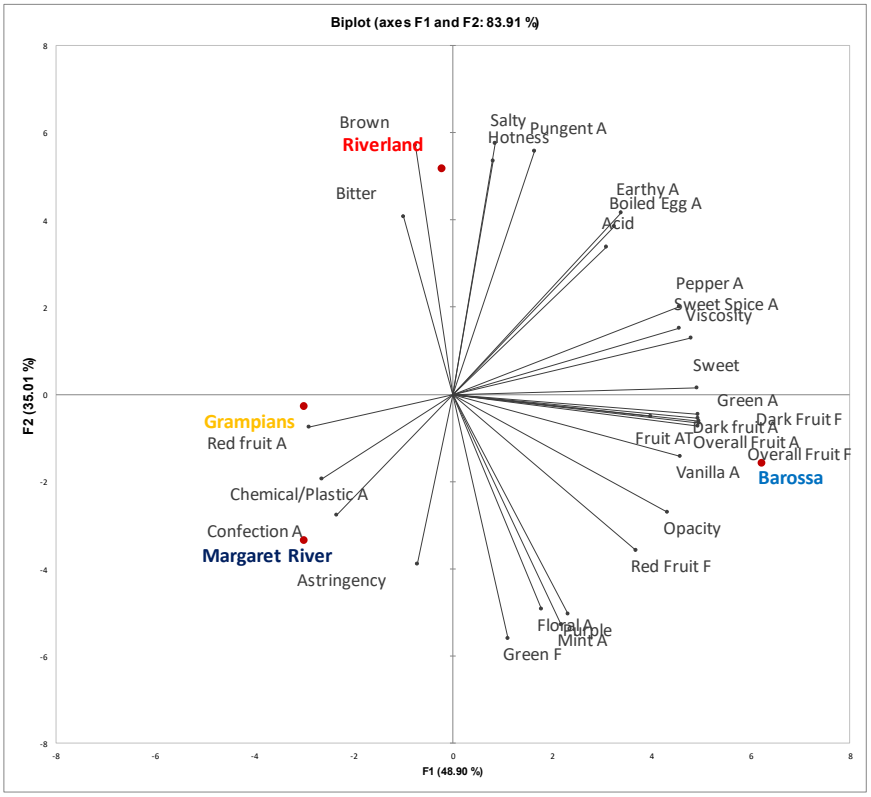


Figure 80. Scores and loadings PCA biplot for the 2014 Shiraz wines pooled by regions showing F1 and F2.

The mean score of each attribute for all clones and for both winemaking replicates and tasting sessions was used for the analysis of regional differences. From this analysis of variance there were significant differences among many of the 29 attributes. Red fruit and green flavour, salty taste and acid were the wine attributes not significantly different

The radar plot of mean scores for all (Figure 81) further highlights the Barossa wines having higher scores than the other three regions for opacity, purple, overall fruit aroma, dark fruit aroma, vanilla aroma, overall fruit flavour and fruit aftertaste. The Barossa also had the highest scores for seven other attributes which were significant over one or more regions. In contrast, the Grampians wines had no highest scores for any attribute. The Riverland wines scored significantly lower in purple and highest in brown colour, hotness and bitterness (negative attributes), Margaret River wines were the most astringent and scored higher in red fruit aroma and lower in dark fruit aroma and flavour, mainly compared with the Barossa.

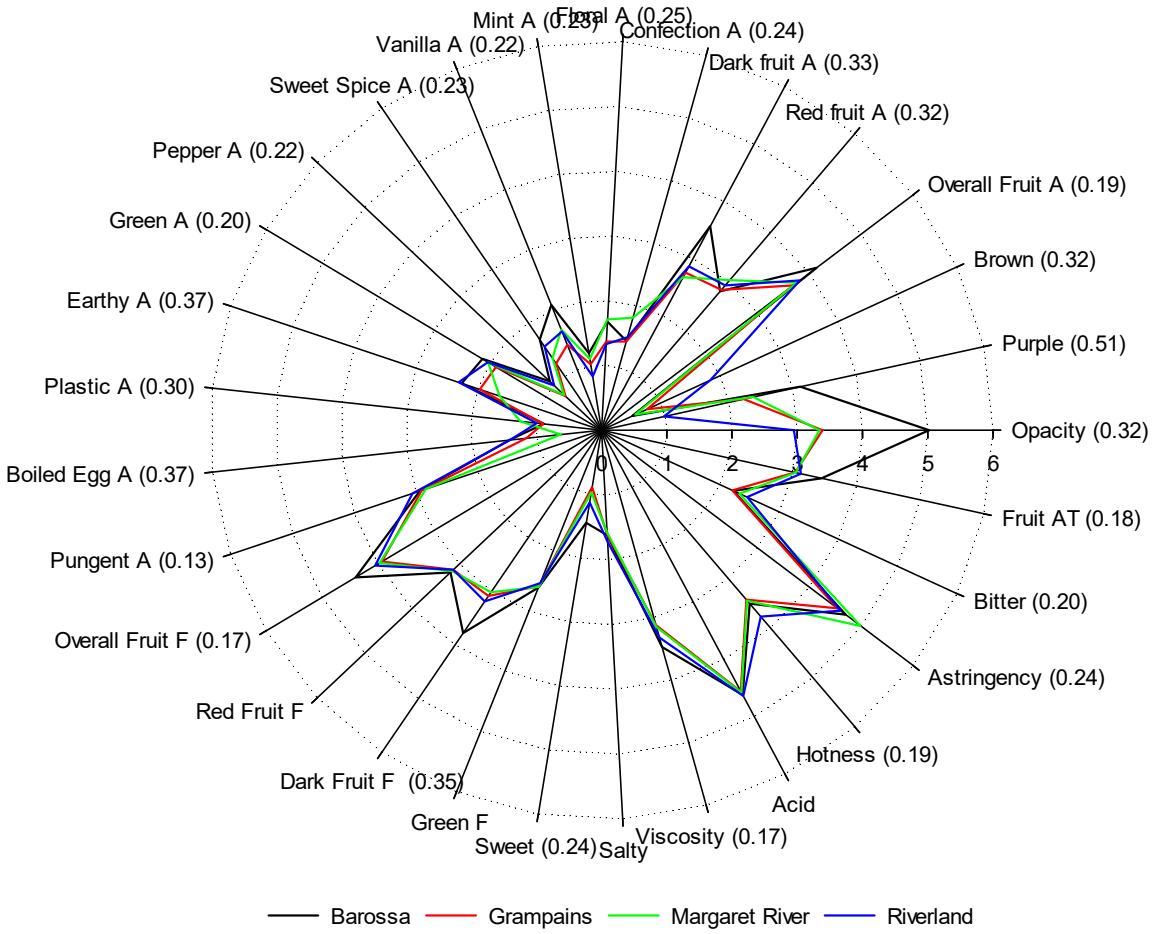


Figure 81. Radar plot of attributes of V14 Shiraz wines grouped by region.
Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different between regions.

7.8.3.2 Within-region variation

The PCA plot of all clones in each region (Figure 82) is similar to Figure 80, with Margaret River, Grampians and Riverland wines primarily on the left hand side of the F1 axis and Barossa on the right hand side. F1 and F2 accounted for 58% of the variability. F3 accounted for only a further 9% of the variation (data not presented). Within each region there was a notable spread along the F1 and F2 axis indicating the significant differences between many of the clones in each region. This is most notable in the distribution of the Barossa and Grampians wines above and below the F2 axis. There were no consistent groupings of clones according to attributes, suggesting that region was the dominant influence on the attributes assessed. The differences between clonal attributes within each region are further highlighted in the radar plots for each region in Figure 82, Figure 83, Figure 84 and Figure 85. Wine scores are the average of the fermentation duplicates. Where there were significant differences; the highest and lowest scores were statistically separated with intermediate scores being similar to the lowest or highest score.

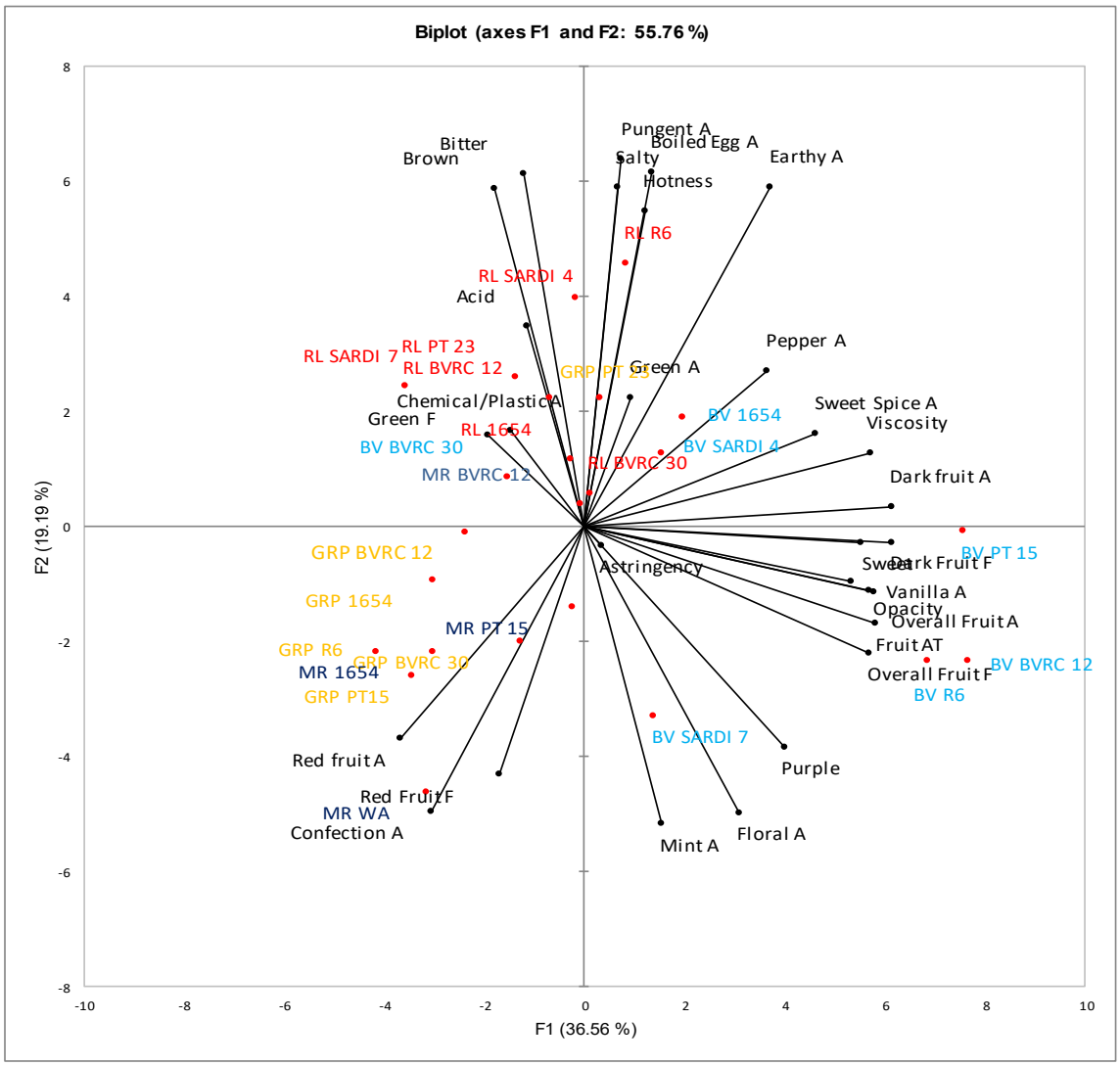


Figure 82. Scores and loadings PCA biplot for the Shiraz clones, showing F1 and F2.
BV = Barossa Valley, GRP = Grampians, MR = Margaret River, RL = Riverland

Barossa

In the Barossa valley wines 23 of the 29 attributes showed significant differences between Shiraz clones (Figure 83). Where there were significant differences, the highest and lowest scores were statistically separated, with intermediate scores being similar to the lowest or highest score. Some clones tended to group together across several of the attributes. For example, with overall fruit aroma and fruit aftertaste, BVRC 12, R6 and PT 15 were grouped highest and 1654, BVRC 30, SARDI 4 and SARDI 7 were grouped lowest. For overall fruit flavour the grouping was similar with SARDI 7 moving into the highest group.

Across the various clones; 1654 did not rate highest or lowest for any attribute; BVRC12 scored highest for opacity, purple, dark fruit and vanilla aromas, and astringency, and lowest for green aroma; BVRC 30 scored highest in green aroma and flavour, and bitter taste, and lowest for opacity, purple, dark fruit and vanilla aromas, and viscosity; PT 15 scored highest in opacity, purple, dark fruit, vanilla and earthy aromas, and viscosity, and lowest for red fruit flavour; R6 had highest scores for dark fruit and pepper aromas, sweet taste and viscosity, and lowest scores for acidity, astringency and bitterness; SARD I4 had the lowest score for sweet taste; and SARDI 7 had highest scores for confection, floral and mint aromas, red fruit flavour and acidity, and lowest scores for pepper and earthy aromas.

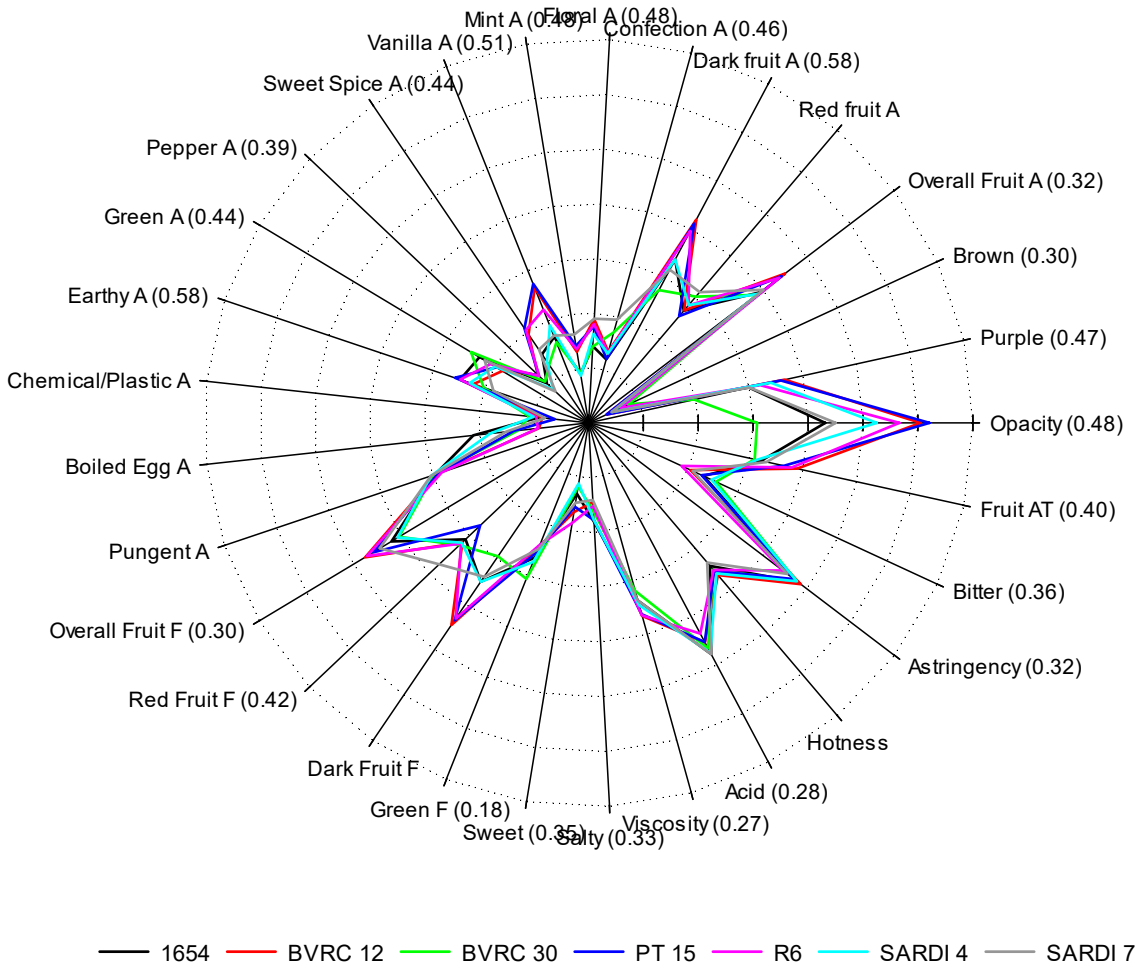


Figure 83. Radar plot of sensory attributes of V14 Shiraz clonal wines from the Barossa.
Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different between clones.

Grampians

In the Grampians region, there were significant differences in 21 of the 29 attributes between Shiraz clones with (Figure 84). BVRC 30 had the highest scores for overall fruit aroma and flavour whilst 1654 had the lowest score for overall fruit flavour (no significant differences with fruit aftertaste). By clone, 1654 had high acidity, and lowest dark fruit and chemical/plastic aromas, sweetness, hotness and astringency; BVRC 12 had the lowest scores for opacity and acidity; BVRC30 had highest scores for red fruit aroma, sweetness and hotness, and the lowest score for green fruit aroma; PT 15 wines had highest scores for red fruit and confection aromas, and lowest scores for dark fruit aroma and flavour, bitterness and acidity; PT 23 had a mix of 13 positive and negative highest scores, and lowest scores for red fruit and confection aromas, and brown colour; and R6 did not have any highest or lowest scores.

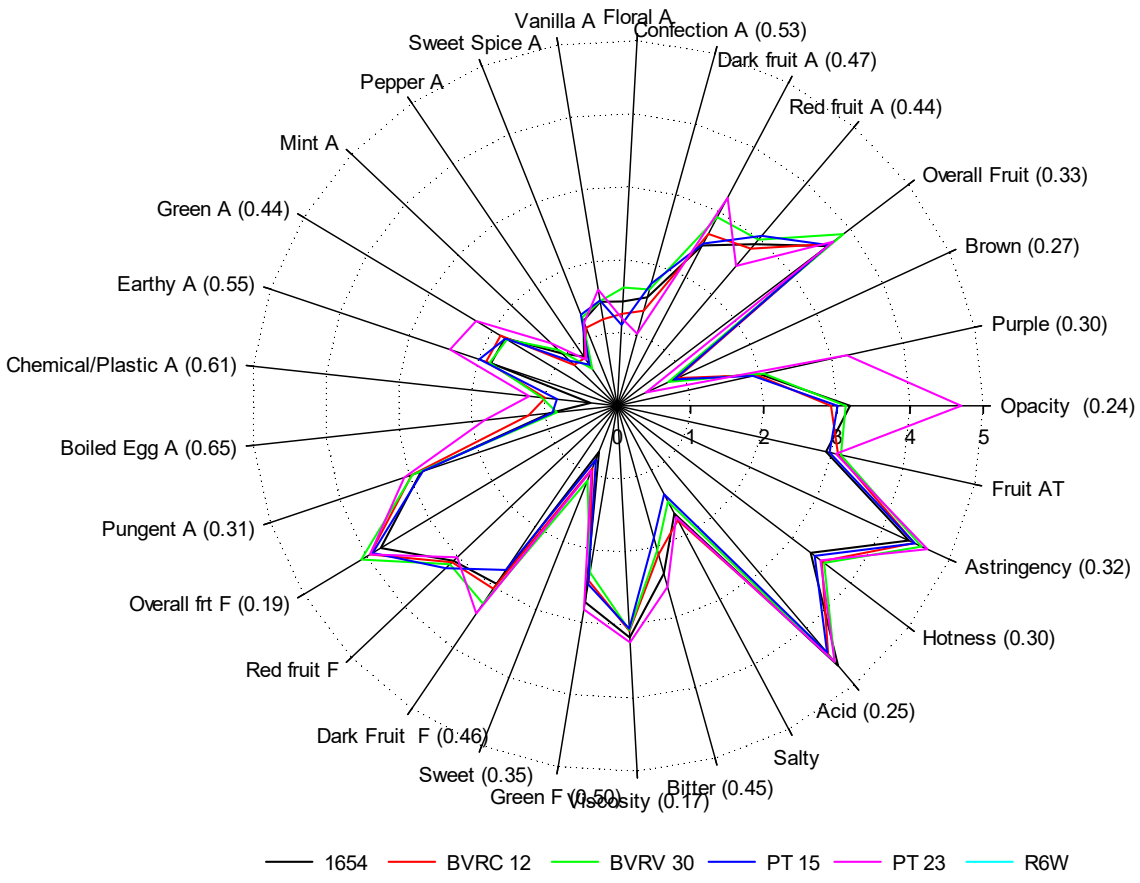


Figure 84. Radar plot of sensory attributes of V14 Shiraz clonal wines from the Grampians
Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different between clones.

Margaret River

There were significant differences between clones in 16 of the 29 attributes in the Margaret River (Figure 85). There were no significant differences between clones for overall fruit aroma, flavour or fruit aftertaste. For individual clones, 1654 had highest confection aroma, green flavour and acidity, and lowest opacity, purple colour, confection and earthy aromas, and sweetness; BVRC 12 scored highest in opacity, dark fruit, confection and pepper aromas, dark fruit flavour, salty taste, bitterness, viscosity, hotness and astringency, and lowest in confection aroma and red fruit flavour; PT 15 had highest scores in purple colour, dark fruit, pepper and earthy aromas, dark fruit and green flavours, and sweetness, and the lowest confection score; and WA had the highest score for red fruit flavour and confection aroma, and lowest scores for dark fruit and pepper aromas, dark fruit and green flavours, salty taste, acidity, hotness, astringency and bitterness.

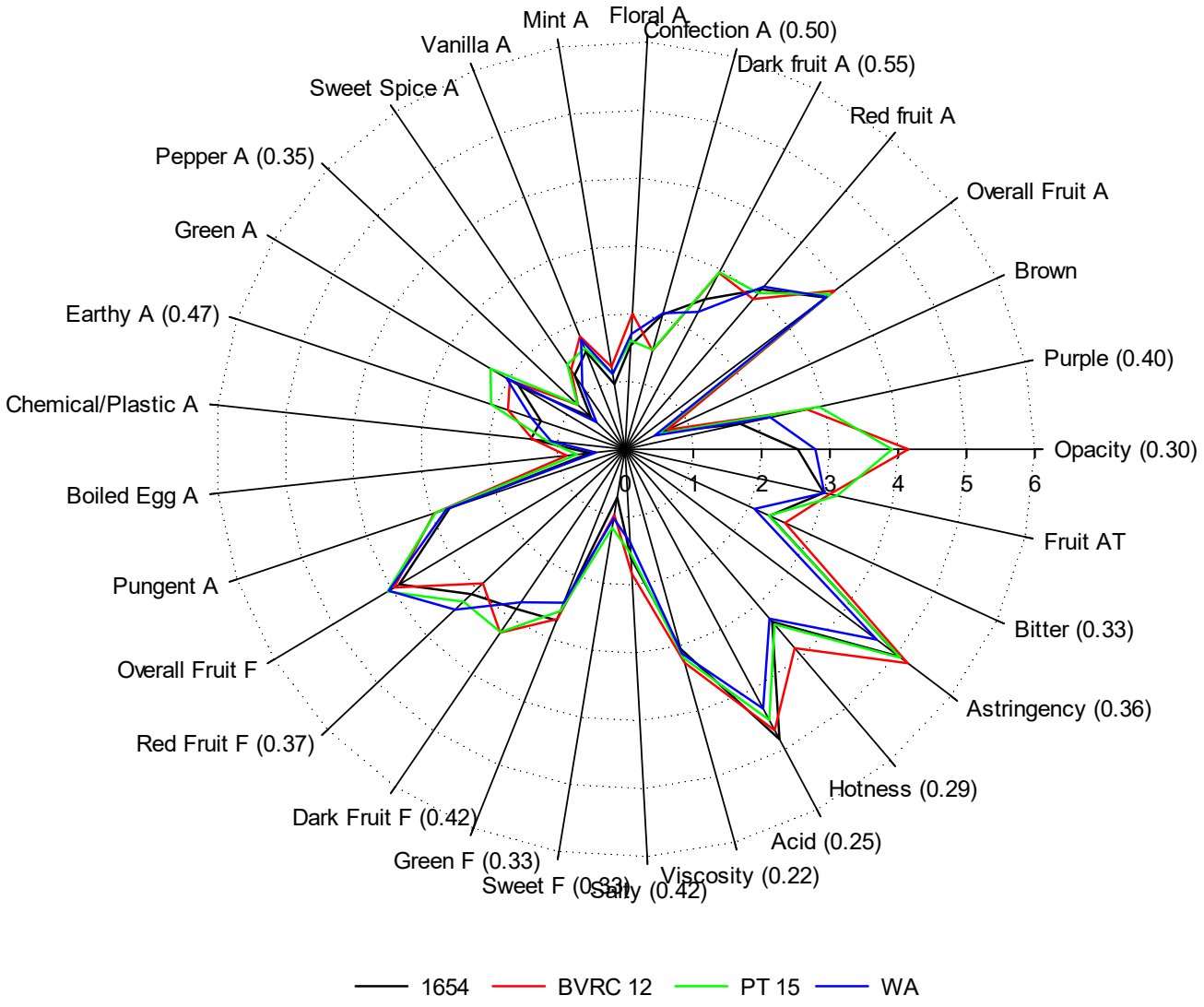


Figure 85. Radar plot of sensory attributes of V14 Shiraz clonal wines from Margaret River. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different between clones.

Riverland

In the Riverland, there were significant differences between Shiraz clones for 21 of the 29 attributes (Figure 86). As a summary of overall perceptions, BVRC30 had the highest score for overall fruit aroma and flavour, whilst SARDI7 had the lowest score for both attributes. Clone 1654 also had a very low score for overall fruit aroma. There were no significant differences between clones for fruit aftertaste.

Looking at attributes for each clone, 1654 had highest scores for mint and green aromas, and lowest scores for brown colour, acidity, astringency and bitter taste; BVRC 12 had the highest scores for astringency and bitterness, and the lowest for brown colour; BVRC 30 had highest scores for red fruit, dark fruit, confection and sweet spice aromas, dark fruit flavours and hotness, and lowest scores for earthy, chemical/plastic and boiled egg aromas; PT 23 did not have any highest scores and scored lowest in green and pungent aromas, and hotness; R6 had highest scores in brown colour, earthy and boiled egg aromas, and sweet taste, and lowest scores in confection aroma and bitter taste; SARDI 4 had highest scores in opacity, purple colour, and chemical/plastic and pungent aromas; and SARDI 7 had the highest score in acidity, and the lowest scores in opacity, purple colour, red fruit, dark fruit, confection, mint and sweet spice aromas, dark fruit flavours and sweet taste.

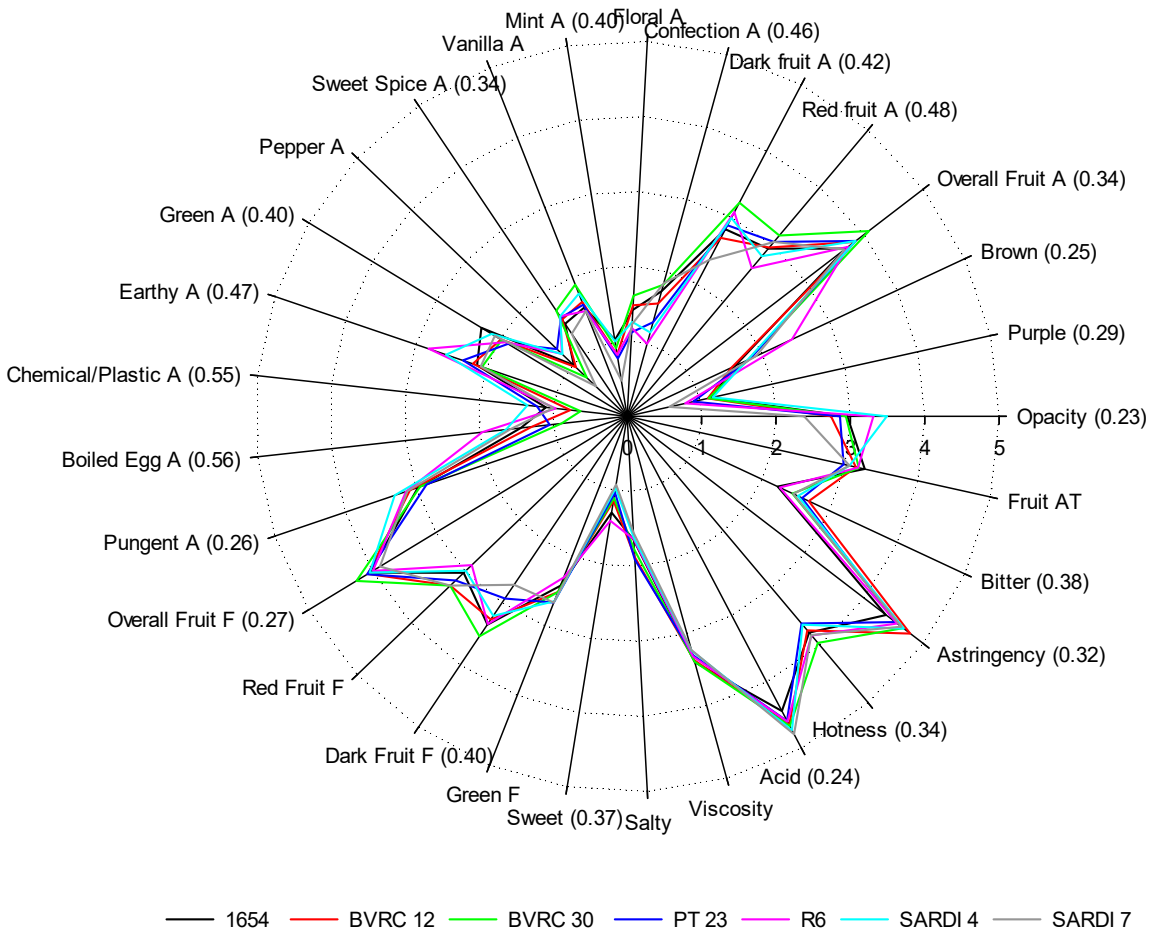


Figure 86. Radar plot of sensory attributes of V14 Shiraz clonal wines from the Riverland. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different between clones.

7.8.3 Sensory analysis of 2015 Shiraz

7.8.3.1 Regional comparison of Barossa, Grampians and Margaret River

Heatwave conditions immediately prior to harvest in the Barossa and Riverland, which initiated rapid ripening, resulted in fruit being higher than the target °Brix and resulted in elevated alcohol concentration (Table 41). The AWRI sensory group considered that the Riverland wines should be assessed separately as the aroma/flavour profiles of these wines were dramatically different from the other regions. The Barossa wines were slightly higher overall in wine alcohol with a mean of 17% with a range of 1.6% compared with the Riverland wines with a mean of 16.6% and a range of 0.6%. In comparison the mean of Grampians wines was 14.2% and Margaret River, 14.3% alcohol.

All of the Margaret River samples were found to have a reductive (rubber, cooked egg) fault and a copper/cadmium trial was conducted to confirm that the compounds were mercaptans. A copper fining trial was then performed to determine if copper treatment eliminated this off-flavour. It was considered that a 0.1 mg/L addition of copper sulphate was appropriate, however 1654 Replicate 1 and PT 15 replicate 2 continued to show strong reductive characters and were excluded from sensory analysis. For the sensory study the other Margaret River samples were treated immediately prior to sensory analysis with 0.1 mg/L copper sulphate.

Principal Component Analysis (PCA) was performed for the mean significant ($P<0.1$) data of 27 of the 30 the sensory attributes (Figure 87). The Barossa wines appeared on the right hand side of the F1 axis with high scores primarily related to pepper, sweet spice, woody, dark fruit, cooked fruit and pungent aromas, dark fruit and chocolate flavours, and brown colour, opacity, acid, viscosity and hotness. Margaret River and the Grampians wines were situated to the left of the F1 axis with these regions being above and below the F2 axis respectively. The Margaret River wines were separated above the F2 axis by the descriptors vegetal, meaty and earthy aromas, green flavour and bitter taste. The results suggest the copper treatment given to the Margaret River samples prior to sensory evaluation was not totally effective at removing the sulfide-related characters, which affected the sensory results for these samples. The masking of fruit-related differences by sulfides accounts for fewer of the aroma attributes being significantly different between clones. The Grampians wines were separated below the F2 axis with descriptors of purple colour, red fruit, overall fruit and confection aromas, red fruit flavour and fruit aftertaste.

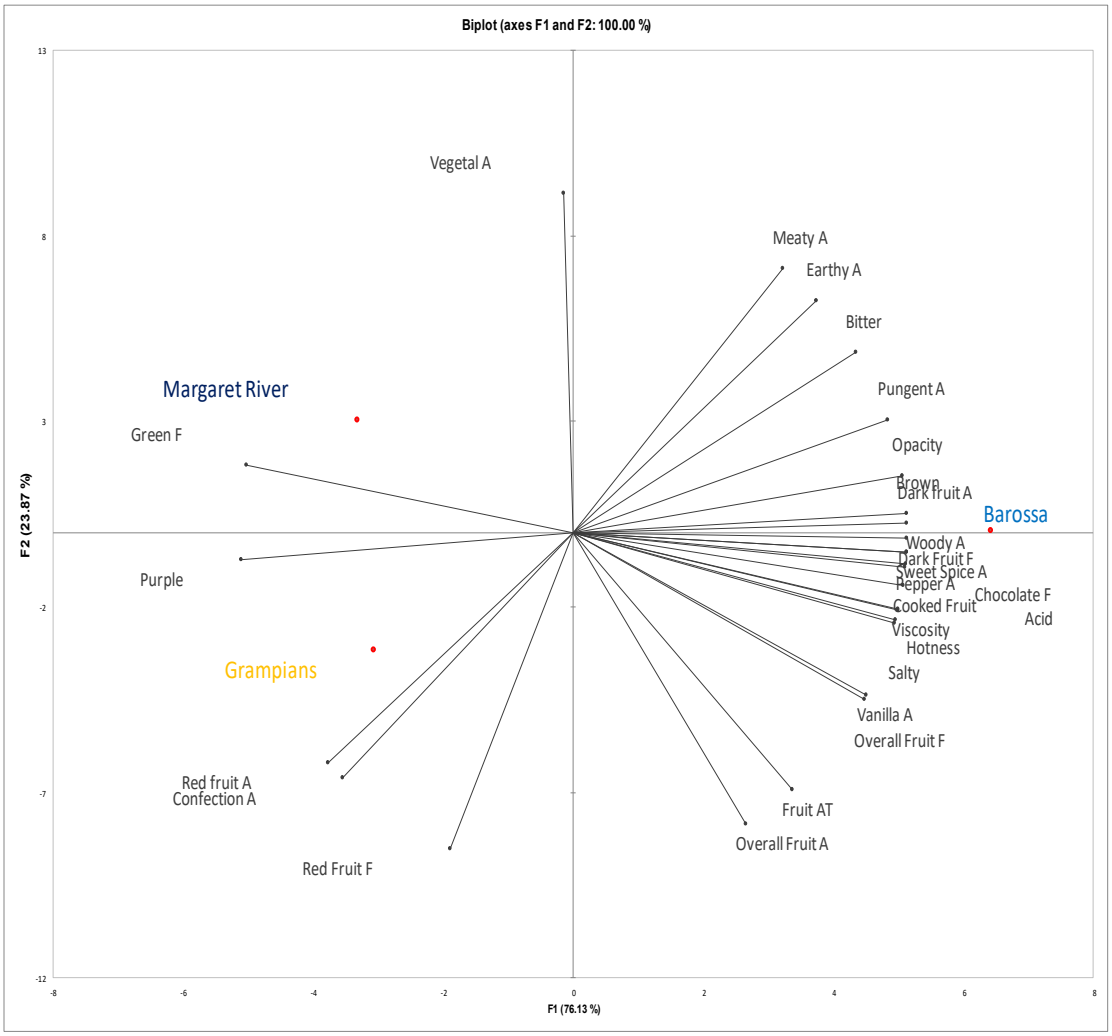


Figure 87. Scores and loadings PCA biplot for pooled data for all clones in Barossa, Grampians and Margaret River showing F1 and F2.

The mean score of each attribute for all clones and for both winemaking replicates and tasting sessions was used for the analysis of regional differences. From this conservative analysis of variance there were significant differences among 24 of the 28 attributes included in the analysis (Figure 88). Pepper, woody and chemical/plastic aromas and salty taste were the wine attributes not significantly different.

The Barossa Valley Shiraz wines were significantly higher than the other two regions for opacity, dark fruit and sweet spice aroma, dark fruit flavour, viscosity and hotness, and the highest score in nine other attributes. Barossa wines were lowest in purple colour, red fruit and confection aromas, and green flavour. The highest scores in brown colour, hotness and viscosity (Figure 88) reflect the elevated alcohol concentration of these wines. The Grampians wines were highest in red fruit aroma and flavour, confection/floral aroma and purple colour, and lowest in opacity, meaty, earthy, vegetal and pungent aromas, and bitter taste. The Margaret River wines were highest in vegetal aroma and green flavour, and lowest in cooked fruit, vanilla and dark fruit aromas, dark fruit flavour, viscosity, acid and hotness. Overall there were more similarities between the Margaret River wines and Grampians than Margaret River and Barossa wines.

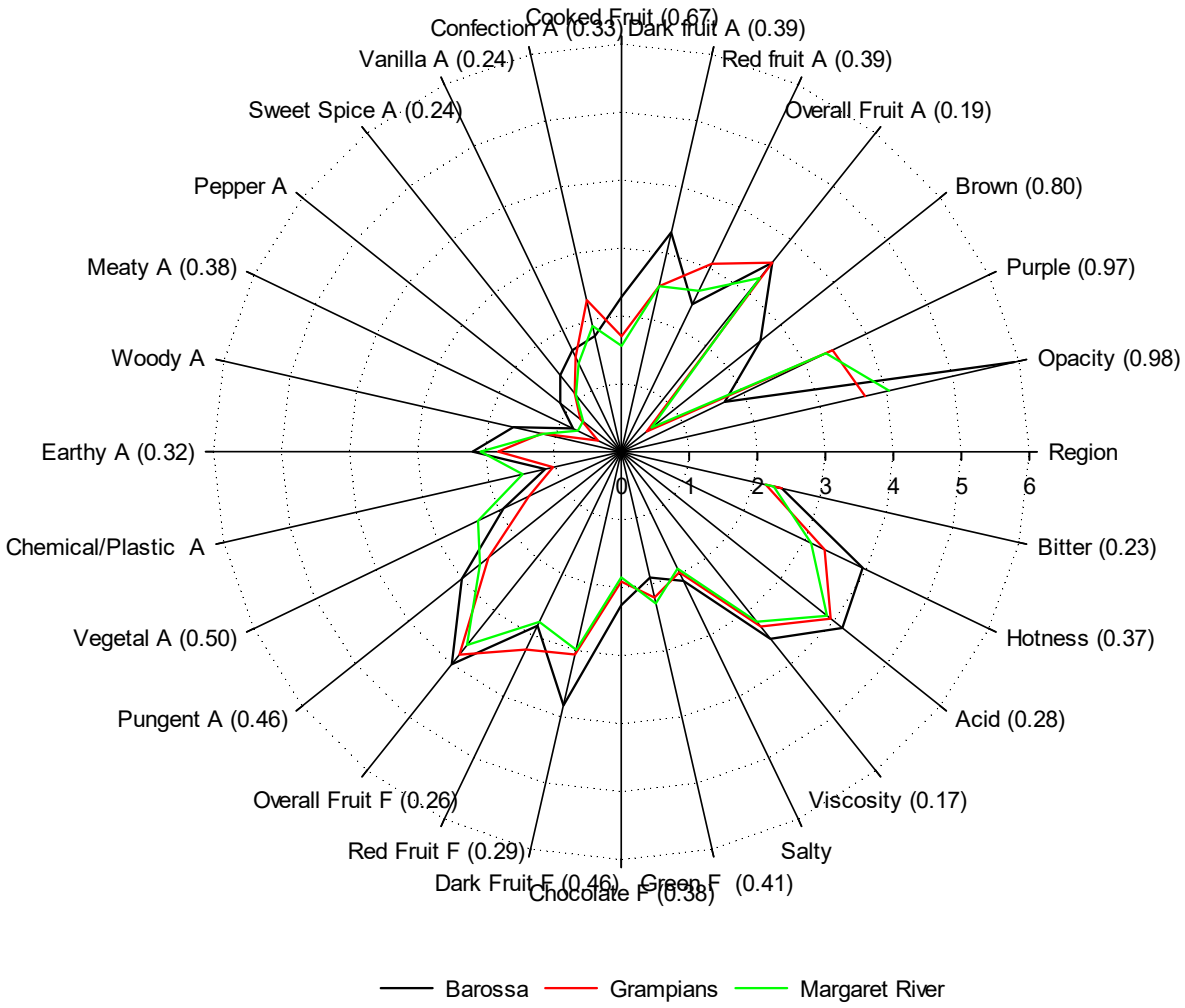


Figure 88. Radar plot of sensory attributes of V15 Shiraz clonal wines from the Barossa, Grampians and Margaret River.
Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different between regions.

7.8.3.2 Within-region variation for Barossa, Grampians and Margaret River

The PCA of all Shiraz clones for each of the three regions using the significantly different attributes (Figure 89) revealed a similar separation of regions as presented in Figure 87. F1 and F2 accounted for approximately 72% of the variation in the data set. The Barossa wines were on both sides of the F2 axis while Grampians wines were grouped to the left and above the F2 axis. The different loadings for Barossa BVRC 12 and BVRC 30 wines potentially highlighted clonal effects as they were a similar alcohol concentration.

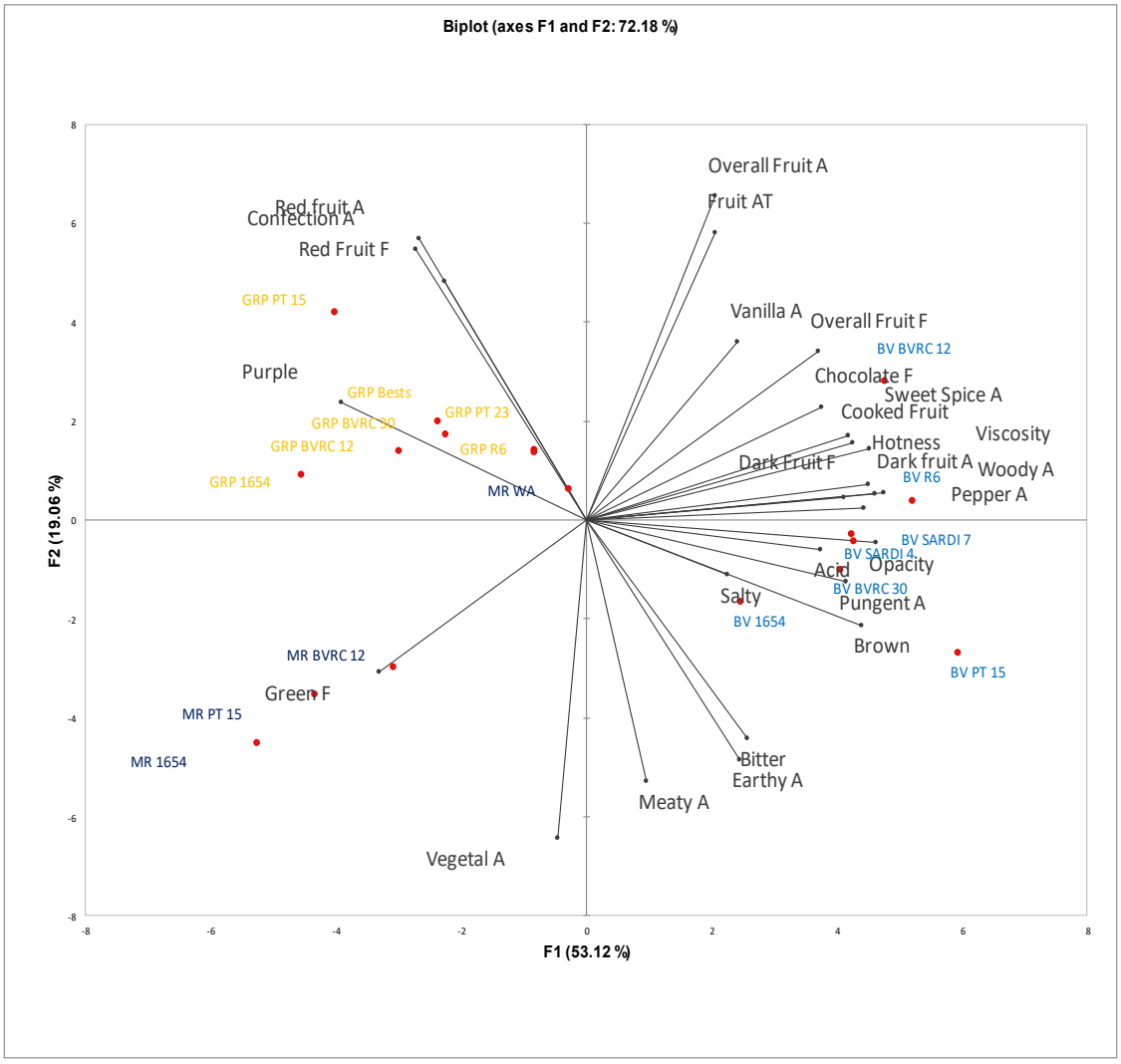


Figure 89. Scores and loadings PCA biplot for the 18 clones, showing F1 and F2. Wines are the average of the fermentation duplicates.
BV = Barossa Valley, GRP = Grampians, MR = Margaret River, RL = Riverland

Barossa

The differences between clonal attributes within the Barossa Valley region are further highlighted in the radar plot for 27 attributes (green and chemical/plastic aromas, and fruit aftertaste omitted), 20 of which showed significant differences between clones (Figure 90). The clone 1654 had no highest scores but many low scores, viz. dark fruit, cooked fruit, vanilla and woody aromas, dark fruit flavour, astringency and bitter taste; BVRC 12 had the highest scores for purple colour, vanilla and woody aromas, and salty taste, and lowest scores for brown and earthy aroma; BVRC 30 had highest scores for vegetal aroma and red fruit flavour, and no lowest scores; PT 15 scored highest for opacity, brown colour, dark fruit, cooked fruit, meaty and woody aromas, and bitterness, with lowest scores for red fruit and confection/floral aromas, and red fruit flavour; R6 scored highest for brown colour, red fruit, cooked fruit and confection/floral aromas, and viscosity; SARDI 4 scored highest for dark fruit flavour, and lowest for opacity and vegetal aroma; and SARDI 7 scored highest for astringency and hotness, and lowest for purple colour, meaty aroma and salty taste.

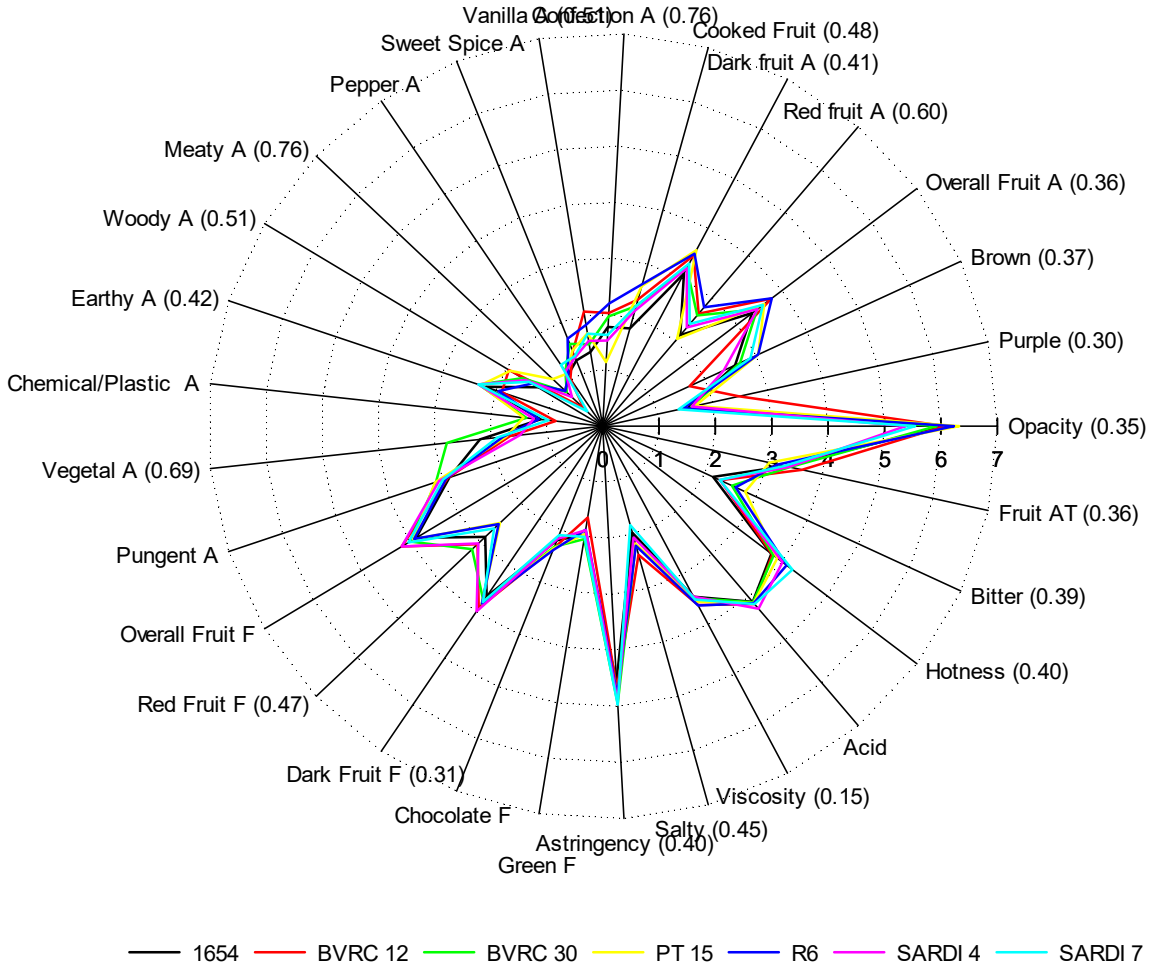


Figure 90. Radar plot of sensory attributes of V15 Shiraz clonal wines from the Barossa.
Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different between clones.

Grampians

With the Grampians region Shiraz wines, 20 of the 28 attributes showed significant differences between the clones (Figure 91). The perception of overall fruit characters showed mixed results for the highest and lowest scoring. For overall fruit aroma, PT 15 had the highest score and BVRC 12 the lowest, and for overall fruit flavour, BVR C30 had the highest score and 1654 and PT 15 the lowest. There were no differences between clones for fruit aftertaste.

With the individual clones, 1654 had the highest score for brown colour, and vanilla, meaty and vegetal aromas, and lowest scores for opacity, dark fruit and woody aromas, chocolate flavour and viscosity; Bests clone had highest earthy aroma, and lowest vanilla aroma, green flavour and acidity; BVCR12 had the lowest red fruit and cooked fruit aromas; BVRC 30 had the highest score for woody aroma and red fruit flavour, and lowest score for chocolate flavour; PT 15 scored the highest for red fruit aroma and red fruit and chocolate flavours, and lowest for purple colour, woody, earthy and vegetal aromas, salty and bitter tastes; PT 23 had the highest scores for cooked fruit aroma, green flavour, and slaty and bitter tastes, and lowest scores for meaty and vegetal aromas, and red fruit flavour; and R6 had the highest scores for opacity, purple colour, dark fruit aroma, viscosity and acid, and the lowest score for brown colour.

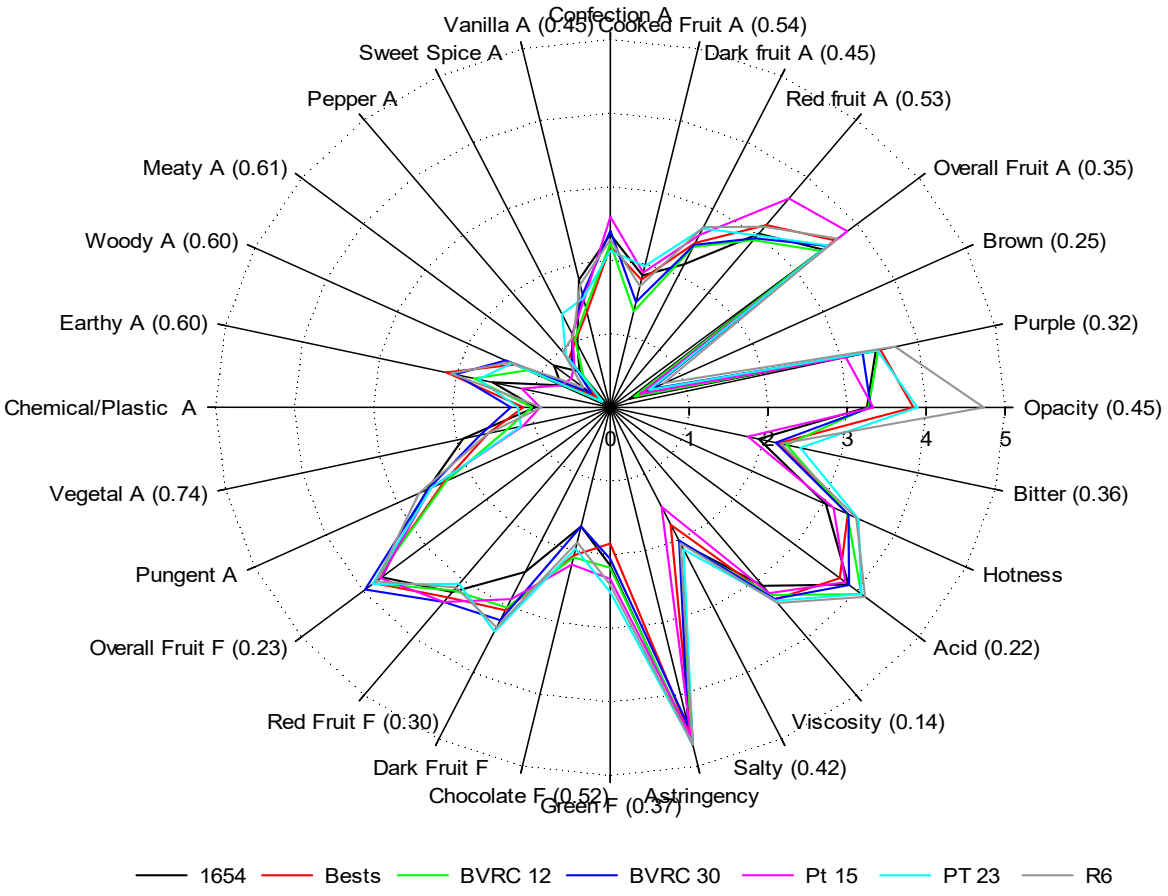


Figure 91. Radar plot of sensory attributes of V15 Shiraz clonal wines from the Grampians. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different between clones.

Margaret River

In the Margaret River region, 13 of the 28 attributes showed significant differences between the Shiraz clones (Figure 92). Of the three attributes assessing overall fruit characters, the WA clone had the highest scores for overall fruit aroma, flavour and aftertaste, whilst 1654 had the lowest overall fruit flavour and aftertaste and BVRC 12 had the lowest overall fruit aroma.

With the individual clones, 1654 had the highest green flavour and lowest score for dark fruit flavour; BVRC 12 had the highest scores for vegetal aroma and green flavour, and lowest scores for opacity, purple colour, dark fruit, sweet spice, pungent, woody and cooked fruit aromas; PT 15 had the highest score for pungent aroma; and WA clone had the highest scores for opacity, purple colour, dark fruit, cooked fruit, sweet spice, woody and pungent aromas, and dark fruit flavour, and the lowest scores for vegetal aroma and green flavour.

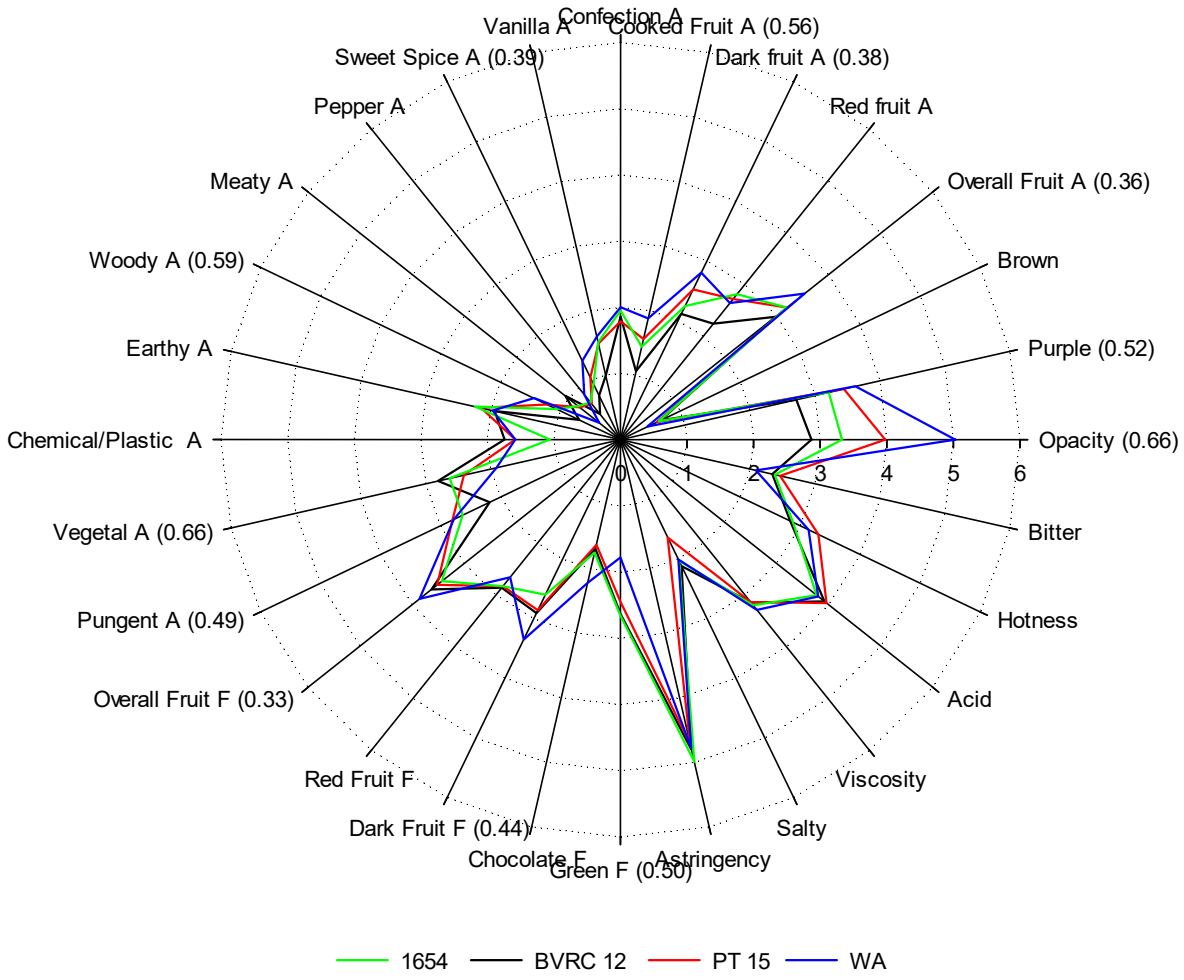


Figure 92. Radar plot of sensory attributes of V15 Shiraz clonal wines from Margaret River. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different between clones.

7.8.3.3 Within-region variation for the Riverland

Principal Component Analysis of the significant traits separated the Riverland Shiraz clones into each of the four quadrats (Figure 93) and F1 and F2 accounted for a total of 66.6% of the variation in the data set. The scores for attributes of BVRC 12 and BVRC 30 were closely aligned and relatively high in chemical/plastic aroma, bitterness and opacity. R6 scored high in dark fruit aroma and flavour, and sweet spice aroma, 1654 scored high in woody and cooked fruit aromas, and PT 23, SARDI 4 and SARDI 7 scored low in most attributes.

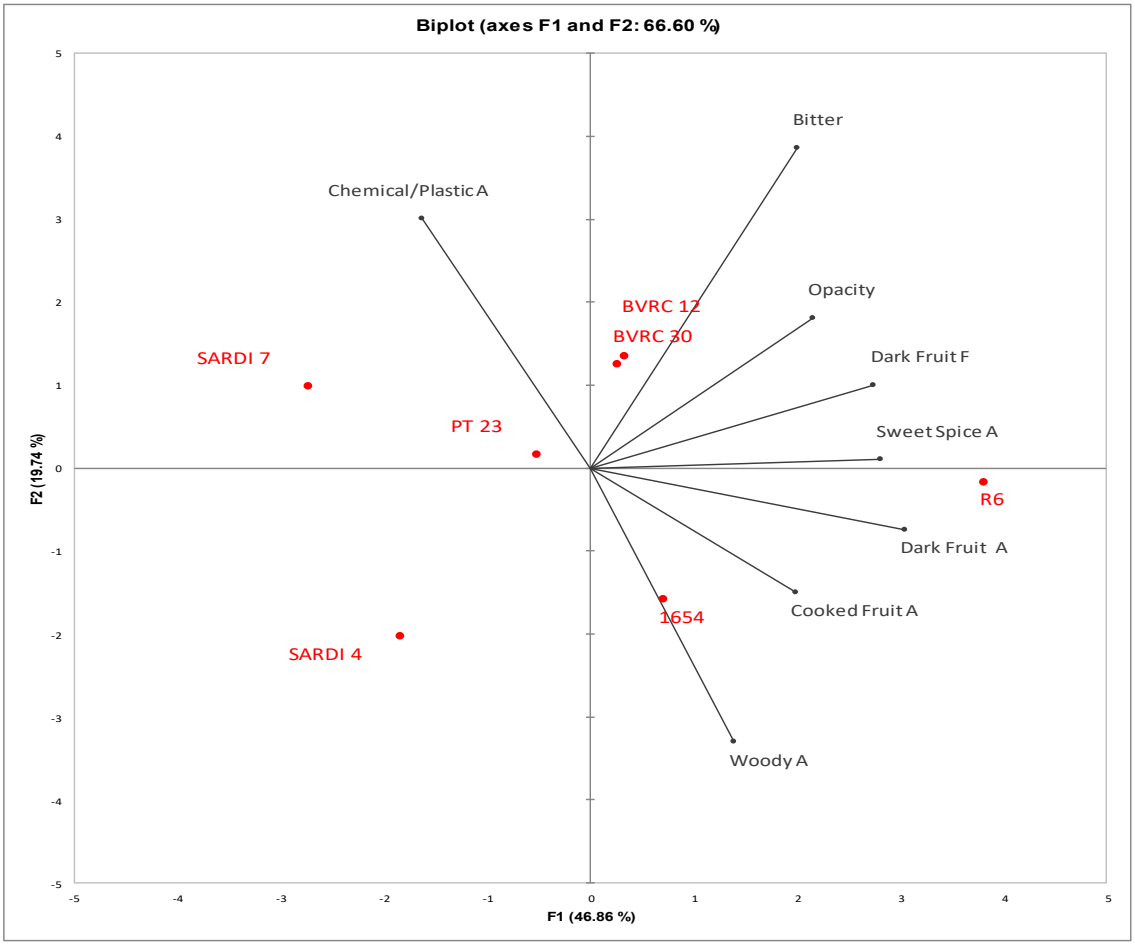


Figure 93. Scores and loadings PCA biplot for the significant attributes of the 2015 Riverland clones showing F1 and F2.

The radar plot of the attributes (green aroma was omitted) highlights that there were significant differences for only eight of the attributes (Figure 94). There were no significant differences between clones for the three overall fruit characters. The clone 1654 scored highest for cooked fruit aroma and lowest for bitterness; BVRC 12 scored highest for opacity; BVRC 30 scored highest for opacity and lowest for cooked fruit aroma; PT 23 scored lowest for woody aroma; clone R6 was rated highest for dark fruit, cooked fruit and sweet spice aromas, dark fruit flavour and bitterness; SARDI 4 was rated highest for the attribute woody aroma and low for sweet spice and dark fruit aroma and bitterness; and SARDI 7 scored highest for chemical/plastic aroma and lowest for opacity, and dark fruit aroma and flavour.

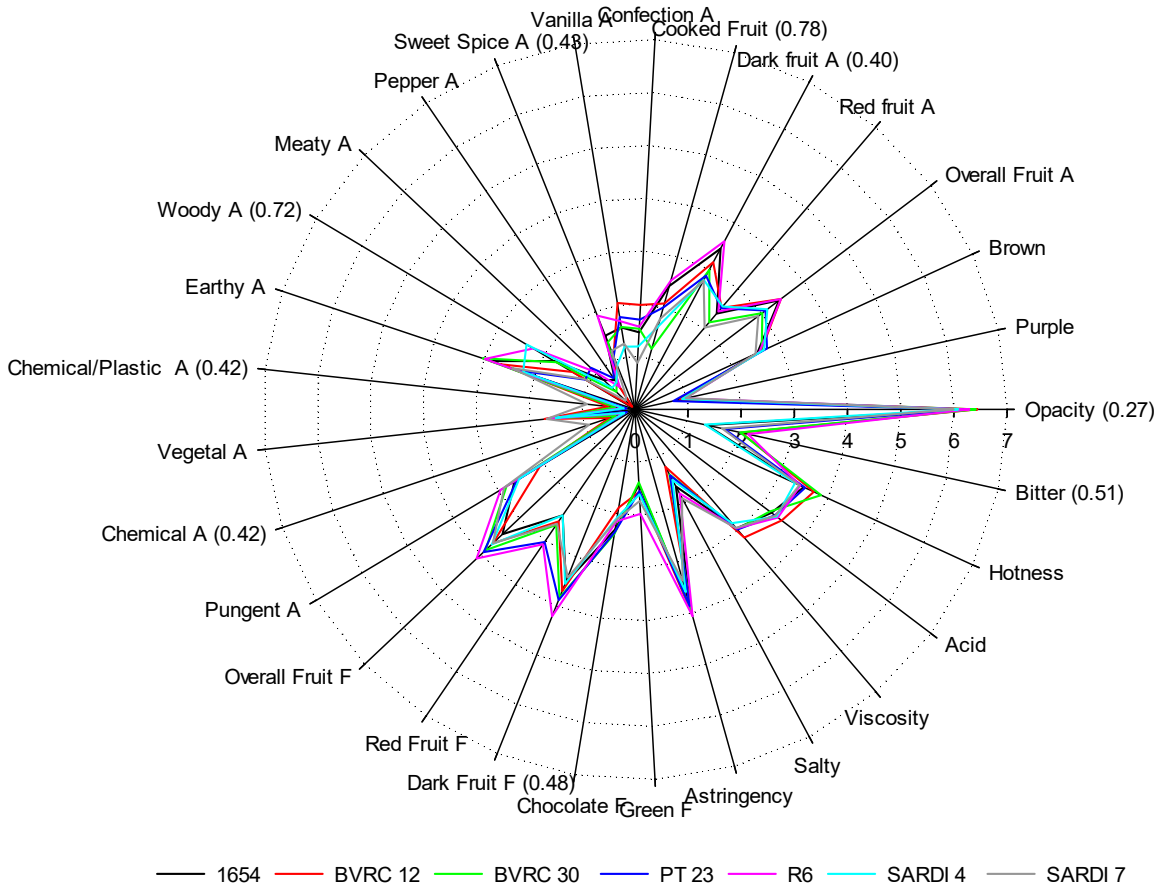


Figure 94. Radar plot of all attributes for the 2015 Riverland clones.
Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different between clones.

7.8.4 Sensory analysis of 2016 Shiraz

7.8.4.1 Regional comparison

Principal Component Analysis (PCA) of the sensory attributes of 2016 Shiraz revealed that for each region, F1 and F2 accounted for approximately 92% of the variability and as in previous years the four regions were spread across the quadrats (Figure 95).

Barossa wines were noted for vegetal aroma and flavour, earthy and barnyard aromas, woody flavour and, salty taste. Margaret River wines were astringent and sweet, with red fruit and confection/floral flavours, and aromas such as fresh green, confection and red fruit. The wines from the Grampians region displayed aromas of mint, vanilla, floral, confection, red fruit and fresh green, and flavours of red fruit and confection/floral. Riverland wines were in the quadrat described by aromas of dried fruit, tomato/HP sauce, chocolate and dark fruit, dark fruit flavour, and brown colour, viscosity and opacity.

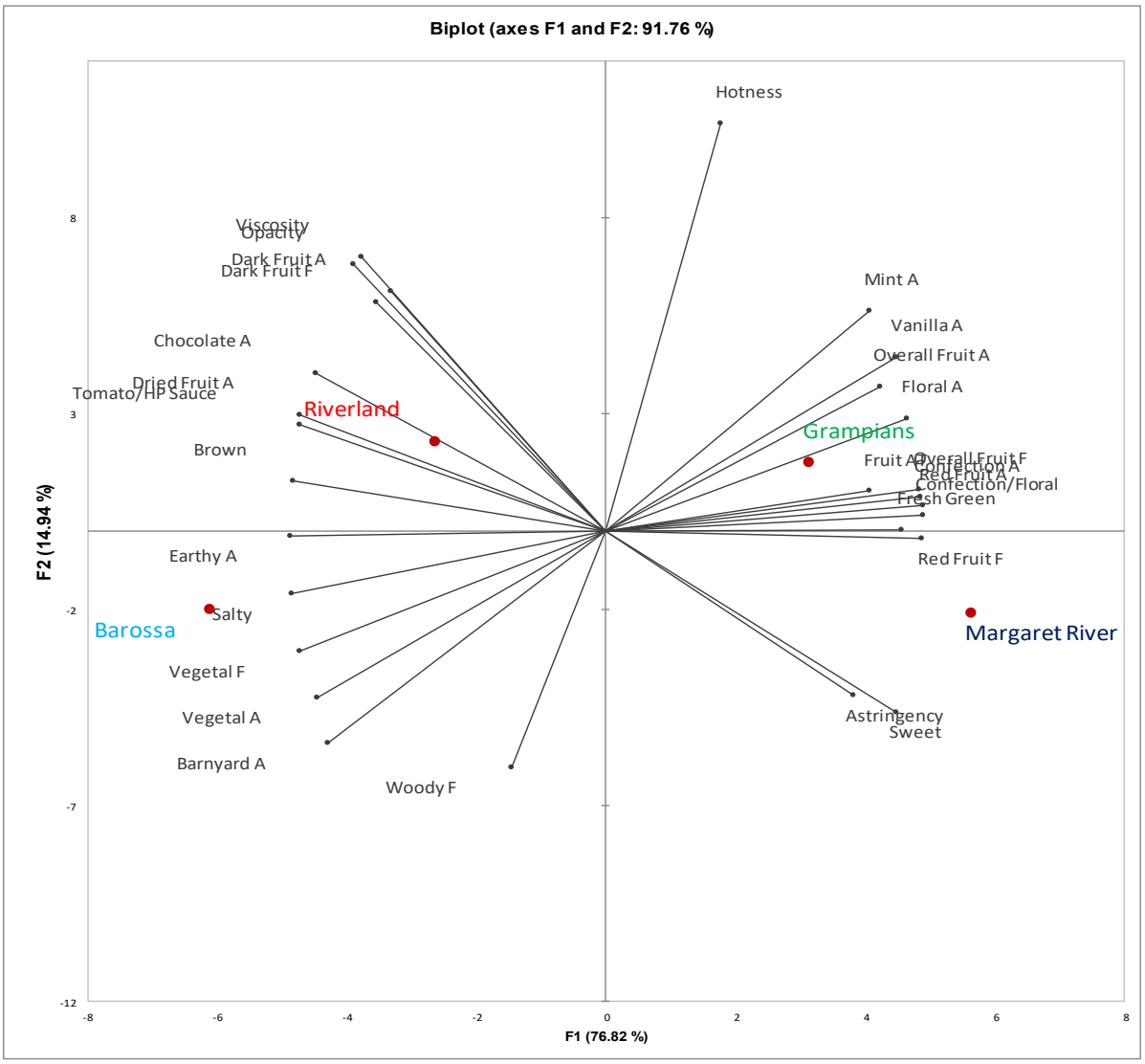


Figure 95. Scores and loadings PCA biplot for the 2016 Shiraz wines pooled by regions showing F1 and F2.

The mean score of each attribute for all clones for both winemaking replicates and tasting sessions for each region was used for the analysis of regional differences. From this conservative analysis of variance there were significant differences among the 28 of the 33 attributes. Chemical/Plastic and pungent aromas, green flavour, acid and hotness were the wine attributes not significantly different.

The radar plot of regional scores that were significantly different (Figure 96) highlights the differences in those 28 attributes. Margaret River wines were highest for overall fruit aroma, flavour and aftertaste, and Barossa Valley wines were lowest for all three of these overall fruit characters.

Considering each region, the Barossa valley wines had highest scores for brown colour, dried fruit, vegetal, tomato/HP sauce, chocolate, earthy and barnyard aromas, vegetal flavour and salty taste, and lowest scores for red fruit, confection, floral, fresh green, mint and vanilla aromas, red fruit and confection/floral flavours, sweet taste and astringency; the Margaret River wines scored highest for red

fruit, confection, fresh green and vanilla aromas, red fruit and confection/floral flavours, sweet taste and astringency, and lowest for opacity, brown colour, dark fruit, dried fruit, tomato/HP sauce, chocolate and earthy aromas, dark fruit and vegetal flavours, salty taste and viscosity; the Grampians wines scored highest in floral, mint and vanilla aromas, and lowest in vegetal and barnyard aromas, vegetal and woody flavours, salty taste and bitterness; and the Riverland wines scored highest for opacity, dark fruit, dried fruit, tomato/HP sauce and chocolate aromas, dark fruit flavours, viscosity and bitterness, and lowest for sweet taste.

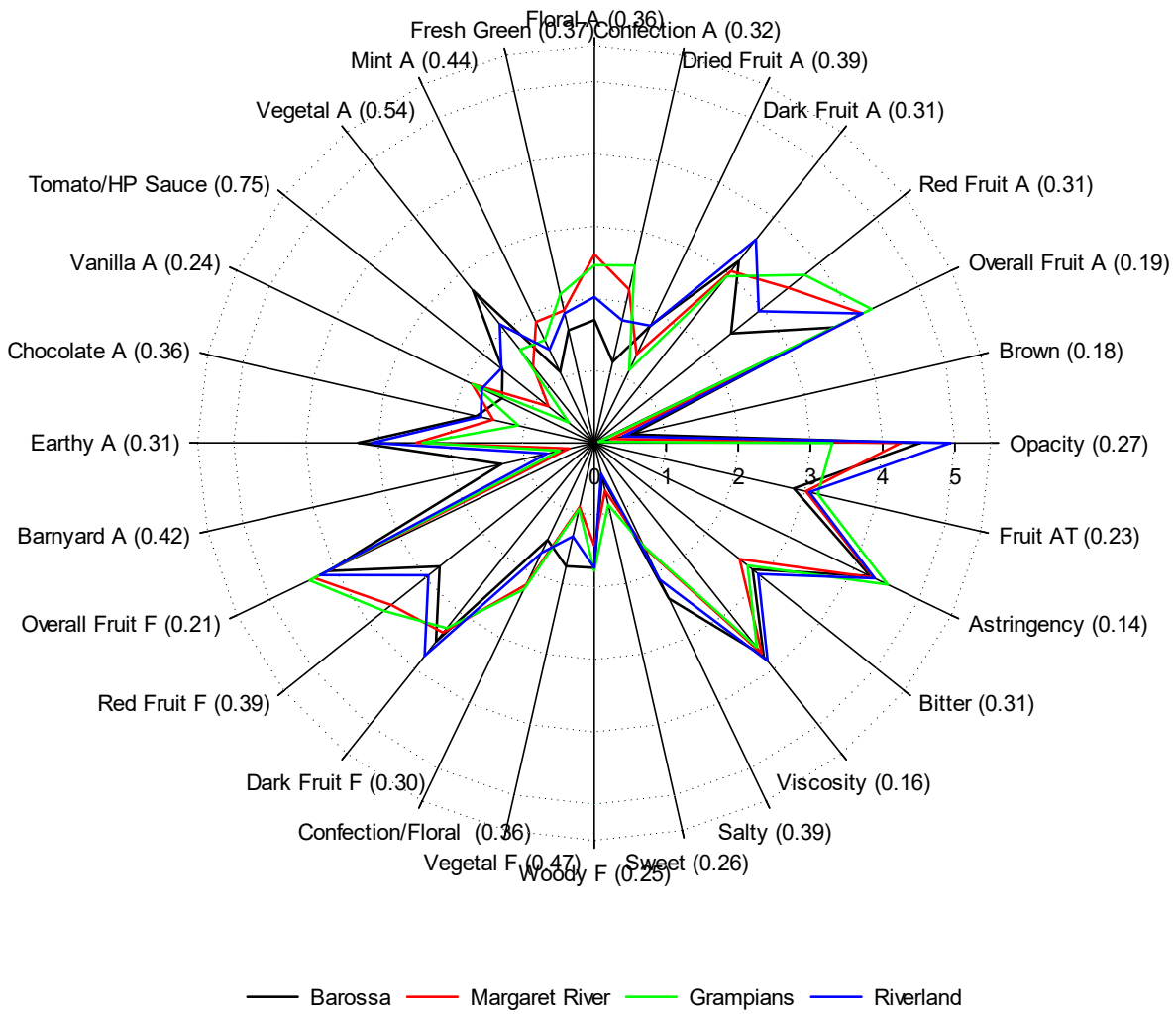


Figure 96. Radar plot of significant sensory attributes of V16 Shiraz wines grouped by region. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different between clones.

7.8.4.2 Within-region comparison

The PCA for 28 significant attributes of all Shiraz clones for each region (Figure 97) grouped the Barossa Valley and Margaret River wines reasonably well by region, although the Riverland and Grampians wines were spread across three of the four quadrants. Two Riverland samples exhibited a large separation along the F1 and F2 axes. PT 23 and SARDI 7 were located in opposite PCA quadrats with PT 23 displaying high scores for astringency, floral, confection, red fruit, and vanilla aromas, and overall fruit aroma, flavour and aftertaste, and SARD I7 lacking those characters and scoring high for vegetal, tomato/HP sauce and barnyard aromas, and vegetal flavour. In the upper left quadrat where most of the Riverland wines appeared, the clone R6 scored higher for opacity, dark fruit, dried fruit and chocolate aromas, dark fruit and woody flavours, and viscosity. Clone PT 23 wines had some of the highest alcohol levels of the of Riverland wines, indicating a greater degree of ripeness at harvest. In the past, this has often been associated with more dark fruit and dried fruit characters. However, with this sample it appears to have maintained its lighter profile.

The Barossa Shiraz wines were spread across upper and lower quadrats to the left of the F1 axis. Some of the spread in the Riverland and Barossa samples could be attributed to the two picking dates, which was done to minimise differences in ^{o}Brix at harvest; however, there was still a 3.5% difference in alcohol in the Riverland clones (Table 42) and a 2% difference in the Barossa wines. In the Riverland, SARDI 7 and SARDI 4 had respectively the lowest and highest wine % alcohol, which may account for the separation either side of the F2 axis. Similarly; in the Barossa, BVRC 30 and SARDI 7 had respectively the lowest and highest % alcohol and these wines were on either side of the F2 axis.

There was a 1.8 % spread in alcohol across the Grampians wines (Table 42), primarily due to one wine-making replicate of 1654 being the least ripe parcel of fruit. The mean score for 1654 resulted in this clone being placed in a different quadrat (Figure 97) and this wine had the highest score for mint aroma and lowest for dark fruit aroma and flavour, chocolate, earthy, woody and opacity (Figure 99). In contrast, R6 was rated highest or nearly highest for these same attributes. Basic chemical measures of Grampians clone R6 (Table 42) indicates that it did not significantly differ from the other Grampians samples; therefore it is reasonable to assume that the differences in attributes between the samples are a product of the clonal differences.

The Margaret River wines were the most uniform in alcohol concentration (0.7% difference) and all wines grouped to the right of the F1 axis (although PT15 was placed above the F2 axis) and were rated high for the attributes floral, fresh green, mint, confection and red fruit aromas, and red fruit and confection/floral flavours, and sweet taste. BVRC 12 scored the highest for red fruit and confection/floral flavours and fresh green, floral and confection aromas and lowest in tomato/HP sauce and earthy aromas (Figure 100) again suggesting that, similar to the Grampians wines, differences in attributes between the samples are a product of the clonal differences.

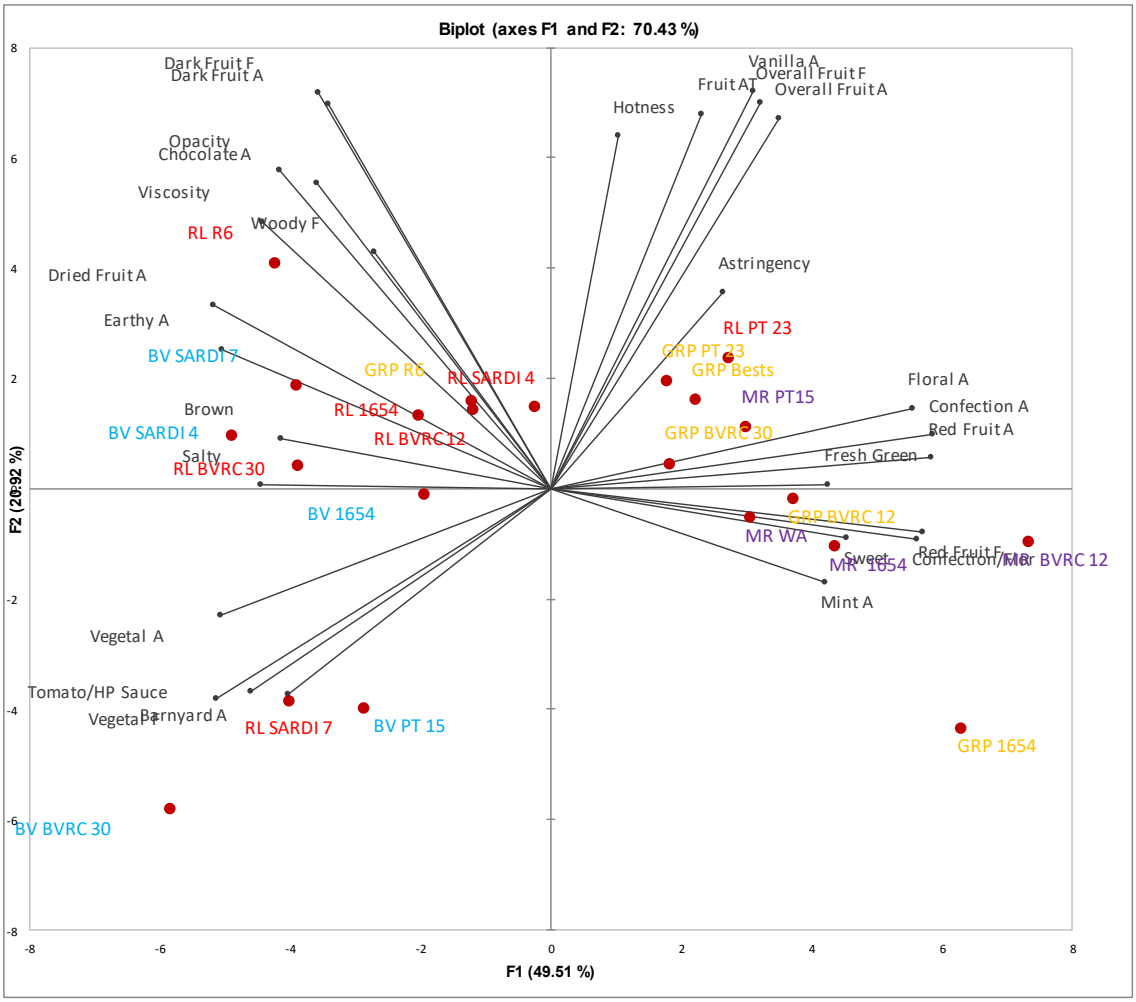


Figure 97. Scores and loadings PCA biplot for the 22 Shiraz clonal wines for the 2016 vintage showing F1 and F2.
Wines are the average of the fermentation duplicates.
BV = Barossa Valley, GRP = Grampians, MR = Margaret River, RL = Riverland

Barossa

In the Barossa, 17 of the 28 attributes showed significant differences between Shiraz clones (Figure 97). The clone SARDI 7 had the highest scores for a range of descriptors including, dark fruit aroma, dried fruit aroma, floral aroma, and overall fruit aroma. Conversely BVRC 30 often scored the lowest for these aroma characters as well as confection/floral flavor and overall fruit flavor. BVRC 30 was the highest scoring clone for tomato/HP sauce and vegetal aroma. The clone 1654 was the highest scoring for confection/floral flavor and was not ranked the lowest scoring for any attribute. PT 23 did not score the highest for any sensory character and was the lowest for brown colour and opacity. The terms red fruit flavor, overall fruit flavor, earthy aroma and opacity were used to describe SARDI 4, which was also the lowest scoring for vegetal flavor.

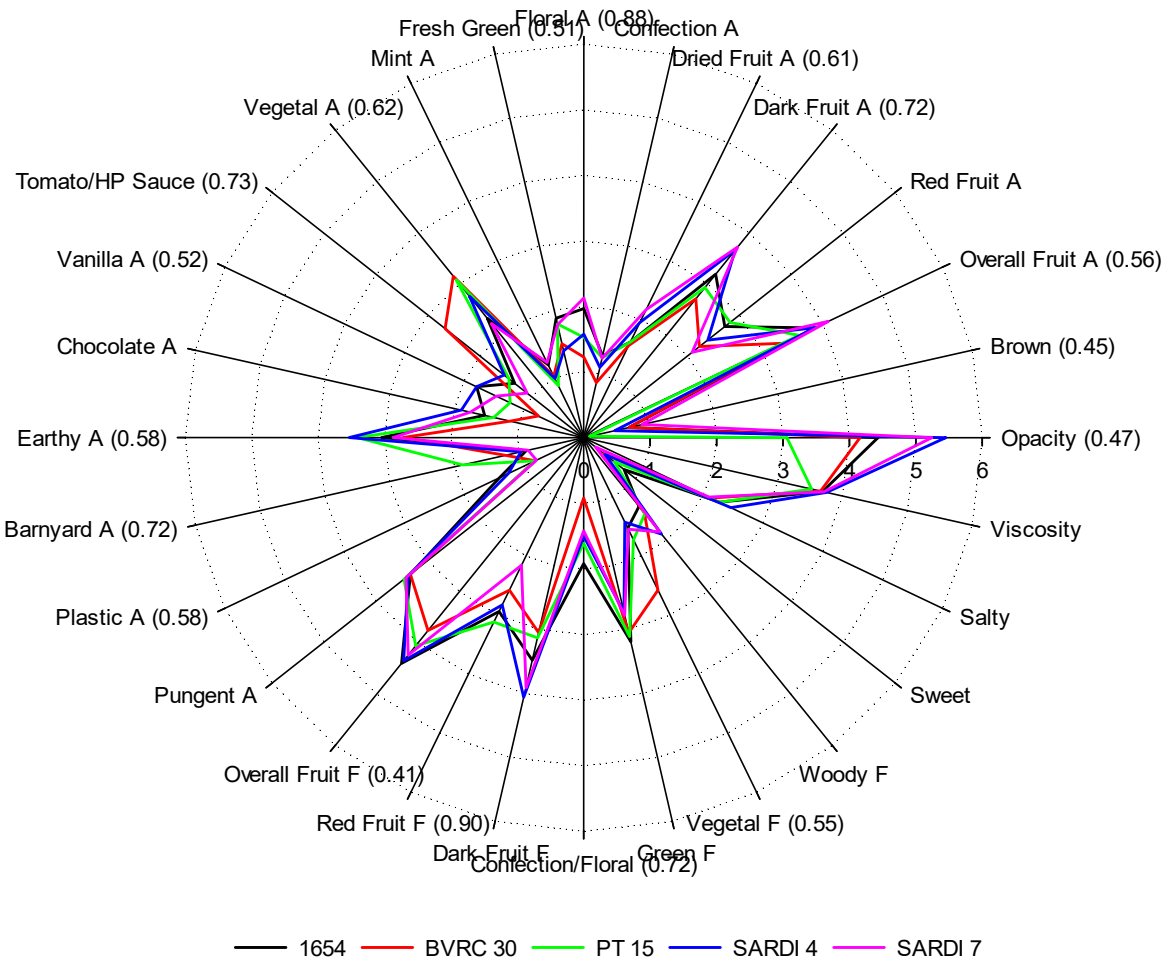


Figure 98. Radar plot of sensory attributes of V16 Shiraz clonal wines from the Barossa. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different between clones.

Grampians

In the Grampians region, 20 of the 33 attributes showed significant differences between Shiraz clones (Figure 99). For overall fruit characters, the Bests and PT23 clones had the highest overall fruit aroma score, and BVRC 12 the lowest (there were no significant differences between clones for overall fruit flavour or aftertaste). For the attributes with significant differences between clones, high and low scores for individual clones were: 1654 had the highest scores for red fruit, confection, fresh green and mint aromas, and red fruit, confection/floral and green flavours, and lowest scores for opacity, dark fruit, dried fruit, vanilla, chocolate, earthy and barnyard aromas, dark fruit and woody flavours and viscosity; Bests clone had the highest scores for earthy and barnyard aromas, and no significantly lowest scores; BVRC12 had a highest score for confection aroma, and lowest scores for fresh green aroma, and green and vegetal flavours; BVRC30 had the lowest score for brown colour; PT 23 had the highest scores for vanilla and chocolate aromas, and lowest scores for mint aroma and green flavour; and R6 had the highest scores for opacity, brown colour, dark fruit and dried fruit aroma, dark fruit, vegetal and woody flavours, and viscosity, and lowest scores for red fruit and confection aromas, and red fruit and confection/floral flavours.

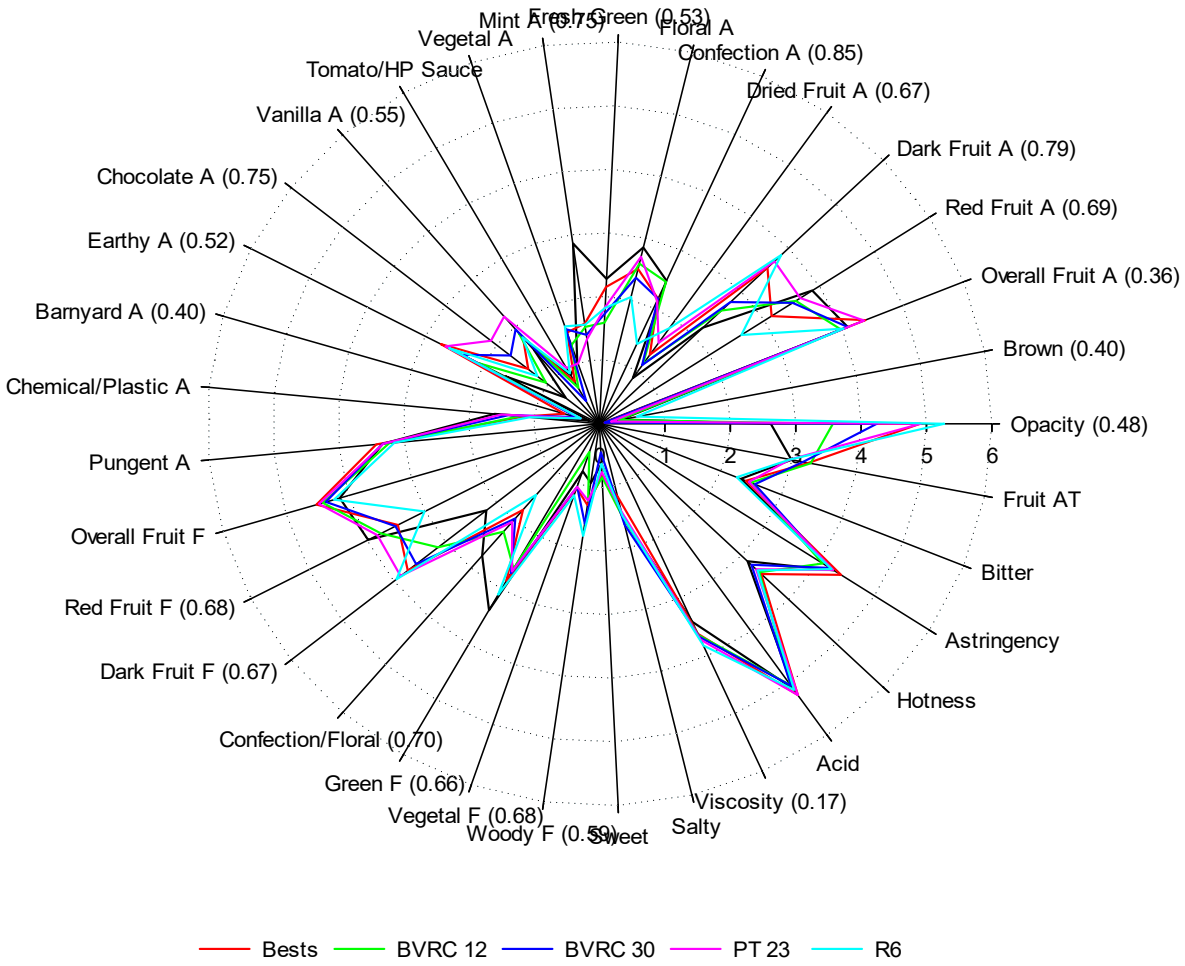


Figure 99. Radar plot of sensory attributes of V16 Shiraz clonal wines from the Grampians. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different between clones.

Margaret River

In the Margaret River region, 13 of the 33 attributes assessed showed significant differences between Shiraz clones (Figure 100). None of the clones exhibitied significant differences between the three overall fruit characters. The attributes of clones where significant differences were detected were: 1654 had the highest score for pungent aroma and the lowest score for hotness; BVRC12 had the highest scores for confection, floral and fresh green aromas, and confection/floral flavour, and lowest scores for opacity, vegetal, tomato/HP sauce and pungent aromas, dark fruit and woody flavours, and viscosity; and PT15 had the highest scores for opacity, vegetal, tomato/HP sauce and pungent aromas, dark fruit and woody flavours, and viscosity and hotness, and lowest scores for confection, floral and fresh green aromas, and confection/floral flavours. The WA clone did not have any highest or lowest attributes.

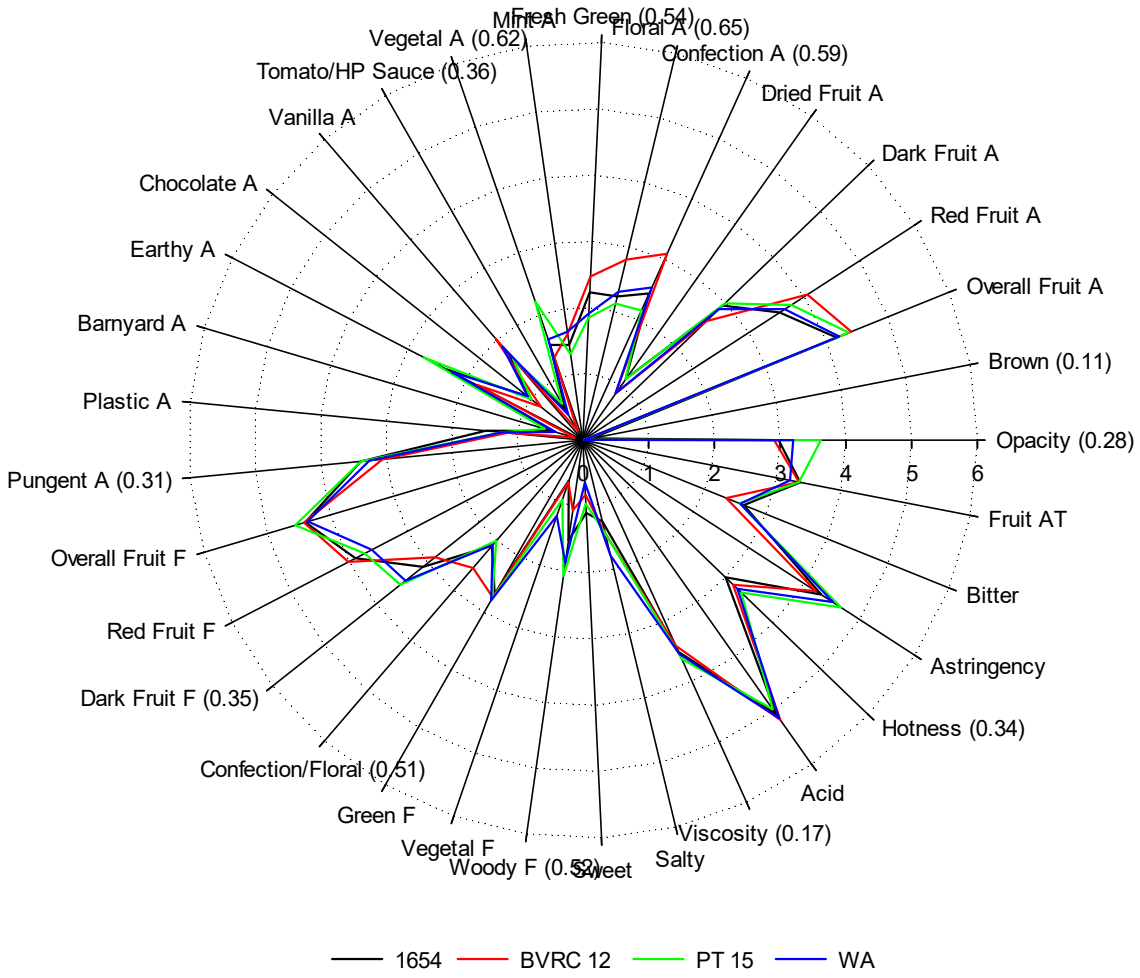


Figure 100. Radar plot of sensory attributes of V16 Shiraz clonal wines from Margaret River. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different between clones.

Riverland

In the Riverland, 19 of the 33 attributes assessed showed significant differences between clones (Figure 101). The highest and lowest attributes of the clones where significant differences occurred were: 1654 had the lowest mint aroma; BVRC 12 had the highest fresh green aroma and lowest barnyard aroma; BVRC 30 had the highest brown colour, vegetal and barnyard aromas, and vegetal flavours, and the lowest fresh green aroma; PT 23 had the highest red fruit, confection, floral and mint aromas, and red fruit flavour, and lowest opacity, dried fruit, vegetal, tomato/HP sauce and earthy aromas, and vegetal flavour; R6 had the highest opacity, dark fruit, dried fruit, chocolate and earthy aromas, and the lowest confection, floral, tomato/HP sauce and pungent aromas, and red fruit flavour; SARDI 4 had the highest pungent aroma; and SARDI 7 had the highest vegetal flavour, and lowest brown colour, red fruit, dark fruit, confection, floral, fresh green, tomato/HP sauce and chocolate aromas.

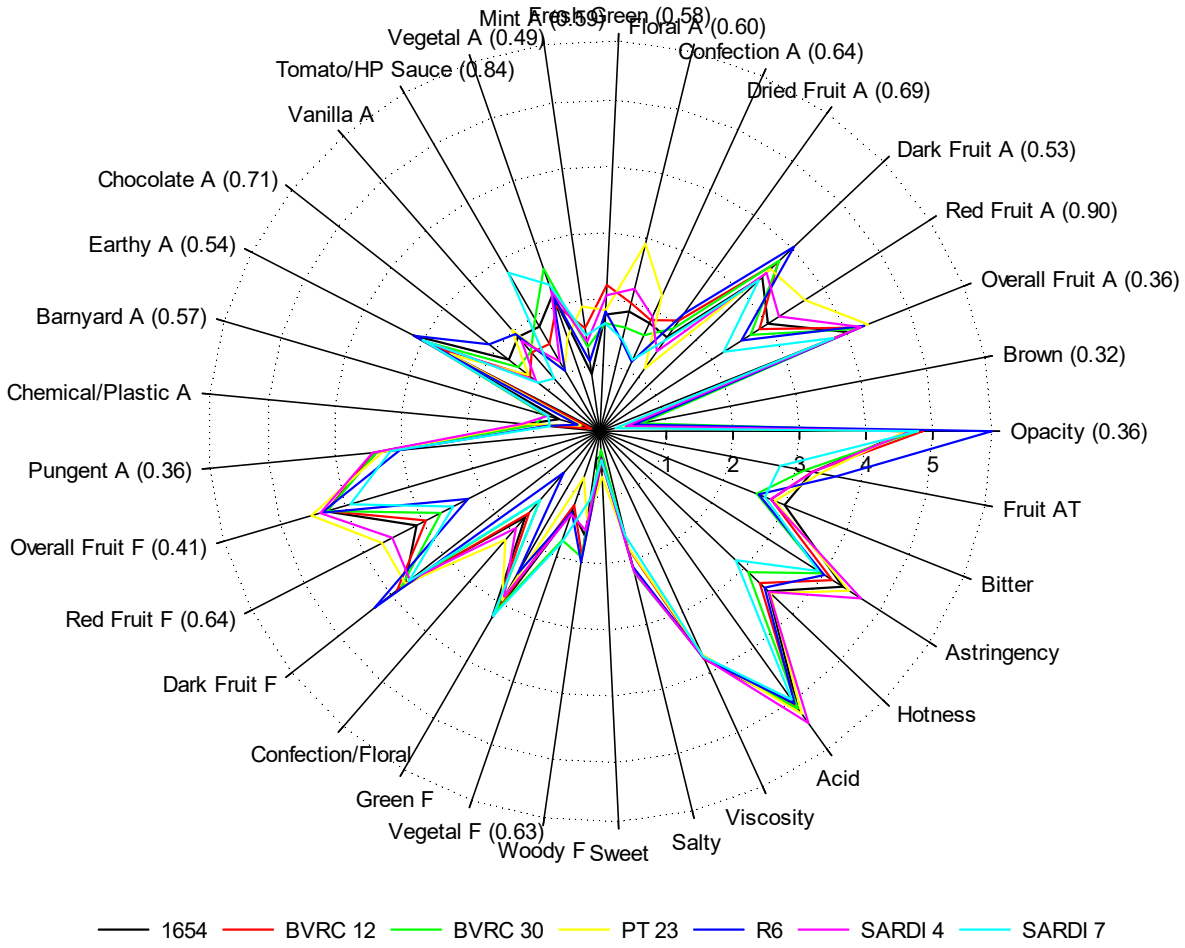


Figure 101. Radar plot of sensory attributes of V16 Shiraz clonal wines from the Riverland. Numbers in parenthesis indicate Least Significant Difference for those attributes that were significantly different between clones.

7.8.5 Analysis of vintage x region for Shiraz clones

From the PCA plots of each region for the three seasons of data for Shiraz clones, the key aroma and flavour attributes are summarised in Table 16. Key PCA plot aroma and flavour attributes for wines from each region and season

. For the Barossa the more common terms were dark fruit, opacity and sweet spice; for the Grampians, red fruit aroma, floral and confection and for Margaret River, red fruit. Although the V15 Riverland wines were absent there were marked differences between V14 and V16 with the latter having a number of descriptors in common with V14 and V15 Barossa wines, however, as previously presented in Section 7.2 these similarities did not appear to be related to climate descriptors.

Table 16. Key PCA plot aroma and flavour attributes for wines from each region and season

	2014	2015	2016
Barossa Valley	Pepper aroma, red fruit flavour, opacity, vanilla aroma, overall fruit flavour, overall fruit aroma, fruit aftertaste, dark fruit aroma, dark fruit flavour, green aroma, sweetness, viscosity, sweet spice aroma	Bitterness, opacity, pungent aroma, earthy aroma, meaty aroma, brown colour, dark fruit aroma, woody aroma, dark fruit flavour, sweet spice aroma, pepper aroma, chocolate flavour, cooked fruit aroma, acidity, viscosity, hotness, salty taste, vanilla aroma, overall fruit flavour	Salty taste, earthy aroma, brown colour, vegetal flavour, vegetal aroma, barnyard aroma, dried fruit aroma, tomato/HP sauce aroma, chocolate aroma
Grampians	Red fruit aroma, plastic aroma, confection aroma	Purple colour, red fruit aroma, confection aroma, red fruit flavour, green flavour	Red fruit flavour, fresh green aroma, confection/floral flavour, red fruit aroma, confection aroma, fruit aftertaste, overall fruit flavour, floral aroma, overall fruit aroma, vanilla aroma, mint aroma
Margaret River	Plastic aroma, confection aroma, astringency, red fruit aroma	Purple colour, green flavour	Vanilla aroma, overall fruit aroma, floral aroma, astringency, sweet taste, red fruit flavour, fresh green aroma, confection/floral flavour, red fruit aroma, confection aroma, overall fruit flavour, fruit aftertaste
Riverland	Bitterness, brown colour, salty taste, hotness, pungent aroma, earthy aroma, boiled egg aroma, acidity	Opacity, brown colour, dark fruit aroma, cooked fruit aroma, woody aroma, earthy aroma, sweet spice	Brown colour, tomato/HP sauce aroma, dried fruit aroma, chocolate aroma, dark fruit flavour, dark fruit aroma, opacity,

		aroma, bitterness, chemical aroma	viscosity, salty taste, earthy aroma

Within a region, Yellow highlight = attribute present in three seasons; Green highlight = attribute present in two of three seasons; No highlight = attribute present in only one season

The Grampians and Riverland regions each had two attributes that were consistently associated with them over the three years. These were red fruit and confection aromas for the Grampians, and brown colour and earthy aroma for Riverland. In the Grampians, red fruit flavour was associated with the regional Shiraz wines in two of three seasons. In the Riverland, bitterness, salty taste, opacity and dark fruit aroma were associated with the region in two out of three seasons.

The Margaret River and Barossa valley regions each had no attributes consistently associated with them in all three seasons. In the Margaret River, confection and red fruit aromas, and astringency were associated with clonal wines in two of the three seasons. Clonal wines from the Barossa Valley had pepper, vanilla, dark fruit, sweet spice and earthy aromas, dark fruit and overall fruit flavours, opacity, viscosity, salty taste and brown colour associated with them in two of three seasons.

There were a sufficient number of common significant sensory attributes for each region for each of the three vintages to compare mean scores (Figure 102). However, possible confounding effects such as slightly different panel members across the three vintages and differences in fruit maturity resulting in wines of differing alcohol concentration within and between vintages created difficulties in drawing sound conclusions from the restricted data set; for this reason no statistical analysis of the data was undertaken. Of interest is the pattern of the radar plots, with Grampians and Margaret River showing similar trends across seasons despite large differences in Growing Degree Days (GDD) and Biologically Effective Day Degree (BEDD). Likewise, the Barossa Valley and Riverland also showed a similar pattern across the three seasons despite large differences in GDD and BEDD. There were quite different patterns of expression of attributes over the three seasons between the Riverland and Margaret River regions despite the latter region having a slightly higher BEDD from budburst to harvest.

Using GDD between budburst and harvest showed that 2014-15 was the coolest of the three years in the Barossa; the wines from this vintage had the highest opacity, hotness and brown scores and the lowest acid and green flavour scores, however the average alcohol content (and hence the most "mature" fruit) was the highest of the three vintages (Table 16) and may account for the hotness score. 2014-15 was also the lowest GDD in the Riverland and while the V15 wines scored highest for opacity and brown the wines were scored lowest for a number of flavour and aroma attributes and similar to the Barossa wines had the highest average alcohol concentration. In contrast is the 2015-16 season which had the highest GDD and resulted in the V16 wines which had the lowest alcohol concentration of the three vintages and returned the highest scores for a number of flavour and aroma attributes.

There was range of 0.6% alcohol concentration in the Margaret River Shiraz wines across the three seasons, perhaps indicating that fruit was of similar ripeness for the three vintages. However, while V15 wines were from the coolest season they tended to have low scores for a number of aroma and flavour attributes suggesting the fruit was "sugar ripe" but not "flavour ripe". In contrast, the V16 wines, which were 0.1% lower in alcohol than V15 wines, had higher aroma and flavour scores for a number of the fruit-driven attributes indicating the fruit was synchronous in flavour and sugar ripeness. The wines were also lower in salt and brown (attributes which could be perceived as negative) indicating the fruit was not physiologically over-ripe.

While there was less variation in alcohol (0.4%) for the Grampians wines across the three seasons than the other regions, the differences between seasons was more apparent. 2015-16 accumulated the

lowest GDD between budburst and harvest and the V16 wines scored highest in a number of fruit aroma and flavour attributes. In contrast the warmer 2013-14 and 2014-15 seasons resulted in V14 and V15 wines with lower scores for similar aroma and flavour attributes, which cannot be put down the masking by elevated alcohol concentration as occurred with some wines from the other regions. These results are more in accord with climate change predictions ie, for wines of similar alcohol concentration a warming environment results in a decoupling of sugar and a reduction in aroma/flavour attributes. Data presented here also highlights the importance, however difficult, of ensuring fruit is harvested at similar maturity (^{o}Brix)

Table 16. Mean percent alcohol of Shiraz wines from each region for each of the three vintages.

	Vintage		
Region	2014	2015	2016
Barossa	14.6	17.0	13.5
Grampians	14.3	14.2	13.9
Margaret River	14.8	14.3	14.2
Riverland	15.6	16.6	14.1

Of interest is whether a hot season can provide a guide to its impact on wine attributes. Although a statistical analysis was not performed on the region x season data (Figure 102) trends can be observed. In the Barossa Valley, Margaret River and Riverland the 2013-14 and 2015-16 seasons had similar and higher GDDs and BEDDs (budburst to harvest) than the 2014-15 season, whereas in the Grampians region, 2013-14 and 2014-15 had the higher cumulative heat units. Apart from opacity (the hotter seasons reduced opacity in all regions) the response to hotter seasons was inconsistent across the regions. Wines from the Grampians region recorded reductions in scores for overall fruit aroma, red fruit aroma, overall fruit flavour, red fruit flavour, green flavour and acidity in the seasons with higher heat units whereas the Barossa Valley, Margaret River and Riverland recorded increased scores in these attributes in the hotter seasons. The results in the latter three regions appear counter-intuitive for a response to hotter seasons.

The hotter seasons in the Grampians also recorded decreases in dark fruit, vanilla, earthy, plastic and pungent aromas, dark fruit and green flavours, viscosity and bitterness, and an increase in astringency. Other regions either showed no change or change which was not consistent across all regions. The lack of consistency in the Barossa Valley and Riverland may be explained by the later harvest date, resulting in higher sugar levels as illustrated by the higher alcohol concentrations in those wines (Table 60). However, increases in red fruit aroma and flavour, green flavour and acidity are not usually associated with overripe fruit. Although the Margaret River wines had similar sugar levels at harvest in the three seasons, based on similar alcohol concentrations over the three years (Table 60), the trends in wine attributes are counterintuitive for what might be expected in hotter seasons. Short-term experiments may not be suitable for predicting wine attribute changes due to hotter seasons, or there is confounding due to other aspects of the regional conditions, harvest timing or calculating seasonal heat units.

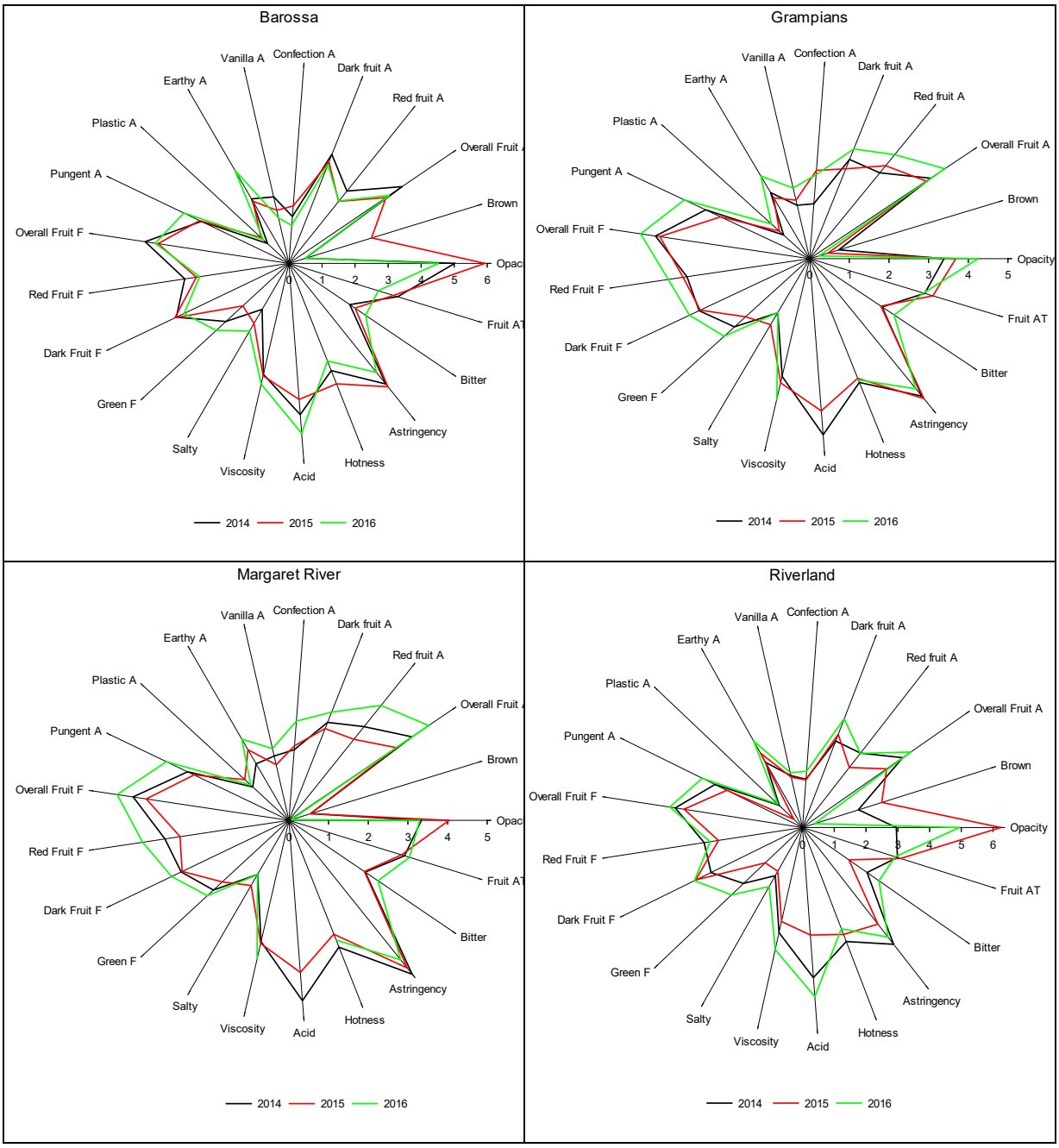


Figure 102. Radar plots of meaned sensory scores of the four regions for the 2014. 2015 and 2016 vintages.

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7.8.6 Assessment of Shiraz clones

In previous sections we reported on the differences in wine sensory attributes between seasons, regions, and between clones within each region, with many of these differences being statistically significant. The current section considers whether there were any consistent differences in any of the aroma and flavour attributes between clones in particular regions.

7.8.6.1 Shiraz clones in the Barossa

In V14, clone BVRC 12 scored numerically higher (and significantly higher than lower scoring clones) for a number of positive aroma and sensory attributes (purple colour, dark fruit, pepper, overall fruit flavour, viscosity, astringency and fruit after-taste) and low scores for negative attributes such as brown and green flavour. Clone R6 scored well for overall fruit aroma, flavour and aftertaste. In comparison BVRC 30, which was selected at the same time as BVRC12, recorded low scores for positive attributes such as purple colour, opacity, overall fruit flavour, floral aroma, overall fruit flavour, was bitter and green. Clone 1654 also did not score well for the three overall fruit characters.

In V15, BVRC 12 again recorded a high score for purple and vanilla, however, was high in brown colour, salty taste and woody aroma. BVRC 30 scored well in red fruit flavour but had high vegetal aroma and was mid-range for all other attributes. Clone R6 scored well for the three overall fruit characteristics, and 1654 scored low. BVRC12 was not assessed in V16 due to winemaking faults. In contrast to previous seasons BVRC 30 recorded the lowest scores for overall fruit, dark and dried fruit, floral vanilla aromas and overall fruit flavour, astringency and fruit after-taste in V16, whilst SA7 scored reasonably well for the three overall fruit characters.

In summary, there did not appear to be a Shiraz clone at the Barossa site that scored consistently higher for positive attributes or lower for negative characters across the three vintages. Clones BVRC12 and R6 rated high, and 1654 and BVRC30 rated low in two of the three seasons.

7.8.6.2 Shiraz clones in the Grampians

In V14, clone PT 23 scored highest for 11 of the 22 significant attributes. Three of the 11 (purple, dark fruit aroma and flavour) could be considered positive attributes while the high scores for green earthy, plastic, boiled egg, and pungent aroma and a bitter taste are negative attributes; the latter may have overpowered the positive traits because the clone did not rate highly for the three overall fruit attributes (aroma, flavour and aftertaste). For these three overall fruit characters, BVRC30 scored well and 1654 had low scores. In V15, PT23 again had the highest salt taste score but BVRC30 had high scores for the three overall fruit characters and 1654 and BVRC12 had low scores. In V16, clone 1654 scored high for red fruit, green, mint and confection characters whilst R6 scored high in dark fruit, dried fruit, vegetal and woody characters and other clones did not score high in many positive attributes.

Clone R6 scored highest for brown colour in each of the three seasons and was variable in dark fruit aroma, ranking highest of the clones in V15 and V16 and having the lowest score for this attribute in V14. A similar pattern was evident for the other clones, with high scores for some attributes in one season but low in another.

In summary, with the exception of the salty taste of PT23 in two of the three vintages, similar to the situation in the Barossa, there did not appear to be a clone from the Grampians site that scored consistently higher for positive attributes or lower for negative characters across the three vintages. In two out three seasons BVRC30 scored high and 1654 scored low.

7.8.6.3 Shiraz clones in Margaret River

In V14, the local selection recorded the lowest scores for 10 of the 16 attributes that were significantly different, although some of these low scores were for the possibly negative attributes of bitter, hotness, salty and green fruit flavour. This selection had high dark fruit aroma and red fruit flavour. Clone BVRC 12 had high scores for the negative attributes of bitter, hotness, salty taste and low scores for red fruit flavour and confection aroma and could therefore be considered the overall lowest ranked clone in V14. In V15, the WA selection was overall the highest ranked clone; again it recorded the lowest scores for green fruit flavour and also vegetal aroma with highest scores for the positive attributes opacity, purple colour, overall fruit, dark fruit and sweet spice aroma, and overall fruit and dark fruit flavour. In V16 there were only 12 attributes with significant differences, with the WA selection receiving neither the highest or lowest score except that it was the least brown in colour. With the three overall fruit characters (aroma, flavour and aftertaste) there were no significant differences between the clones in V14 and V16, but in V15 the WA clone had highest scores and 1654 andBVRC12 had the lowest scores.

In summary, in two of the three seasons at Margaret River, the local WA selection was the most consistent clone for high scores for positive attributes and low scores for negative attributes.

7.8.6.4 Shiraz clones in the Riverland

There did not appear to be any consistently high or low ranked clone for the Riverland site, although with only eight significantly different attributes in V15, an overall ranking is problematic. In V16, the NSW clone PT23 recorded high scores for the fruit attributes red fruit aroma and flavour, overall fruit aroma and flavour and confection, floral and mint aroma and low scores for vegetal flavour and earthy aroma. In V14, PT23 recorded the lowest hotness and pungent aroma.

SARDI 7 was possibly the overall lowest ranked wine based on sensory scores. In V16 it recorded the lowest scores for overall fruit, red fruit and dark fruit aroma and chocolate and overall fruit flavour and the highest score for vegetal flavour and tomato/HP sauce aroma. In V14 SARDI 7 had the lowest score for overall fruit aroma and flavour, dark fruit aroma and flavour, sweet flavour and low scores for mint and sweet spice aromas and were the least purple of all the clonal wines. Although there were only eight significantly different attributes in V15, SARDI 7 had the lowest scores for dark fruit aroma and flavour. SARDI7 also had the lowest scores for overall fruit aroma, flavour and aftertaste in two of the three seasons.

7.8.7 Regional clonal tastings

A key activity was to conduct regional tasting of the clonal wines from each vintage and commenced in 2015 with tastings of Vintage 2014 Chardonnay and Shiraz wines. This also offered the opportunity of comparing the regional tastings with sensory aroma and flavour scores from the structured AWRI tastings presented in the previous section.

7.8.7.1 South Australia, Victoria, ACT and New South Wales

A number of regional tastings were conducted across South Australia, Victoria and New South Wales, and listed in the Table 17. These were facilitated by regional associations and well-attended by local winemakers/viticulturists with numbers ranging from approximately 10 to 60 participants. The regional associations decided which wines to taste, however at each tasting at least one clone from every region was included. Each workshop consisted of a tasting, feedback from the audience, and then a presentation of the results of the AWRI sensory analysis. For all of the workshops the participants were asked to rank the wines from most to least preferred. Participants who found ranking up to 12 wines difficult were asked just to indicate their most and least preferred wines. The four sets of data presented below in Tables 19-22 were typical of regional tastings in the Eastern States; individuals had clear preferences for a specific wine while others rated the same wine as least preferred. There were also some regional preferences, for example note the lower ranking of I10V1 from Drumborg at the Great Western tasting compared the highest ranking of the same wine for the Yarra Valley group.

Table 17. List of workshops held in South Australia, Victoria, ACT and NSW

Year	Location(s)
2015	May Great Western May Sunbury October Barossa Valley
2016	May Great Western June Yarra Valley July Adelaide AWITC workshop September McLaren Vale November Canberra November Hunter Valley December Barossa Valley
2017	May Orange May Great Western May Mornington Peninsula May -Yarra Valley May Milawa

Table 18. Barossa tasting of seven 2015 vintage Shiraz clones grown in the Barossa

Clone	**Mean Rank[#]**
BVRC30	2.8
BVRC12	3.6
SARDI 4	3.9
1654	4.0
PT 15	4.0
SARDI 7	4.3

R6W	4.5

[#] A lower the mean rank score indicates greater overall preference by the 29 participants who completed the assessment sheet.

Table 19. Great Western tasting of ten 2015 vintage Chardonnay clones including Clone 76 from all regions.

Region	Clone	Mean rank[#]
Great Southern	76	4.2
Drumborg	76	4.7
Drumborg	277	4.8
Drumborg	I10V5	4.9
Drumborg	96	4.9
Drumborg	95	4.9
Margaret R	76	5.1
Drumborg	I10V1	5.9
Drumborg	78	5.9
Riverland	76	8.1

[#] A lower the mean rank score indicates greater overall preference by the 17 participants who completed the assessment sheet.

Table 20. Yarra Valley (Healesville) tasting of ten 2015 vintage Chardonnay clones including Clone 76 from all regions

Region	Clone	Mean rank[#]
Drumborg	I10V1	4.0
Drumborg	96	4.2
Margaret R	76	4.7
Great Southern	76	4.9
Drumborg	76	5.0
Drumborg	78	5.1
Drumborg	95	6.2
Riverland	76	6.3
Drumborg	277	6.3
Drumborg	I10V5	8.4

[#]A lower the mean rank score indicates greater overall preference by the 46 participants who completed the assessment sheet.

Table 21. Canberra Shiraz tasting of 2015 wines of four clones from three regions.

Wines from each region were presented as a group and participants were asked to rank the four wines.

Region	**Clone**	**Mean rank[#]**
Barossa	BVRC12	2.1
Barossa	R6W	2.2
Barossa	1654	2.7
Barossa	BVRC30	3.0
Grampians	1654	2.4
Grampians	BVRC 30	2.5
Grampians	BVRC 12	2.5
Grampians	R6W	2.6
Riverland	BVRC 30	2.3
Riverland	R6W	2.5
Riverland	1654	2.6
Riverland	BVRC 12	2.6

[#]A lower the mean rank score indicates greater overall preference by the 33 participants who completed the assessment sheet.

7.8.7.2 Western Australia

Margaret River (October 2015)

At this regional tasting, Chardonnay clonal wines from Riverland and Margaret River were blind tasted together with Shiraz clonal wines from Margaret River and Barossa (2014 vintage). Participants were asked to indicate their most preferred wine and these scores are presented below. Clone 227 was the preferred Riverland Chardonnay clone and the Gingin clone most preferred from Margaret River while PT15 was the preferred Shiraz clone from the Barossa and Margaret River.

Chardonnay				Shiraz			
Riverland		Margaret River		Barossa		Margaret River	
Clone	Preference	Clone	Preference	Clone	Preference	Clone	Preference
277	67%	Gingin	58%	PT15	67%	PT15	50%
96	33%	96	25%	BVRC12	25%	BVRC12	42%
76	0%	95	17%	R6W	8%	1654	8%
95	0%	76	0%	1654	0%	WA Select	0%
		277	0%	BVRC30	0%		
				SARDI 4	0%		
				SARDI 7	0%		

Mount Barker (October 2015)

Chardonnay clones from Margaret River and Great Southern were blind tasted while Shiraz clones originated from Barossa, Margaret River and Grampians (2014 vintage). Participants were asked to indicate their most preferred wine and these scores are presented below. Chardonnay 277 was the most preferred clone but there was a divergence of opinion for the Gingin clone. Similar to the Margaret River tasting, Shiraz BVRC12 was one of the preferred wines along with PT15.

Chardonnay				**Shiraz**					
Margaret River		**Great Southern**		**Barossa**		**Margaret River**		**Grampians**	
Clone	Preference	Clone	Preference	Clone	Preference	Clone	Preference	Clone	Preference
277	30%	277	36%	BVRC12	50%	WA Select	36%	BVRC12	55%
Gingin	30%	76	18%	PT15	38%	BVRC12	27%	BVRC30	36%
95	20%	96	18%	R6W	12%	PT15	27%	1654	9%
76	10%	Gingin	18%	1654	0%	1654	10%		
96	10%	95	9%	BVRC30	0%				
		I10V1	0%	SARDI 4	0%				

Winemakers' trial forum – Margaret River (June 2016)

The six Great Southern Chardonnay clones from 2015 were blind tasted by 24 WA winemakers. Participants were asked to indicate their most preferred. Similar to the 2015 tastings, Chardonnay 277 was the most preferred while the Gingin clone did not rank as highly in 2015. Clone 76 was clearly the least preferred Chardonnay, although the acid profile of this wine was described as potentially suited to sparkling production.

Clone	% Preferred
277	45%
95	20%
Gingin	20%
96	10%
I10V1	10%
76	0%

Clone Workshop – Mount Barker (February 2017)

The 2015 Chardonnay and Shiraz wines from Great Southern, Margaret River and Grampians were blind tasted by 12 local winemakers. They were able to rank the wines from most to least preferred (Table below) and for Shiraz the group scored PT15 Shiraz from Margaret River as most preferred while the same clone from the Grampians was marked down.

Chardonnay		Shiraz	
Great Southern	Margaret River	Grampians	Margaret River
Clonal ranking	Clonal ranking	Clonal ranking	Clonal ranking
95	96	PT23	PT15
I10V1	76	BVRC12	BVRC12
277	Gingin	BVRC30	WA Selection
96	95	R6W	1654
Gingin	277	Bests	
76		PT15	
		1654	

Clone Workshop – Margaret River (July 2017)

The 2016 Chardonnay and Shiraz wines from Great Southern, Margaret River, Barossa, Riverland and Grampians were blind tasted by 20 local winemakers. The attendees were able to rank the wines and Chardonnay 277 and Shiraz BVRC12 ranged from the most to least preferred depending on region of origin.

	Chardonnay			Shiraz			
Region	Riverland	Margaret River	Great Southern	Riverland	Barossa	Margaret River	Grampians
Most preferred	96 and 277	Split	Gingin and 76	R6W and PT23	SARDI 7	PT15	BVRC12
Least preferred	76 and 95	277	I10V1 and 277	1654	BVRC30	WA and BVRC12	1654

Winemakers' trial forum – Great Southern (August 2018)

Four Great Southern Chardonnay clones from 2017 were blind tasted by seven Great Southern producers and asked to indicate which single wine was the most preferred and, as presented below, there was clear preference for I10V1, with 95 and 76 not preferred by any of the participants..

Clone	% Preferred

I10V1	71%
277	29%
95	0%
76	0%

August 2015
Approximately 22 people attended a tasting at the Margaret River Trial Forum which included the 2014 WA Shiraz clones. The group ranked clone BVRC12 first with 45% of the tasters preferring this clone and ranked clone PT15 second at 27%. The other two clones, 1654 and WA Selection both scored 14% in terms of preference.

February 2017
An overview of the trial and an opportunity to taste the 2015 Margaret River Shiraz clones was presented to the Geographe Wine Industry Association. Approximately 40 people attended (tasting results not presented).

June 2017
Presented at the Margaret River Horticulture Trade Day an overview of the project and current outcomes. Chardonnay and Shiraz clonal wines from the Margaret River trial site were on hand for delegates to taste. Approximately 100 people attended (tasting results not presented).

October 2017
Fourteen members from the Blackwood Valley Wine Industry Association attended a tasting of Chardonnay clonal wines. Clones from the Riverland (SA), Margaret River and Great Southern regions were compared and discussed. The group preferred clone 95 from the Riverland, Clone 96 from Margaret River and Gingin from Mt Barker. The tasting was well-received and the producers showed great interest in general clonal diversity.

November 2017
Presented the 2017 Margaret River and Great Southern Chardonnay clones to a group of 14 winemakers at the Margaret River Winemakers' Trial Forum (data not presented).

7.8.7.3 Outcomes of regional tastings

The regional tastings were well-received in all the regions and overall well-attended, reflecting industry interest in clones at the regional level. While it was not the intent of this project to identify if clone X was more preferred than clone Y the workshop participants were readily able to determine differences between clonal wines within and across the regions. There were many positive comments regarding the overall quality of the small lot wines, although some participants commented that commercially, the Shiraz in particular would have picked slightly riper. There were numerous requests for return visits with future vintages, for example repeat tastings were conducted with the Great Western, Barossa and WA groups and is a reflection of the interest in the clonal wines.

The project has demonstrated that clones do have a role in adding diversity and complexity to Australia's most widely planted red and white varieties. Hopefully this will be reflected in increased demand from vine propagation businesses for a wider selection of clonal planting material.

7.9 Testing for virus and virus-like diseases

7.9.1 Chardonnay

In year four of the project, examples of each clone at each site were sampled and tested for virus and virus-like diseases. From a sub-sample of five vines per clone, three to four shoots of approximately 300mm in length were collected per vine and placed into plastic bags. The samples were kept in an insulated container with ice or a refrigerator until dispatch to the laboratory (Crop Health Services, Bundoora, Victoria). Samples from Western Australia and South Australia were submitted in October 2017 and those from Victoria were submitted in January 2018.

The samples from the five vines per clone were pooled and extractions for PCR testing undertaken. The method for most analyses was CHS 310 PCR (chalcone synthase promotor 310 PCR) and RT-PCR (real time PCR), with phytoplasmas also analysed with 14 nested PCR. Two tests were conducted for rupestris stem pitting associated virus (RSPaV; in cases where negative results were obtained in the first test) and for grapevine virus A. The viruses and virus-like diseases that were tested are shown in Table 22. Ampelovirus is a general test for the group of viruses GLRaV-1, GLRaV-3, GLRaV-4, GLRaV-5 and GLRaV-9, and Closteroviridae is a general test for GLRaV-2.

RSPaV was detected in all samples submitted (Table 22). GLRaV-5 and closteroviridae were detected in nearly half of the samples. No samples were detected with GLRaV-4, GLRaV-9, GPGV, GVA, GVB or phytoplasma. Overall 18.5% of the tests resulted in a positive detection.

Table 22. Virus tests conducted on 29 samples of Chardonnay and summary of results.

Test name	Code	Not detected	Detected	Total
Ampelovirus	AmpeloV	25	4	29
Closteroviridae	Clost	17	12	29
Grapevine fleck virus	GFkV	22	7	29
Grapevine leafroll-associated virus 1	GLRaV-1	27	2	29
Grapevine leafroll-associated virus 2	GLRaV-2	27	2	29
Grapevine leafroll-associated virus 3	GLRaV-3	24	5	29
Grapevine leafroll-associated virus 4	GlraV-4	29	0	29
Grapevine leafroll-associated virus 5	GLRaV-5	15	14	29
Grapevine leafroll-associated virus 9	GLRaV-9	29	0	29
Grapevine pinot gris virus	GPGV	29	0	29
Grapevine virus A	GVA	29	0	29
Grapevine virus B	GVB	29	0	29
Rupestris stem pitting associated virus	RSPaV	0	29	29
Phytoplasma	Phplas	29	0	29

Detailed results for each clone and site show variations in virus and virus-like disease detections within clones and across sites (Table 23). All positive results for the Ampelovirus test were matched by positive results for GLRaV-3 or GLRaV-5. However 12 positive results for the closteroviridae test

Table 23. Results of PCR testing for virus and virus-like diseases in samples of Chardonnay covering nine clones and five sites.

Clone	Location	AmpeloV	Clost	GFkV	GLRaV-1	GLRaV-2	GLRaV-3	GLRaV-4	GLRaV-5	GLRaV-9	GPGV	RSPaV	GVA	GVB	Phplas
76	Grampians	+	-	-	-	-	-	-	+	-	-	+	-	-	-
	Drumborg	-	+	-	-	-	-	-	+	-	-	+	-	-	-
	Riverland	-	-	-	-	-	-	-	-	-	-	+	-	-	-
	Margaret R	-	-	-	-	-	-	-	-	-	-	+	-	-	-
	Great Sthn	-	-	+	-	-	-	-	-	-	-	+	-	-	-
78	Grampians	-	-	+	-	-	-	-	+	-	-	+	-	-	-
	Drumborg	-	+	+	-	-	-	-	+	-	-	+	-	-	-
95	Grampians	-	-	-	-	-	-	-	+	-	-	+	-	-	-
	Drumborg	-	+	-	-	-	+	-	+	-	-	+	-	-	-
	Riverland	-	-	-	-	-	-	-	-	-	-	+	-	-	-
	Margaret R	-	-	-	-	-	-	-	-	-	-	+	-	-	-
	Great Sthn	-	-	+	-	-	+	-	-	-	-	+	-	-	-
96	Grampians	-	-	-	-	-	-	-	+	-	-	+	-	-	-
	Drumborg	-	+	-	-	-	+	-	+	-	-	+	-	-	-
	Riverland	-	-	-	-	-	-	-	-	-	-	+	-	-	-
	Margaret R	+	+	-	-	-	+	-	-	-	-	+	-	-	-
	Great Sthn	-	-	-	-	-	-	-	-	-	-	+	-	-	-
277	Grampians	-	-	-	-	-	-	-	+	-	-	+	-	-	-
	Drumborg	-	+	+	-	-	-	-	-	-	-	+	-	-	-
	Riverland	-	-	-	-	-	-	-	-	-	-	+	-	-	-
	Margaret R	-	-	-	-	-	-	-	-	-	-	+	-	-	-
	Great Sthn	-	-	+	-	-	-	-	-	-	-	+	-	-	-
I10V5	Grampians	-	+	-	-	-	-	-	+	-	-	+	-	-	-
	Drumborg	-	+	-	-	+	+	-	+	-	-	+	-	-	-
I10V1	Drumborg	-	+	-	-	-	-	-	+	-	-	+	-	-	-
	Great Sthn	+	-	-	-	-	-	-	+	-	-	+	-	-	-
Gingin	Margaret R	-	+	-	+	-	-	-	-	-	-	+	-	-	-
	Great Sthn	-	+	-	+	-	-	-	-	-	-	+	-	-	-
Pen 58	Drumborg	+	+	+	-	+	-	-	+	-	-	+	-	-	-

only resulted in two positive tests for GLRaV-2. GLRaV-5 was detected in 13 of the 14 samples from Victoria but in only 1 of the 15 samples from WA and SA. Samples from Victoria frequently have this virus but other states do not (Fiona Constable pers. comm.) and there is no clear reason for this. GLRaV-5 (and GLRaV-9) are regarded as mild leafroll viruses. The Bernard clones planted in the Drumborg region were propagated at Nuriootpa, SA, so the presence of GLRaV-5 in Victoria does not seem to be linked to the source of nursery material.

Grapevine fleck (GFkV) is symptomless in most varieties and has been associated with low yielding vines that are also affected by leafroll and rugose wood disorders (Krake et al. 1999). Samples that contained such a combination were Penfold 58 (Drumborg), 95 (Great Southern) and 78 (Grampians and Drumborg). Fleck was also detected in 277 at Drumborg and Great Southern and 76 at Great Southern.

GLRaV-1 was only detected in the Gingin clone at Margaret River and Great Southern, whilst GLRaV-2 was only detected in two clones (I10V5 and Penfold 58) at the Drumborg site. GLRaV-3 was detected in 95 (at Drumborg and Great Southern), 96 (Drumborg and Margaret River) and in I10V5 at Drumborg. GLRaV-4 and GLRaV-9 were not detected in any sample.

Although the sites were assumed to have the same clone, the virus status could be different across sites. There may be several reasons for this. For some clones, such as the Bernard clones, there have been multiple importations. Clonal planting materials sourced from different nurseries may have different virus infections. In addition, trial vines in our study may have been infected by nearby vineyards, such as the leafroll virus spread by mealybugs and scales. The I10V1 vines in the Drumborg region were grafted, and therefore could have received a virus infection from the rootstocks; however, the virus content was similar to the I10V1 at Great Southern. In addition the results from virus testing can be inconsistent, with variation in titre within a vine and between vines occasionally leading to false negative results.

7.9.2 Shiraz

Shiraz clones were sampled and tested for virus and virus-like diseases as described above for the Chardonnay clones. RSPaV was detected in all samples submitted (Table 24). GLRaV-5 was detected in one third of the samples. No samples were detected with GFkV, GLRaV-1, GLRaV-2, GLRaV-4, GLRaV-9, GPGV, GVA, GVB or phytoplasma. Overall 13.1% of the tests resulted in a positive detection.

Table 24. Virus tests conducted on 24 samples of Shiraz and summary of results.

Test name	Code	Not detected	Detected	Total
Ampelovirus	AmpeloV	19	5	24
Closteroviridae	Clost	19	5	24
Grapevine fleck virus	GFkV	24	0	24
Grapevine leafroll-associated virus 1	GLRaV-1	24	0	24
Grapevine leafroll-associated virus 2	GLRaV-2	24	0	24
Grapevine leafroll-associated virus 3	GLRaV-3	22	2	24
Grapevine leafroll-associated virus 4	GlraV-4	24	0	24
Grapevine leafroll-associated virus 5	GLRaV-5	16	8	24

Grapevine leafroll-associated virus 9	GLRaV-9	24	0	24
Grapevine pinot gris virus	GPGV	24	0	24
Grapevine virus A	GVA	24	0	24
Grapevine virus B	GVB	24	0	24
Rupestris stem pitting associated virus	RSPaV	0	24	24
Phytoplasma	Phplas	24	0	24

Detailed results for each clone and site show variations in virus and virus-like disease detections within clones and across sites (Table 25). A positive result for the Ampelovirus test was matched by positive results for GLRaV-3 or GLRaV-5 in three out of five samples. Of the five positive results for the closteroviridae test, none were associated with the detection of GLRaV-2. GLRaV-5 was detected in 6 of the 7 samples from Victoria but in only 2 of the 17 samples from the WA and SA. Samples from Victoria frequently have this virus but other states do not (Fiona Constable pers. comm.) and there is no clear reason for this. GLRaV-5 (and GLRaV-9) are regarded as mild leafroll viruses.

GLRaV-3 was detected at two sites (Riverland and Margaret River) in the BVRC 12 clone. Putting aside RSPaV, which seems to be ubiquitous in Australian vines, and GLRaV-5, largely present only in Victoria, overall the clones were remarkably free of virus and virus-like diseases.

Table 25. Results of PCR testing for virus and virus-like diseases in samples of Shiraz covering ten clones and four sites.

Clone	Location	AmpeloV	Clost	GFkV	GLRaV-1	GLRaV-2	GLRaV-3	GLRaV-4	GLRaV-5	GLRaV-9	GPGV	RSPaV	GVA	GVB	Phplas
BVRC 12	Grampians	-	+	-	-	-	-	-	+	-	-	+	-	-	-
	Riverland	-	-	-	-	-	-	-	-	-	-	+	-	-	-
	Barossa	+	+	-	-	-	+	-	-	-	-	+	-	-	-
	Margaret R	-	-	-	-	-	+	-	-	-	-	+	-	-	-
BVRC 30	Grampians	-	+	-	-	-	-	-	+	-	-	+	-	-	-
	Riverland	+	+	-	-	-	-	-	+	-	-	+	-	-	-
	Barossa	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Bests	Grampians	-	-	-	-	-	-	-	-	-	-	+	-	-	-
R6W	Grampians	+	-	-	-	-	-	-	+	-	-	+	-	-	-
	Riverland	-	-	-	-	-	-	-	-	-	-	+	-	-	-
	Barossa	-	-	-	-	-	-	-	+	-	-	+	-	-	-
PT 15	Grampians	-	-	-	-	-	-	-	+	-	-	+	-	-	-
	Barossa	-	-	-	-	-	-	-	-	-	-	+	-	-	-
	Margaret R	-	-	-	-	-	-	-	-	-	-	+	-	-	-
PT 23	Grampians	-	-	-	-	-	-	-	+	-	-	+	-	-	-
	Riverland	+	-	-	-	-	-	-	-	-	-	+	-	-	-
SA 1654	Grampians	-	-	-	-	-	-	-	+	-	-	+	-	-	-
	Riverland	-	-	-	-	-	-	-	-	-	-	+	-	-	-
	Barossa	-	-	-	-	-	-	-	-	-	-	+	-	-	-
WA	Margaret R	+	+	-	-	-	-	-	-	-	-	+	-	-	-
SARDI 4	Riverland	-	-	-	-	-	-	-	-	-	-	+	-	-	-
	Barossa	-	-	-	-	-	-	-	-	-	-	+	-	-	-
SARDI 7	Riverland	-	-	-	-	-	-	-	-	-	-	+	-	-	-
	Barossa	-	-	-	-	-	-	-	-	-	-	+	-	-	-

8 Shiraz genomics

The diverse geographic origin of the Shiraz clones used in the project offered the opportunity to investigate if genomic differences could be detected.

AWRI were contracted to undertake this investigation, with the following report prepared by Simon Schmidt, Michael Roach and Anthony Borneman.

8.1 Collection of grapevine leaf material and DNA extraction

Leaf material was collected on 5 November 2015. Yalumba nursery (Nick Dry) kindly supplied plant material of three Shiraz clones imported from France and other clonal material was collected from the SARDI Research Centre in the Barossa Valley (Table 26). DNA was isolated from 10 g fresh weight of grape leaf material using a nuclear DNA extraction protocol adapted from Peterson et al. (2000). Nuclear DNA concentration was estimated using a Qubit Fluorescence Broad Range Kit (Thermo Fischer Scientific). DNA QC was performed using a Tapestation (Agilent Technologies). There was substantial variation in DNA yields from the various clones; however, sufficient material (500 µg) was available from each clone for subsequent analysis by sequencing.

Table 26. Identification of Shiraz clones used and DNA extraction metrics

ID	Clone	Origin	DNA conc mg/ml	Tape	Total (mg)
7	R6W	Chateau Tahbilk (Victoria)	56	50	18
1	SARDI 4	SARDI – ex Barossa Valley	12	16	0.7
6	SARDI 7	SARDI – ex Barossa Valley	20	24	9
9	BVRC 12	SARDI - ex Barossa Valley	12	16	0.9
10	BVRC 30	SARDI - ex Barossa Valley	10	15	1.2
3	1654	Tulloch ex Nuriootpa Research Centre	24	50	15
5	PT23	Selected from pruning trial at Griffith	50	44	18
8	PDFS	Imported 2001	18	25	0.4
2	Yalumba2	Côte-Rôtie (France)	11	12	0.6
4	Yalumba4	Côte-Rôtie (France) - Sales discontinued due to virus symptoms	16	17	0.9

8.2 Sequencing

8.2.1 *De novo* genome assembly

A novel strategy was adopted for analysis of the material in this study, using recently developed technology. This technology, created by 10x Genomics, enables the creation of synthetic long reads by using a microfluidic device to create highly indexed sequencing libraries from high molecular weight DNA. These libraries can then be sequenced using short read sequencers (such as the Illumina HiSeq) and synthetic long reads can be reconstructed using a custom analysis pipeline called Chromium. This approach has the advantage that it is significantly cheaper than conventional long read sequencing technologies (e.g. PacBio), requiring less input DNA while still offering many of the same advantages, such as creation of phased assemblies and the capacity to map structural variations. It has predominantly been designed to work with human genomes but at least one publication has reported its suitability for the analysis of plant genomes (Coombe *et al.* 2016). This technology became available in Australia in Nov 2016 at the Australian Genome Research Facility (AGRF).

Two Chromium Chip Kits and 10 Chromium Library prep kits were purchased and library preparation was completed in January 2017 by the AGRF. Samples were sequenced using 10 lanes of a HiSeq 2500 in high output mode, 2 x 125 bp reads. Earlier trials suggested that 125 bp read lengths would not substantially compromise the assembly and mapping efforts compared with the recommended read lengths of 150 bp around which the 10x genomics system was optimised. Basic sequence records are provided in Table 27. Transfer of the raw data to the AWRI from AGRF was completed on 28 March 2017.

Table 27. Shiraz clones sequencing records

Clone ID	Seq run	Clone ID	AGRF run ID	Flowcell ID	Lane	Indexes
Shiraz_1	1	PT23	CAGRF13675	CAAYTANXX	4	SI-GA-D1
Shiraz_2	2	SARDI 4	CAGRF14280	CAJHGANXX	6	SI-GA-A2
Shiraz_3	2	Yalumba 2	CAGRF14280	CAJHGANXX	7	SI-GA-A3
Shiraz_4	2	1654	CAGRF14280	CAJHGANXX	8	SI-GA-A4
Shiraz_5	3	Yalumba 4	CAGRF14280_2	CAT13ANXX	4	SI-GA-A5
Shiraz_6	3	SARDI 7	CAGRF14280_2	CAT13ANXX	5	SI-GA-A6
Shiraz_7	3	R6W	CAGRF14280_2	CAT13ANXX	6	SI-GA-A7
Shiraz_8	3	PDFS	CAGRF14280_2	CAT13ANXX	7	SI-GA-A8
Shiraz_9	4	BVRC 12	CAGRF14280_3	CAU14ANXX	2	SI-GA-A9
Shiraz_10	4	BVRC 30	CAGRF14280_3	CAU14ANXX	3	SI-GA-A10

Clones were given a clone ID for brevity during analysis. Clones Shiraz_1, 2, and 5 were demultiplexed using supernova demux and then assembled using supernova, both part of the 10X Genomics Supernova assembler suite (Weisenfeld *et al.* 2017) using 28 cores and 200 GB of RAM. The three assemblies were all very similar with regards to assembly statistics; Shiraz_5 was chosen as the best. The supernova assembly statistics for SHIRAZ_5 are shown in Table 28.

Table 28. Supernova summary statistics

	Size	Description
Long scaffolds	3.79 kb	Number of scaffolds >= 10 kb
Edge N50	5.38 kb	N50 size of raw graph assembly edges in bases
Contig N50	33.51 kb	N50 contig size
Phaseblock N50	0.28 Mb	N50 size of phase blocks in bases
Scaffold N50	0.24 Mb	N50 size of scaffolds in bases
Scaffold N60	0.17 Mb	N60 scaffold size
Assembly size	0.36 Gb	Assembly size (for scaffolds >= 10 kb)

The Shiraz contig level assembly was analysed using Quast (Gurevich et al. 2013). The assembly size was larger than the predicted size of 450-500 Mb (Table 29) based on the assembly of other wine grape varieties (Velasco et al. 2007). A common problem for repetitive diploid genome assemblies is the presence of syntenic contigs in the final haploid assembly. The assembly was curated using Purge_Haplotigs (commit-3115b96) (Roach et al. 2018) and re-analysed using quast (Table 29). The curated assembly size was much closer to the predicted size. Aggressive deduplication resulted in approximately 17,000 fewer contigs in the curated assembly with a concomitant improvement in the assembly N50.

Table 29. Quast analysis of raw supernova contig assembly and curated assembly

	SUPERNOVA ASSEMBLY	CURATED ASSEMBLY
NUMBER OF CONTIGS	60 033	43 011
CONTIGS >= 25 KB	2 430	2 411
TOTAL LENGTH	549 Mb	508 Mb
LARGEST CONTIG	2.9 Mb	2.9 Mb
GC CONTENT (%)	34.49	34.39
N50 (BP)	10 472	11 290

Genome assembly 'completeness' was assessed using BUSCO v3.0.0 with the embryophyta_odb9 dataset (Simao et al. 2015). BUSCO searches genome assemblies for core genes that should be in the genome exactly once (these core genes are also referred to as Universal Single-Copy Orthologs or 'BUSCOs'). In the curated assembly 93.6 % of BUSCOs were found. Only 4.8 % of these BUSCOs were fragmented and just 2.6 % were duplicated in the assembly (Table 30). Genome completeness is therefore predicted to be high, and gene fragmentation and duplication are both predicted to be low.

Table 30. BUSCO analysis for curated Shiraz assembly

	NUMBER OF BUSCOS	PERCENTAGE OF BUSCOS (%)
ALL BUSCOS	1 440	100
COMPLETE BUSCOS FOUND	1 278	88.75
-->COMPLETE, SINGLE-COPY	1 241	86.18
-->COMPLETE, DUPLICATED	34	2.60
FRAGMENTED BUSCOS	69	4.79
MISSING BUSCOS	93	6.46

Overall the Shiraz reference genome built from Shiraz clone Yalumba 4 has an overall quality consistent with, or better than, other contemporary grapevine genomes generated from short read sequence data (Velasco et al. 2007, Da Silva et al. 2013, Di Genova et al. 2014).

8.3 Inter-clonal comparisons

8.3.1 Mapping

The 10x Genomics Long Ranger suite was used for mapping sequencing data to the reference assembly (Zheng et al. 2016, Weisenfeld et al. 2017). Sequencing data for all ten Shiraz clones was demultiplexed using longranger mkfastq. The genome reference was indexed prior to mapping using longranger mkref. Mapping of the clones was conducted on in-house servers, and on an eResearchSA Virtual Machine using the longranger align pipeline. The summary reports for all clones indicated all had ideal metrics with the exception of Shiraz_9 which had 38.5 % duplicate reads and as such only a 51.6 % mapping rate (compared to <1 % duplication and 85-90 % mapping rate for the rest of the clones).

Shiraz_9 demultiplexing was rerun and the fastq files were analysed with fastqc (data not shown). The results confirmed that the seq data did indeed contain a very high percentage of duplicate reads and that the error with this data would probably have occurred prior to sequencing, during library preparation. The data was nevertheless initially included in the variant calling pipeline.

8.3.2 Variant calling

A GNU Make based pipeline was developed to perform the variant calling, filtering and comparisons for all of the Shiraz clones. The pipeline flowchart is shown in Figure 103. The bam files were

analysed for read coverage and areas with poor mapping for any of the clones were masked for all of the clones, for the rest of the pipeline. Variant calling was performed using Varscan v2.4.3 (with Java v1.8.0_121) (Koboldt et al. 2012). High confidence calls were pooled to create a 'gold' set of variant calls. Lenient variant calling was carried out at the 'gold' variant sites for each clone and used to build a table of SNPs and INDELs (single nucleotide polymorphisms and insertions/deletions). Any sites with ambiguous variant calls for any clone were ignored, and sites with calls that differed for at least one clone were output to a table of marker variant calls. A summary of marker variants by sample group is provided in Table 31.

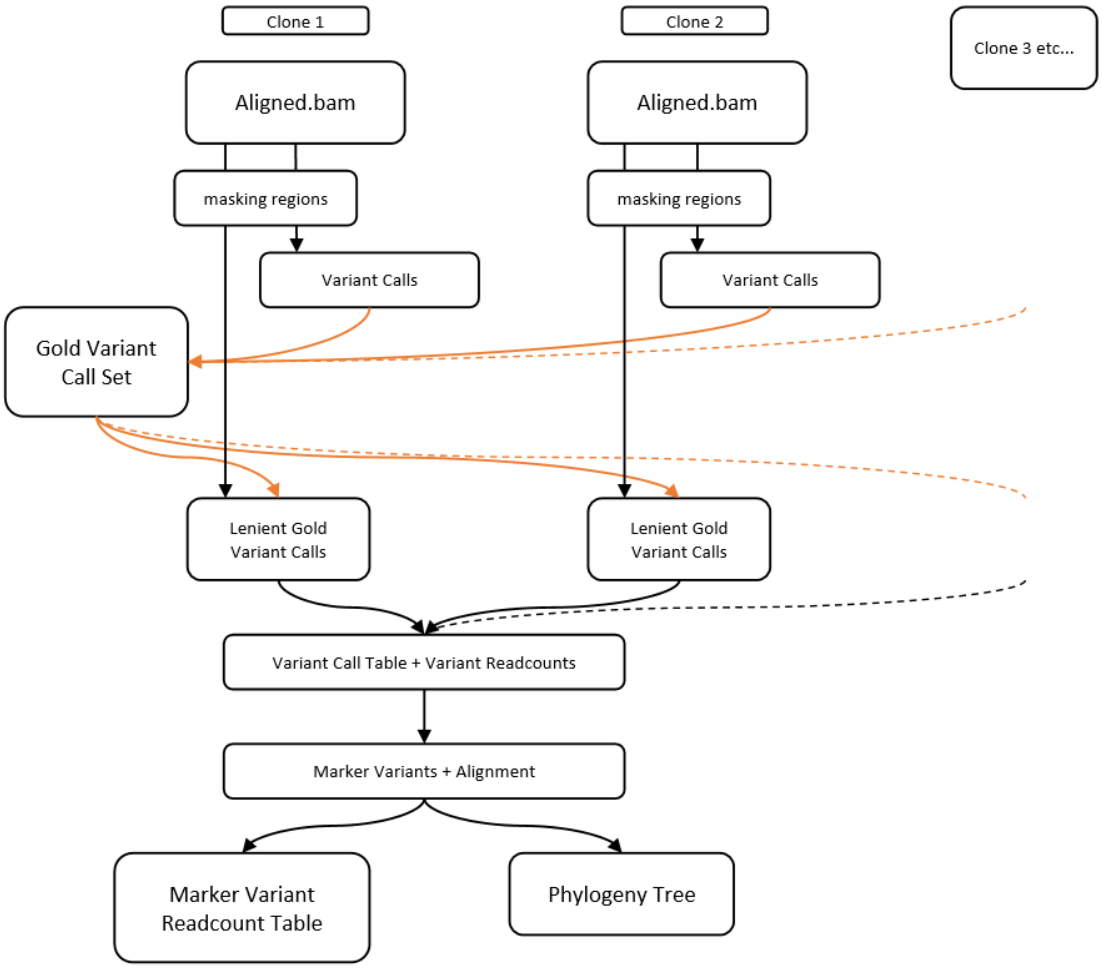


Figure 103. Variant calling pipeline for Shiraz clones

Table 31. Summary of marker variants by sample group.

Sample group	Marker SNPS and INDELS
Yalumba 2/Yalumba 4/PDFS	69
Yalumba 2	46
Yalumba 4	41
Pdfs	36
1654	22
PT 23	14
SARDI 4	14
BVRC 30	9
SARDI 7	6
R6W	5
PT23/Yalumba 2/Yalumba 4/PDFS	2
Yalumba 4/PDFS	1
Total markers	265

A read counts table was produced for the marker variant calls, and a fasta alignment file was produced. The fasta sequences consisted of all of the variant calls concatenated together and this was used for building the phylogenetic tree. At each variant call site a 100-bp kmer (100-mer) was generated (with the variant at the kmer center) and queried against *Vitis vinifera* entries in the RefSeq and RepBase databases using blastn.

8.3.3 Shiraz clone phylogeny

The phylogenetic tree (Figure 104) was created in Rstudio using the libraries APE (Paradis et al. 2004), and phangorn (Schliep 2011). The fasta marker variant alignment file was imported and converted to a phyDat bin object. A distance matrix was constructed using the F81 model, the distance matrix subjected to NJ clustering and edge lengths were optimised. Bootstrap values were calculated, and the tree was exported for rendering in FigTree (http://tree.bio.ed.ac.uk/software/figtree/) and Inkscape. Manual inspection of the bam files showed that SHIRAZ_9 (which had been omitted from the pipeline due to poor data quality) contained all of these and hence belonged to the clade with Shiraz_1, 2, 4, 6, 7 and 10. There were two other SNPs that were absent in Shiraz_1, 3, 5 and 8, and these SNPs were absent as well in Shiraz_9. Therefore, it is likely that Shiraz_9 (BVRC 12) places on the tree closest to Shiraz_1 (PT 23).

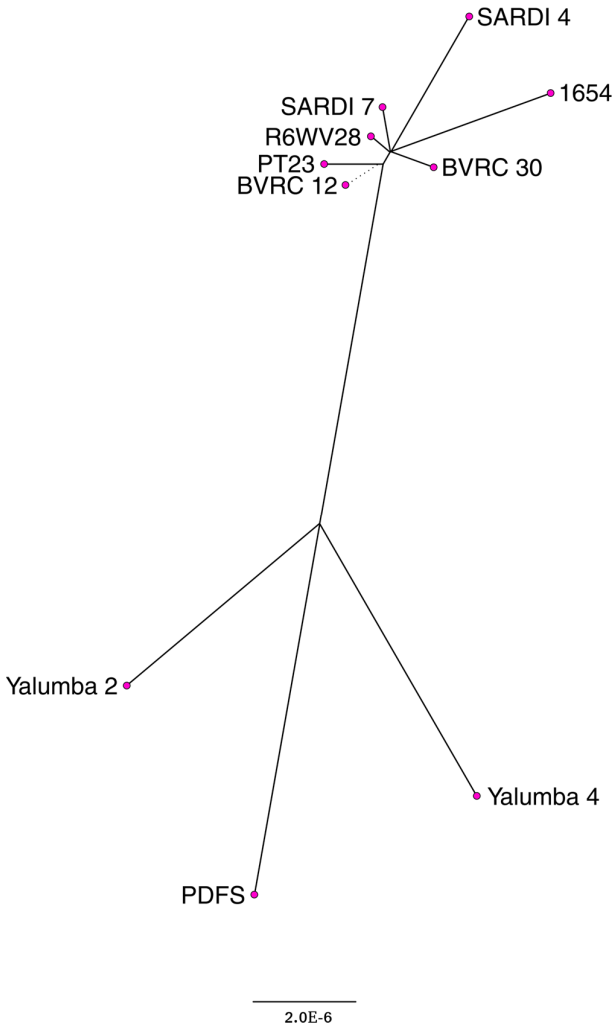


Figure 104 Phylogenetic tree based on 265 single nucleotide polymorphisms (SNPs) where the SNP was different for at least one clone.

R6W is referenced as R6WV28 in the figure.

8.4 Results

Of the 265 nucleotide variants identified in this work, 69 SNPs/INDELs were shared by Yalumba 2, Yalumba 4, and PDFS, separating them from the rest of the clones and hence forming a distinct clade. These clones were all registered/imported in 2001 from France. The shared nucleotide variants demonstrate a period of common origin for these clones for a significant period before clonal isolation programs established their separate lineages but after Shiraz was brought to Australia. Despite their shared heritage, these imports are also quite distinct from each other, with 46, 41 and 36 SNPs/indels distinguishing them. This degree of genetic diversity is similar to that observed between clones of Chardonnay (Roach et al. 2018).

Australian Shiraz clonal isolates, while being quite distinct from more recently imported material, exhibited less intra-clade diversity than the imported Shiraz. Clone 1654 was found to have the highest number of unique SNPs (22, Table 31). This is consistent with 1654 being an isolate from one of the first documented clonal selections in South Australia (McCarthy 1986). The next most diverse clones within the Australian clade are PT 23 and SARDI 4 with 14 SNPs/INDELs each distinguishing

them. Across the group there is comparatively little genetic diversity evident. The least differentiated clone was R6W, which shares all its heterozygosity with the other clones except for 5 SNPs.

This is consistent with Australian material being initially derived from highly related progenitor vines, noting that all Shiraz was originally imported perhaps during, and after 1788. It is possible that the vineyards from which subsequent selections were made, despite being geographically dispersed and containing old vines, were planted with material that shared their genetic heritage. Because the source material is from old vines and grapevine biomass is commonly maintained in a way that will limit the accumulation of vegetative material, there has been limited opportunity to accumulate somatic mutations, resulting in the fairly limited intra-clade diversity evident in this collection.

Blast searches of these variations identified a small number of hits to annotated loci (Table 32). Of note were several leucine rich repeat (LRR) type disease resistance genes, several proteases (subtilisin-like SBT4.9 and carboxy terminal processing) and phosphatases. It has not been established whether the identified variations in these genes are likely to result in a modification to the activity of those genetic elements. It is simply a list of candidate genes that may be functionally affected by the mutations in the respective clones.

8.5 Discussion[1]

The phylogenetic tree showed that the seven Shiraz clones originating as part of Australia selection programs were more genetically similar to each other, than to the three clones that were recently imported from Europe. The focus on selecting clones from historic blocks, and the use of modern nursery practices (the maintenance of mother and source blocks) is designed to prevent genetic change. As the Australian clones are located in one clade, they are likely to have originated from one importation event; however, further investigation of Shiraz clonal diversity would be needed to confirm this.

The differences in the proportion of SNP's in common between clones do not directly relate to the magnitude differences in observed phenotypes. For example, when Chardonnay clones available in Australia were fully sequenced, the clade that contained I10V1 also contained mutants that had red fruit or star flowers (Roach et al. 2018b). So while the SNP differences in between the Shiraz clones selected in Australian were relatively small, there was large clonal variation between vine growth or fruit style as reported here.

[1] Discussion by SARDI.

Table 32. BLAST hit descriptions and probability values associated with single nucleotide variants identified as uniquely associated with Shiraz clones. NCBI Transcript reference sequences database, BLAST v2.8.

Hit description	Expect value
GI|1105490780|REF|XM_019220254.1| PREDICTED: VITIS VINIFERA SOMETHING ABOUT SILENCING PROTEIN 10	2.00E-14
GI|1105494586|REF|XM_019221005.1| PREDICTED: VITIS VINIFERA WAS/WASL-INTERACTING PROTEIN FAMILY	5.00E-144
GI|1104509035|REF|XM_019218068.1| PREDICTED: VITIS VINIFERA SERINE/THREONINE-PROTEIN PHOSPHATASE	1.00E-140
GI|731403116|REF|XM_010656622.1| PREDICTED: VITIS VINIFERA MUCIN-2-LIKE (LOC104880308), MRNA	5.00E-139
GI|1104530022|REF|XM_010658998.2| PREDICTED: VITIS VINIFERA MUCIN-5AC-LIKE (LOC104880885), TRANSCRIPT	1.00E-135
GI|1104674045|REF|XM_019216373.1| PREDICTED: VITIS VINIFERA SOLUBLE SCAVENGER RECEPTOR CYSTEINE-RICH	2.00E-48
GI|1104530664|REF|XM_002274432.3| PREDICTED: VITIS VINIFERA PUTATIVE RECEPTOR-LIKE PROTEIN KINASE	1.00E-144
GI|1104524877|REF|XM_002273800.4| PREDICTED: VITIS VINIFERA CONSERVED OLIGOMERIC GOLGI COMPLEX	5.00E-39
GI|1104527083|REF|XM_010657855.2| PREDICTED: VITIS VINIFERA MYOSIN-17 (LOC100243893), TRANSCRIPT	2.00E-78
GI|1104673128|REF|XM_019216244.1| PREDICTED: VITIS VINIFERA TMV RESISTANCE PROTEIN N-LIKE (LOC100246044),	5.00E-154
GI|1104683219|REF|XM_010645982.2| PREDICTED: VITIS VINIFERA G-TYPE LECTIN S-RECEPTOR-LIKE SERINE/THREONINE-PROTEIN	3.00E-27
GI|1104537153|REF|XM_002283392.3| PREDICTED: VITIS VINIFERA PROTEIN VACUOLELESS1 (LOC100260824),	2.00E-43
GI|1104496802|REF|XM_002285525.4| PREDICTED: VITIS VINIFERA CARBOXYL-TERMINAL-PROCESSING PEPTIDASE	2.00E-62
GI|1105491711|REF|XM_019220430.1| PREDICTED: VITIS VINIFERA SUBTILISIN-LIKE PROTEASE SBT4.9 (LOC109122734),	2.00E-67
GI|1105491709|REF|XM_019220429.1| PREDICTED: VITIS VINIFERA SUBTILISIN-LIKE PROTEASE SBT4.4 (LOC100253594),	1.00E-15
GI|1105494624|REF|XM_010654047.2| PREDICTED: VITIS VINIFERA GLUCOSE-1-PHOSPHATE ADENYLYLTRANSFERASE	5.00E-44
GI|1104670111|REF|XM_002284650.4| PREDICTED: VITIS VINIFERA DCTP PYROPHOSPHATASE 1 (LOC100241572),	5.00E-54
GI|1104656201|REF|XM_002266292.3| PREDICTED: VITIS VINIFERA 60S ACIDIC RIBOSOMAL PROTEIN P1 (LOC100261912),	3.00E-106
GI|1104544078|REF|XM_002272221.3| PREDICTED: VITIS VINIFERA ANAPHASE-PROMOTING COMPLEX SUBUNIT	3.00E-111
GI|1105484332|REF|XM_010647574.2| PREDICTED: VITIS VINIFERA PENTATRICOPEPTIDE REPEAT-CONTAINING	1.00E-60
GI|1104520327|REF|XM_019222637.1| PREDICTED: VITIS VINIFERA STARCH SYNTHASE 3, CHLOROPLASTIC/AMYLOPLASTIC	9.00E-12
GI|1104542184|REF|XM_002278735.3| PREDICTED: VITIS VINIFERA GTP-BINDING PROTEIN TYPA/BIPA HOMOLOG	7.00E-23
GI|1105494936|REF|XM_010654541.2| PREDICTED: VITIS VINIFERA APOPTOTIC CHROMATIN CONDENSATION INDUCER	7.00E-08
GI|1104503912|REF|XM_019218654.1| PREDICTED: VITIS VINIFERA UNCHARACTERIZED LOC109122214 (LOC109122214),	1.00E-140
GI|1104506218|REF|XM_019218302.1| PREDICTED: VITIS VINIFERA UNCHARACTERIZED LOC109122088 (LOC109122088),	1.00E-35
GI|1104506322|REF|XM_010648814.2| PREDICTED: VITIS VINIFERA PROBABLE DISEASE RESISTANCE PROTEIN	3.00E-12
GI|1105494114|REF|XM_010653921.2| PREDICTED: VITIS VINIFERA PROTEIN ENABLED HOMOLOG (LOC104879790),	1.00E-30
GI|1104506322|REF|XM_010648814.2| PREDICTED: VITIS VINIFERA PROBABLE DISEASE RESISTANCE PROTEIN	9.00E-27
GI|1104673931|REF|XM_019216346.1| PREDICTED: VITIS VINIFERA UNCHARACTERIZED MITOCHONDRIAL PROTEIN	7.00E-58

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9 Outcome/Conclusion

1. This project has demonstrated that by using descriptive sensory analysis there are statistically significant differences in sensory attributes of a range of Chardonnay and Shiraz clones growing in a number of the major regions in Australia. These differences were apparent in all years that small lot wines were made. However, there were no consistent trends in the differences between clones. At regional tastings participants demonstrated clear preferences for individual clones, however, these preferences varied across regions and between seasons. These two outcomes indicate that there is merit in planting a range of clones within vineyards and then using the diversity between the wines for winemakers to determine the specific end-product for the market place.
2. The significant differences in sensory attributes between regions and years highlighted the importance of both in influencing wine sensory attributes. Current methodologies of describing seasonal growing conditions, such as heat summation units, did not appear to account for the differences in wine sensory attributes between seasons and regions; hence to imply that future climate change will result in a particular region producing wines similar to a currently warmer region may be erroneous. From the limited data set further evidence is presented of the impact of a warming climate on harvest date and vintage duration.

10 Recommendations

1. Continue and expand the Shiraz genomics study. The limited data set presented here suggests that there are detectable DNA differences between the Shiraz clones evaluated, and, perhaps more importantly, differences between the Australian clones and the limited set from France.
2. If possible, future longitudinal studies of wine sensory properties using descriptive sensory analysis should endeavor to use as many as possible similar descriptors each year to permit more in-depth analysis of seasonal influence. Such future studies should also engage considerable biometrician expertise early in the project life to analyse the large data set; this was a shortcoming of the project reported here.
3. Continue recommendations to Industry of the advantages of using a range of clones of all varieties in any vineyard development.

11 Conference presentations to Industry

16th AWITC workshop and Plenary 2013
An oral presentation was made at the 16th AWITC and the project team also conducted a tasting of selected Chardonnay and Shiraz clones.
The oral presentation was reported in the Conference Proceedings.

17th AWITC workshop 2019
Richard Fennessy and M McCarthy conducted a tasting workshop at the 2019 Australian Wine Industry Technical Conference

International presentations
Oral presentation at 2018 Sustainable Ag. Expo. San Luis Obispo, California, 12th November 2018
Oral Presentation to staff and students at California Polytechnic State University, San Luis Obispo, California, 13th November 2018.

12 Intellectual Property

Nil

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Mr Ralph Cadman provided technical assistance at the Victorian sites and Mr Bruce Henderson provided technical assistance in SA.

15 Appendix 1. Clonal Information.

A 'clone' has been defined as "a population of plants, all members of which are descendants by vegetative propagation from a single individual" (Nicholas 2006). Some 'clones' in our study can be traced back to an individual source vine, e.g. the Bernard Chardonnay clones and the South Australian clones, but others do not have an identified original source vine. For example, the Gingin Chardonnay vines were originally from 24 cuttings of Chardonnay introduced from California in 1957 from an unidentified source or sources of vines, and the Bests Shiraz were originally an old block of pre-phylloxera Shiraz at Bests Wines, Great Western, of undetermined source.

The 'clones' without identified source vines might more appropriately be termed selections. In the case of the Gingin Chardonnay and Bests Shiraz, many subsequent plantings were derived from cuttings collected across the original Gingin or Bests blocks rather than from an individual vine, i.e. mass selection. In this report 'clone' is used to encompass clones from individually selected vines and selections from unknown or mass selected sources.

General history and origin of Chardonnay clones

Penfold 58

This selection is present in one trial in the Henty region. The clone was imported into NSW in 1958 by Penfolds Wines. Source vines are listed in the CSIRO Grape variety collection (1988) as Chardonnay 1959/CX/Europe and in the then Sunraysia Horticulture Centre, Irymple, collection (1987) as Chardonnay Penfold 58 ex NSW (planted in 1969). The clone has been popular for its wine quality attributes along with a tendency to produce bunches that do not set as heavily as other clones.

The French "Bernard" clones

There have been a number of Australian importations of the French clones that were initially selected by M. Raymond Bernard, from several locations in Burgundy, France. Clonal selection and registration in France is a long and detailed process, where the selections undergo extensive viticultural, phenological, and winemaking evaluation, with a minimum of 15 years assessment to determine clonal differentiation and authenticity prior to clonal registration. These clones, known as the Bernard clones, were registered in France as clones in the early 1970s. With the various importations, it is not always clear as to the place of provenance of the clones, i.e. from an official French organisation, or a nursery or vineyard. A summary of characteristics from studies in France is provided in Table 33 (see also similar descriptions by Bernard 1987).

In the Australian Active List of Fruit Imports (Accession List) (1995) the first registered imports of the clones 76, 95, 96 and 277 were in 1985 probably by a private importer. They were given the Accession numbers of IC858269, IC858279, IC858316 and IC858317 respectively. This was followed by a Commonwealth (CSIRO) importation in 1988 of the same four French Chardonnay clones, referred to as the Bernard, or Dijon clones, numbers 76, 95, 96 and 277. These clones were given the Accession numbers IC888544, IC888545, IC888546 and IC888547 respectively and released in 1994 (Active list

1995). After importation, these four clones were subsequently put through Fragmented Shoot Apex Culture (FSAC) by CSIRO in the 1990s, and have been listed separately in the CSIRO collection list as FSAC C clones (the last C denoting CSIRO), to be differentiated from the original imports.

Table 33. Information on the French Chardonnay clones (Anon 2006)

Clone	**76**	**78**	**95**	**96**	**277**
Attribute					
Region/department of selection	Saone-et Loire	Cote-d'Or	Cote-d'Or	Cote-d'Or	Cote-d'Or
Year of registration as clone	1971	1971	1971	1971	1973
Region of data collection	Bourgogne, Champagne, Languedoc, Val -de- Loire	Bourgogne, Champagne, Val -de- Loire	Bourgogne, Champagne, Languedoc,	Bourgogne, Champagne, Languedoc, Val -de- Loire	Bourgogne, Val -de- Loire
Fertility	mod	mod- high	mod	mod	mod- high
Bunch weights	low- mod	mod	low- mod	high	mod- high
Berry size	low- mod		low- mod	mod	low- mod
Production levels	mod	high	mod	mod- high	mod-high
Vigour	mod		mod- high	high	mod- high
Sugar at maturity	mod- high	low	mod-high	mod-high	mod
Total Acid	mod		low - mod	mod- high	mod
Oenological aptitude	aromatic wines, balanced, fine and typical	Not very expressive in still wine	Fine aroma, rich structure and balanced	Elegant, aromatic, balanced	Delicate, elegant floral, well structured (if not overcropped)

Several other registered importations of the Bernard clones occurred into quarantine stations at Kingston, Tasmania, in 1987 and South Perth, WA, in 1989 and Yalumba nursery planted source blocks of Bernard clones in 1989. There could have been separate private importations of Bernard clones

undertaken at a similar time to the Commonwealth imports. The trial material in the Riverland at Oxford Landing vineyard is from this material. It is assumed that the French trial material in the WA vineyards were from the CSIRO importations, that were subsequently imported to WA and distributed to the study sites via local nurseries.

An importation of seven Bernard clones 76, 78, 95, 96, 115, 125 and 277, was undertaken by Seppelts in 1984. The clones remained in a cool room for several years and eventually were propagated at the Nuriootpa Research Station in 1988. Vines were then planted at Padthaway, SA, and Drumborg, Victoria (Henty region) in 1997. Cuttings from the Drumborg planting were propagated to establish the plots in the Kym Ludvigsen vineyard in the Grampians region (Kym Ludvigsen pers. comm.).

In addition, another group of Bernard clonal imports was made by SARDI, from Sidney, British Columbia, Canada, and planted out in 1992. They were known under their Canadian clonal names of Q plus a 5 digit number, with two of them reported to be the French Bernard clones. Q949-03 was evidently clone 76, and Q949-08 clone 277 (Nicholas 2006). It is unknown whether any commercial plantings under the Canadian imports were undertaken.

The history of clone 78 in SA is unclear. It is listed on the Kapunda (ex South Australia Vine Improvement Inc.) clonal list, and the RVIC (Riverland Vine Improvement Committee) list, but has no provenance stated. It is not listed as present in any state (government) register. On the Accession List (Anon. 1995) clone 78 is listed as being imported into WA in 1986 and released in 1989. Clone 78 was again imported into WA in 1989 and listed as still in quarantine in 1995. These may have been private imports.

Clone 78 in our study established at in the Henty and Grampians regions originated from a separate importation by Seppelts. Clone 78 was also established at Oxford Landing from an importation by Yalumba nursery. However this clone was removed from the Oxford landing planting due to atypical Chardonnay characters. This clone was not the same as the 78 planted in the Henty and the Grampians regions. Coincidently one of the Bernard Chardonnay selections in France, clone 77, is described as having muscat sensory characters and it may be possible the clone 78 at Yalumba and Oxford Landing was actually clone 77.

In 1997 the French established their official ENTAV-INRA® (Establissement National Technique pour l' Amelioration de la Viticulture-Institut National de la Recherche Agronomique; now Institut Francais de la Vigne et du Vin - IFV) trademark program for grapevine clonal material, with material of the same numbers as those original Bernard clones, as well as more recent clonal selections. That official material is not available in Australia currently for commercial use.

A similar situation occurred in the USA, at the University of California Davis (UCD), where some importations of the French material occurred prior to the establishment of the ENTAV-INRA® registration system. The first batch of Bernard clones were imported to Oregon State University in the mid-1980s and then on to the Foundation Plant Service (FPS) in 1987-88 for public distribution (Sweet 2007). These clones tested positive for Rupestris Stem Pitting associated Virus and they all underwent shoot tip culture before release between 1997 and 2002. All of these clones were renamed with FPS numbers, i.e. 76 (FPS 69 and 76), 78 (FPS 39), 96 (FPS 70 and 96) and 277 (FPS 42, 49 and 51). A direct import from France in 1988 of clone 95 was released in 1997 as FPS 37, 38 and 95. In 1997 FPS were provided with authorised ENTAV-INRA® clones from France and these were registered in 2000. Further details for each clone are available at http://www.ngr.ucdavis.edu/fgrdetails.cfm?varietyid=437.

In the 1990's the then SAVII, (South Australian Vine Improvement Inc.), rebadged many Chardonnay clones with the names of SAVII plus number, including some of the Bernard clones and the Q group of imports. Chardonnay SAVII 01 is clone Q949-03 (76), SAVII 02 is 95, SAVII 03 is 96, SAVII 04 is clone Q949-08 (277), and SAVII 09 is 78 (Nicholas 2006).

The clones from University of California Davis

The clones sourced from the Foundation Plant Material Service at the time (FPMS) at the University of California Davis, USA, FVI10V1 and IFV10V5, were imported into Australia in 1969, and FVI10V1 again to Victoria in 1971. These clones were named according to their position in the block at UCD, e.g. Chardonnay FVI10V5 is from the Foundation Vineyard, block I, row 10, vine 5. The I10V1, I10V3 and I10V5 clones were originally from one vine, Olmo #68, selected by Professor Harold Olmo, and had then undergone different heat treatment regimes. They were sourced from the Martini vineyard in Carneros, that in turn had been planted indirectly from material from the Wente vineyard. The aim of the clonal selection by Harold Olmo was to improve yield, and reduce the phenomena of hen and chicken present in much of the Chardonnay material at the time, and to reduce the supposed virus infection.

Chardonnay is believed to have been introduced from Meursault in the Burgundy region, France, into California in 1882 by Charles Westmore (Sweet 2007). Some material went to the Wente Vineyard, Livermore, and the Wente Vineyard alsoprocured Chardonnay directly from Montpellier in around 1912. The Wente and Masson vineyards were one of the few vineyards with Chardonnay to survive the Prohibition period (ended 1933) but yields were notoriously low.

A mass selection of cuttings from the Wente vineyard was planted in F McCrea's Stony Hill Vineyard in Napa County. Louis P Martini subsequently took material from the Stony Hill Vineyard to establish Chardonnay in his own vineyard in Stanly Lane. Olmo undertook clonal selection in the Martini vineyard planting them in trials at the Oakville experimental Vineyard of UC Davis. From the trials Olmo selected a number of vines, one of which was #68. Dr Austin Goheen produced heat treated vines from #68 which were planted in the West Armstrong (WA) vineyard where Goheen planted his heat treated vines. WAK4V53 heat treated 164 days was planted in the Foundation Vineyard Block I, row 10, vine 1 and became known as FVI10V1 or FPS06. Similarly WAK4V61 heat treated 114 days became FVI10V5 or FPS08. Some of these clones imported into Australia have also undergone fragmented shoot apex culture (FSAC), by CSIRO and Victoria.

The FPMS changed to theFoundation Plant Services (FPS) on 1 June 2003. There has been considerable work by the UCD and FPS to trace back their clones to their original source, the location identifier from the original vineyard, and further back to the selector and European origins where possible. This may facilitate traceability for some of the material imported into Australia (see http://www.ngr.ucdavis.edu/fgrdetails.cfm?varietyid=437).

WA clone Gingin

The earliest recorded introduction of Chardonnay in the Accession List appears to be in 1957. Ikin (1978) lists a Chardonnay import into Western Australia in 1957 (IW576002). This period coincides with a number of imports of grape varieties into that state, e.g. Rotundifolia (IW566001), Colombard (IW576003), Emperor (IW576004) and Ribier (IW586005). A copy of a Grape Variety Distribution form from the University of California, College of Agriculture, Davis, shows that in February 1957 cuttings of Pinot Chardonnay (along with French Colombard, Emperor, Delight, Perlette and 1613 rootstock) were dispatched to the Department of Agriculture, Western Australia (Hayward 2017-18). The clone was released from quarantine in in 1964 and a small planting established at Belhus Estate vineyard, Upper Swan Valley, in 1965. A larger planting of what was originally Chardonnay IW576002 was made with cuttings from Belhus Estate at the Valencia vineyard of the Moondah Brook wine company, near the locality of Gingin WA. At some stage after that IW576002 became known as the Gingin clone.

The introduction of IW576002 likely came about from the eight month period Dr Harold Olmo spent in WA in 1955. It was during the mid 1950s that Olmo was undertaking his Chardonnay clonal selection work in California. He appears to have facilitated the importation of Chardonnay into WA in 1957 (Hayward 2017-18).

If so, it is not clear what the source of the selection was. It may have been from the Martini Stanly Lane vineyard (this planting material came indirectly from the Wente vineyard) where Olmo began selecting clones for the Universities program in 1955 (Asher 1990). Those selections were called the Martini selections and were later designated FPS 04-08 and 14 after heat treatment and were termed the 'Davis' or 'Wente' clones in California. They were imported to Australia variously as I10V1, I10V3, I10V5, G9V5 and G9V7, all relatively high yielding clones.

Given the Gingin clone characteristically has poor set, it is akin to the non-heat treated 'old Wente' material once used in California that had a high degree of shot berries. Olmo had released some of the healthy Martini material after 1955 before it had progressed through the indexing and heat treatment program of the plant pathologists (Asher 1990). Other possible sources of the Gingin clone are Chardonnay-1, which has been traced back to 1930 in the UCD/FPS system but the iriginal source is unknown (Sweet 2007), or a clone chosen by Olmo in Meursault, France, in 1951 (Wolpert et al. 1995).

The Gingin clone is sometimes named locally in WA as the 'Mendoza' clone (Bell 2016, Farmer 2008, Hayward 2017-18). The evidence for this is not clear. A summary of Chardonnay clones in the FPS (Sweet 2007) did not mention any Chardonnay imports from Mendoza, Argentina, although Sweet (pers. Comm. 2018) has confirmed a record of a selection from Mendoza in 1961 which became Chardonnay 01A in the Foundation Vineyard. Australia imported the Chardonnay clone FPS 01A and here it was given the designation FVC2V16/CX/UCD Mendoza (IC688025). It was subsequently planted in SA and Victoria state grapevine collections andwas noted for its poor yield (hen and chicken) and had limited distribution.

New Zealand imported the Mendoza clone from CSIRO Australia in 1971, where it has low to moderate yields of medium clusters prone to some hen and chicken (Hoskins and Thorpe 2010). Hence some may have linked the Gingin clone with the Mendoza clone due to its cropping habit. If the Mendoza clone was imported into the USA in 1961 then the IW576002 clone imported in 1957 cannot be the Mendoza clone.

Numerous introductions of Chardonnay clones have occurred into Australia. Initially the Federal Government kept track of importations and these were published in a series of Accession lists. Eventually private importers took over from Government bodies and their importations went unrecorded in the Accession lists. Table 34 summarises the published introductions of Chardonnay clones into Australia.

Table 34. Chardonnay clones used in the trial and their possible introductions

Chardonnay Clone	**Introductions to Australia Importer and year**	**Accession numbers for the CSIRO/government imports only**	**Also known as**
76	CSIRO 1988, Seppelts 1984 Yalumba ? SARDI Q series, 1992 Private, 1985 and 1987. WA, 1989 private	IC858269 IC888544	Bernard, or Dijon clone SAVII 01 FPS 69 and 76
78	Seppelts, 1984 Listed as introduced to WA in 1986 and 1989 , Seppelts introduction	-	Bernard, or Dijon clone SAVII 09 FPS 39
95	CSIRO, 1988 Seppelts, 1984 Yalumba, ? Private, 1985 and 1987 WA, 1989 private	IC858279 IC888545	Bernard, or Dijon clone, SAVII 02. FPS 37, 38 and 95
96	CSIRO, 1988, Seppelts, 1984 Yalumba, ? Private, 1985 WA, 1989 private	IC858316 IC888546	Bernard, or Dijon clone SAVII 0 FPS 70 and 963
277	CSIRO, 1988 Seppelts, 1984 Yalumba, ? SARDI, Q series, 1992 Private, 1985 and 1987 WA, 1989 private	IC858317 IC888547	Bernard, or Dijon clone SAVII 04 FPS 42, 49 and 51
FVI10V1	CSIRO, 1969	IC698127	FPS 06#

	Victoria, 1971 SA, 1973 (from CSIRO) WA, 1972 (from CSIRO) Qld, 1979 (from Victoria)	IV712307	Clone 6 – NZ
FVI10V5	CSIRO, 1969 SA, 1975 (from CSIRO) WA, 1972 (from CSIRO) Qld, 1979 (from CSIRO) NSW, 1982 (from CSIRO)	IC698129	FPS 08
Gingin	WA, 1957	IW576002	Incorrectly as 'Mendoza'
Penfold 58	NSW, 1958 by Penfolds Wines Planted at SHC Irymple 1969.	-	1959/NX/Europe in CSIRO collection

General history and origin of Shiraz clones

South Australian selections

The first group of selections are BVRC 12, BVRC 30 and 1654. They were selections made in the late 1950s, 60s and 70s at the Barossa Viticultural Research Centre (BVRC), Nuriootpa, now known as the Nuriootpa Research Centre.

The 1654 selection came out of the first clonal selection process at the research station in 1958 carried out by Harry Tulloch, with yield per vines assessed on 0.1 hectare plantings. The source of the Shiraz planting material is noted as Nuriootpa (McCarthy 1986), with sources of other varietal material noted as specific subregions of the Barossa, Watervale and Langhorne Creek. The clone 1654 was the highest yielding individual vine from that planting, along with other material such as 1127 and 2626. In 1966 a statistically designed clonal trial was established at Loxton and included planting material from the top 6 and lowest 2 yielding vines. In that trial, between 1972 and 1978, the average yield for 1654 was 19.4 kg/vine, just behind selection 1125. The selections were also later screened for fanleaf and leafroll virus.

In 1966 at Nuriootpa, Max Loder increased the potential population of source vines by broadening the area of collection for the selections, with 44 selections made and planted. The initial trials with a broader range of material showed little significant difference between yields, however this was primarily due to insufficient replicates, consequently from 1973 all new clonal trials were established as single vine plots with many replicates of each clone. Clone 12 (later BVRC12) was ranked in the Loder trial as the 6th highest yield over 4 years, and clone 30 (BVRC 30) as the 42nd ranked yielding vine. Clones from the earlier Tulloch trial were not included.

Subsequent Shiraz clonal trials were established in different regions, with more repetitions per clone. The four selections 1654, BVRC30, BVRC12 and BVRC33 were assessed in Nuriootpa with BVRC12 yielding significantly higher than 1654 (Table 35) and no significant differences between the remaining combinations. Small yield differences have been noted with Shiraz clonal trials, compared to some of the differences found between clones of other varieties.

Table 35. Yield (kg/vine) of four Shiraz clones planted in a clonal selection at Nuriootpa

Clone	Yield (kg/vine) 1978-86
BVRC12	9.2
BVRC30	8.7
BVRC33	8.4
SA1654	8.1

Least Significant Difference = 0.8

A selection process started in 1986 has produced the clones referred to as Heritage Shiraz clones including SARDI 4 and 7. The then SA Dept Agriculture, Nuriootpa, together with local vine improvement groups assessed about 150 vineyards across the regions of Barossa, Eden Valley, McLaren Vale and Langhorne Creek. The vines were at that stage over 60 years of age, planted prior to 1926 on own roots. Individual vines were selected for good bunch composition, trueness to type, healthy leaf condition and absence of virus symptoms over two successive seasons. From this process, 40 vines were selected, cuttings taken and planted out in a replicated trial at Nuriootpa in 1989 with BVRC12 and ESA3021 (a clone from the Hunter Valley) as comparisons. Yield component measurements were taken in 1993, and these again showed no statistical differences between clones, however, there were some significant differences in ^{0}Brix at harvest. Later, qualitative assessments including anthocyanin and phenolic concentration were made and 10 selections were made, which after virus indexing, eight were propagated for release. Barossa Vine Improvement also had the 8 clones DNA typed to confirm the cultivar was Shiraz, and entered into agreement with SARDI to distribute the eight clones.

Victorian selections

The two Victorian selections are R6W and the Bests clone. In the mid-1970s seven selections were made from a Shiraz block in the Chateau Tahbilk. Nagambie, vineyard, reputedly planted around the 1860s. Selections were made on the basis of absence of virus symptoms, yield and maturity. One of the seven selections was named R6W and three vines were planted at the Sunraysia Horticulture Centre, Mid Area block in 1977 (along with the other six selections). Cuttings from the middle vine in the panel (which happened to be vine 28 in the row) were provided to South Australia and the clone was re-named R6WV28.This clone is the most widely planted of the Tahbilk selections in Victorian vineyards together with plantings in other states. The Bests selection originates from the Bests vineyard at Great Western established in 1866 by Henry Best. It is likely Henry Best sourced his vines from his brother Joseph Best who had established the Great Western vineyard (the present Seppelt site). The source of the Shiraz planted by Joseph Best is unclear but may well have been originally derived from vines imported by James Busby in 1833. Various blocks of Shiraz derived from the 1866 planting are established at the Bests vineyard. The material from Bests vineyard was generally supplied as 'mass selections', and has been planted on other vineyards locally but not widely distributed elsewhere. Clonal selections of the Bests selection have been made recently.

New South Wales selections

The NSW selections PT 15 and PT 23 were selected from a pruning trial (PT), planted in the early 1960s at Griffith using material selected from Murrumbidgee Irrigation Area (MIA) growers. The original source of the MIA Shiraz is unknown. Thirty two candidate clones were selected from four vigorous vines growing in each of eight vineyards in the MIA and incorporated into the pruning trial. Four top yielding clones were selected and PT15 was originally designated PT4/3NGr and PT23 was designated PT6/3Ngr (Peterson and Murray 1973).

The first accession numbers were allocated in 1961 as AN610019 for PT15 and AN610020 for PT23. They are also known as NSW15 or NSW23. Dry (2004) suggested that these selections could be traced back to the Busby Shiraz which was originally selected from Hermitage Hill in the Rhone Valley in France but he provided no details.

Western Australian selection

In the WA register there are 4 clones of Shiraz listed, viz. 12 (presumably BVRC12), R6W, 1654, and PT15. They appear to have been imported from the eastern states in the last couple of decades. BVRC12 and PT15 were in quarantine in WA in 1993. There has been Shiraz in Western Australia from 1920 or earlier as noted in the report on the WA Grape industry by Prof Harold Olmo in 1955. Grapevine material first arrived with the early settlers from the Cape of Good Hope and vineyards were planted in the Swan Valley around the 1830s.

16 Appendix 2. Wine analysis at bottling of Chardonnay and Shiraz clonal wines for each vintage.

(Data supplied by AWRI)

Chardonnay

Table 36. Wine analysis of 2014 Vintage Chardonnay clones at bottling.

Region	Clone	Rep	Alc. (% v/v)	pH	TA (g/L)	G+F (g/L)	VA (g/L)	FSO_2 (mg/L)	TSO_2 (mg/L)
Riverland	96	2	14.0	3.03	7.8	0.9	0.4	32	109
	95	1	14.4	3.46	7.7	0.6	0.3	40	123
	277	1	14.0	3.02	7.8	0.8	0.3	34	120
	76	2	13.7	3.24	7	0.9	0.3	34	120
	78	1	14	3.34	7.3	1.8	0.4	30	104
Grampians	96	2	13.6	3.22	6.9	0.7	0.3	37	98
	95	1	13.6	3.28	6.6	0.3	0.3	32	104
	277	1	13.7	3.22	7	0.3	0.3	34	99
	76	2	14.0	3.26	6.8	< 0.3	0.3	45	114
	78	1	13.2	3.15	7.2	< 0.3	0.1	32	91
	I10V5	1	12.5	3.20	7.2	0.3	0.3	34	120
Great Southern	96	1	12.8	3.01	8.7	0.5	0.34	37	125
	95	1	13.0	2.97	9	0.7	0.3	35	125
	277	2	13.2	3.03	8.5	1	0.4	38	122
	76	2	12.8	2.97	9.3	0.5	0.4	34	123
	I10V5	2	14.1	3.17	7.2	0.5	0.3	30	117
	Gingin	1	14.3	3.20	7.5	2.2	0.4	38	130
Margaret River	96	1	13.1	3.25	6.4	1.6	0.3	40	115
	95	1	12.6	3.02	8	0.6	0.3	42	109
	277	2	13.2	3.13	7.3	1.1	0.3	40	102
	76	2	13.2	3.09	7.7	1.6	0.3	42	109
	Gingin	2	13.4	3.04	8.6	1.7	0.3	38	115

Table 37. Wine analysis of 2015 Vintage Chardonnay clones at bottling.

Region	Clone	Rep	Alc. (% v/v)	pH	TA (g/L)	G+F (g/L)	VA (g/L)	FSO_2 (mg/L)	TSO_2 (mg/L)
Riverland	76	1	13.9	3.44	6.9	0.4	0.34	18	110
	76	2	13.5	3.45	6.9	0.4	0.34	15	105
	277	1	13.4	3.40	6.7	0.5	0.29	19	96
	277	2	13.4	3.39	6.7	0.6	0.31	22	106
	95	1	13.2	3.40	6.4	0.5	0.28	18	97
	95	2	13.2	3.4	6.5	0.5	0.29	16	105
	96	1	13.2	3.40	6.4	0.4	0.31	17	98
	96	2	13.3	3.41	6.3	0.5	0.31	14	88
Grampians	78	1	12.0	3.19	7.6	< 0.3	0.31	13	91
	78	2	12.2	3.18	7.7	0.4	0.25	< 4	101
	76	1	12.6	3.08	8.4	0.4	0.31	< 4	102
	76	2	12.6	3.08	8.6	0.4	0.30	13	89
	I10V5	1	11.0	3.01	10.1	0.3	0.06	10	89
Great Southern	Gingin	1	13.8	3.21	6.7	1.2	0.36	24	115
	Gingin	2	13.7	3.12	7.1	2.0	0.36	21	106
	76	1	12.4	2.97	8.3	0.6	0.36	24	104
	76	2	12.5	2.99	8.1	0.8	0.36	26	108
	96	1	12.3	3.10	7.5	0.7	0.33	23	111
	96	2	12.4	3.15	7.1	0.9	0.34	24	111
	95	1	12.6	3.05	7.8	0.7	0.33	26	115
	95	2	12.7	3.10	7.6	0.8	0.34	23	109
	277	1	12.9	3.11	7.4	0.7	0.34	24	109
	277	2	12.8	3.07	7.3	0.9	0.30	28	108
Margaret River	95	1	13.2	3.15	6.9	0.9	0.31	25	98
	95	2	13.1	3.14	7.0	0.8	0.31	24	97
	96	1	12.5	3.12	7.2	0.7	0.27	25	105
	96	2	12.7	3.16	7.1	0.4	< 0.25	29	109
	76	1	12.8	2.99	8.0	0.8	0.28	21	96
	76	2	13.1	3.09	7.2	0.8	0.34	24	100
	Gingin	1	13.7	3.06	7.6	1.1	0.41	28	108
	Gingin	2	13.7	3.07	7.6	1.4	0.41	28	106
	277	1	12.8	3.07	7.3	0.9	0.31	26	104
	277	2	12.8	3.14	7.5	0.8	0.37	23	97
Drumborg	I10V5	1	11.5	2.95	9.9	0.2	0.09	25	104
	I10V5	2	11.5	2.94	9.5	0.3	0.10	32	111
	I10V1	2	13.2	3.06	8.1	1.5	0.30	19	102
	78	1	12.9	3.05	8.5	0.5	0.28	19	94
	78	2	12.8	3.03	8.6	0.8	0.27	18	99
	96	1	12.8	3.06	8.7	0.4	0.31	23	99
	96	2	12.8	3.05	7.9	1.7	0.26	21	98
	277	1	12.8	3.02	8.6	0.6	0.31	16	96

277	2	12.8	3.02	8.8	0.4	0.30	17	99
76	1	12.8	3.05	8.6	0.4	0.29	5	100
76	2	12.8	3.06	8.7	0.4	0.28	9	98
95	1	12.8	3.04	8.7	0.3	0.29	25	102

Table 38. Wine analysis of 2016 Vintage Chardonnay clones at bottling.

Region	Clone	Rep	Alc. (% v/v)	G+F (g/L)	pH	TA (g/L)	VA (g/L)	FSO_2 (mg/L)	TSO_2 (mg/L)
Riverland	76	1	13.9	1.2	3.42	5.4	0.28	40	144
	76	2	13.6	1.0	3.40	5.7	0.28	41	143
	95	1	14.0	1.3	3.45	5.6	0.34	47	150
	95	2	14.1	1.2	3.48	5.5	0.38	40	134
	96	1	14.3	1.3	3.41	5.3	0.3	45	138
	96	2	14.2	1.4	3.40	5.5	0.29	46	138
	277	1	13.9	1.1	3.39	5.5	0.28	45	138
	277	2	13.9	1.0	3.39	5.5	0.28	46	144
Grampians	76	1	14.0	1.0	3.41	6.2	0.33	35	135
	76	2	14.0	1.1	3.39	6.3	0.34	35	136
	78	1	13.5	0.8	3.45	6.1	0.36	38	150
	78	2	13.4	0.8	3.44	6.2	0.36	37	144
	95	1	13.5	0.7	3.44	6.1	0.31	35	141
	95	2	13.6	0.6	3.43	6.1	0.30	37	132
	96	1	14.1	0.8	3.43	6.1	0.36	36	138
	96	2	14.1	0.8	3.41	6.4	0.35	36	134
	277	1	14.1	0.7	3.50	6.1	0.39	37	155
	277	2	14.0	0.8	3.44	6.4	0.38	34	149
	I 10V5	1	12.9	0.6	3.46	5.9	0.36	35	155
	I 10V5	2	12.9	0.6	3.44	6.0	0.36	36	147
Drumborg	58	1	12.6	< 0.3	3.11	7.8	0.37	37	125
	58	2	12.5	< 0.3	3.11	7.7	0.36	38	114
	76	1	13.1	1.1	3.13	7.7	0.38	36	123
	76	2	13.1	0.6	3.14	7.7	0.38	37	125
	78	1	12.2	< 0.3	3.09	8.1	0.37	36	115
	78	2	12.2	< 0.3	3.08	8.1	0.36	37	119
	95	1	12.1	< 0.3	3.04	8.4	0.34	36	116
	95	2	12.2	< 0.3	3.04	8.5	0.34	37	112
	96	1	12.6	1.3	3.07	7.9	0.34	37	142
	96	2	12.6	0.6	3.07	8.2	0.33	37	137
	277	1	12.5	< 0.3	3.09	9.1	0.38	35	123
	277	2	12.7	< 0.3	3.10	8.9	0.37	35	122
	I 10V1	1	13.1	0.7	3.06	8.1	0.44	36	145
	I 10V1	2	12.9	0.6	3.02	8.6	0.37	35	141
	I 10V5	1	11.5	0.5	2.99	9.2	0.21	36	130
	I 10V5	2	11.5	1.2	2.98	9.1	0.18	40	120
Margaret River	76	1	12.7	0.9	3.16	6.7	0.28	40	120
	76	2	12.8	0.9	3.13	7.0	0.30	55	140
	95	1	13.0	1.2	3.21	6.4	0.27	43	126

	95	2	13.1	1.1	3.24	6.3	0.27	43	121
	96	1	12.8	1.2	3.24	6.2	< 0.25	43	121
	96	2	12.8	0.9	3.23	6.2	< 0.25	46	122
	277	1	12.9	1.5	3.16	6.6	0.25	50	131
	277	2	13.1	1.4	3.23	6.2	0.29	47	130
	Gingin	1	13.5	2.2	3.15	7.2	0.36	39	128
	Gingin	2	13.4	2.3	3.09	7.5	0.31	42	125
Great Southern	76	1	12.9	0.7	3.17	7.6	0.40	41	123
	76	2	13.1	1.3	3.24	7.4	0.44	43	133
	95	1	13.2	0.8	3.13	7.5	0.32	38	121
	95	2	13.2	1.1	3.15	7.5	0.38	40	127
	96	1	13.2	0.9	3.19	7.2	0.34	41	130
	96	2	13.3	1.1	3.23	7.0	0.37	40	129
	277	1	13.1	0.8	3.14	7.6	0.35	40	115
	277	2	13.2	0.8	3.18	7.4	0.36	40	118
	GG	1	13.8	1.0	3.23	7.4	0.45	41	121
	GG	2	13.9	0.9	3.26	7.3	0.47	40	130
	I10V1	1	13.7	1.4	3.22	6.9	0.37	38	117
	I10V1	2	13.8	0.8	3.25	6.8	0.40	37	110

Table 39. Wine analysis of 2017 Vintage Chardonnay clones at bottling.

Region	Clone	Rep	Alc. (% v/v)	G+F (g/L)	pH	TA (g/L)	VA (g/L)	FSO_2 (mg/L)	TSO_2 (mg/L)
Riverland	76	R1	13.7	1	3.44	6.5	0.35	52	139
	76	R2	13.7	0.8	3.47	6.5	0.39	52	142
	95	R1	13.2	0.5	3.55	6.4	0.39	52	142
	95	R2	13.3	0.4	3.56	6.4	0.38	48	137
	96	R1	13.6	0.7	3.53	6.4	0.39	49	140
	96	R2	13.6	0.5	3.53	6.4	0.38	54	145
	277	R1	13.7	0.7	3.56	6.5	0.4	51	144
	277	R2	13.7	0.7	3.56	6.4	0.4	48	138
Drumborg	76	R1	11.9	0.6	3.21	7.9	0.42	44	130
	76	R2	11.9	0.6	3.22	7.9	0.4	44	128
	95	R1	12.1	0.6	3.15	7.8	0.41	45	117
	95	R2	12.1	0.5	3.13	7.9	0.41	43	121
	96	R1	11.7	0.6	3.18	8.9	0.39	44	118
	96	R2	11.8	0.7	3.17	8.9	0.39	44	117
	277	R1	12.1	0.8	3.18	8.9	0.41	42	115
	277	R2	12.1	0.7	3.19	8.9	0.41	46	120
Grampians	76	R1	12.4	1.3	3.38	5.8	0.3	42	121
	76	R2	12.4	1.1	3.38	5.8	0.29	45	118
	95	R1	12.2	0.8	3.43	5.5	0.33	42	130
	95	R2	12.2	0.9	3.43	5.6	0.33	43	135
	96	R1	12.4	0.9	3.37	6	0.31	45	120
	96	R2	12.4	0.9	3.36	6	0.31	44	119
	277	R1	12.6	1	3.35	6.4	0.34	42	119
	277	R2	12.5	0.9	3.35	6.4	0.33	41	114
Great Southern	76	R1	12.3	0.7	3.07	7.7	0.33	43	124
	95	R1	12.2	0.9	3.12	7.2	0.26	45	130
	96	R1	12.3	0.9	3.14	7.2	0.29	46	139
	277	R1	12.2	0.8	3.07	7.4	0.27	45	132
	Gingin	R1	13.7	1.2	3.2	7.3	0.37	46	144
	I10V1	R1	13.3	1.2	3.32	6.3	0.38	46	137
Margaret River	76	R1	12.8	1.1	3.01	7.5	0.36	43	124
	76	R2	12.9	1.2	3.09	7.1	0.39	45	130
	95	R1	13.3	1.3	3.19	6.4	0.28	45	121
	95	R2	13.4	1.2	3.25	6.2	0.31	46	120
	96	R1	12.8	1.1	3.21	6.2	0.29	46	124
	96	R2	12.8	0.8	3.2	6.3	0.26	45	118
	277	R1	12.8	0.9	3.2	6.3	0.25	44	115
	277	R2	12.7	0.9	3.11	6.9	0.31	45	116
	Gingin	R1	13.9	1.5	3.07	9	0.42	43	124

Gingin	R2	13.9	1.1	2.99	8.1	0.48	43	123

Table 40. Wine analysis of 2014 Vintage Shiraz clones at bottling.

Region	Clone	Rep	Alc. (v/v)	pH	TA (g/L	G+F (g/L)	VA (g/L)	FSO_2 (mg/L)	TSO_2 (mg/L)
Barossa	R6W	1	15.0	3.19	7.2	0.2	0.36	50	94
	R6W	2	15.0	3.08	7.7	0.3	0.34	53	99
	SARDI 4	1	15.3	3.18	7.8	0.2	0.33	42	86
	SARDI 4	2	15.0	3.2	7.5	0.2	0.34	51	112
	SARDI 7	1	13.9	3.12	7.5	0.2	0.32	43	86
	SARDI 7	2	14.3	3.13	7.6	0.2	0.31	51	93
	BVRC 12	1	14.6	3.16	7.2	0.2	0.36	56	114
	BVRC 12	2	14.8	3.31	6.9	0.8	0.38	50	91
	PT 15	1	14.4	3.26	6.7	0.3	0.27	50	88
	PT 15	2	14.7	3.26	6.6	1.1	0.23	48	99
	1654	1	14.7	3.14	7.2	0.2	0.34	48	110
	1654	2	14.4	3.09	7.6	0.2	0.26	45	91
	BVRC 30	1	14.2	3.11	7.4	0.4	0.32	46	96
	BVRC 30	2	14.1	3.06	7.4	0.2	0.29	43	94
Riverland	SARDI 7	1	15.5	3.38	7.5	0.2	0.61	35	101
	SARDI 7	2	15.6	3.36	7.3	0.2	0.57	50	122
	BVRC-12	1	15.5	3.49	6.3	1.1	0.56	35	96
	BVRC-12	2	15.5	3.37	7.1	0.7	0.52	48	126
	BVRC-30	1	15.7	3.39	7.2	1.2	0.5	26	93
	BVRC-30	2	15.5	3.34	7.1	1	0.51	42	99
	1654	1	15.6	3.68	6.6	0.5	0.49	42	86
	1654	2	14.9	3.68	6.5	< 0.3	0.51	37	91
	R6W	1	16.0	3.73	6.4	1	0.55	46	112
	R6W	2	15.5	3.71	6.2	0.7	0.53	51	114
	SARDI 4	1	15.4	3.26	7.4	0.6	0.47	51	126
	SARDI 4	2	15.7	3.31	7.6	0.8	0.5	42	118
	PT 23	1	15.8	3.44	7.3	0.4	0.59	51	122
	PT 23	2	15.6	3.44	6.7	0.6	0.48	35	99
Grampians	PT 23	1	14.3	3.50	5.5	0.5	0.28	72	107
	PT 23	2	14.7	3.37	5.8	0.6	0.34	74	112
	1654	1	14.6	3.39	5.8	0.4	0.38	48	99
	1654	2	14.4	3.38	5.9	0.2	0.22	70	118
	BVRC 12	1	14.6	3.38	6.0	0.2	0.26	72	118
	BVRC 12	2	14.7	3.40	5.9	0.1	0.23	77	123
	BVRC 30	1	14.4	3.43	5.9	< 0.1	0.21	66	107
	BVRC 30	2	14.6	3.41	5.9	0.3	0.37	70	112
	PT15	1	13.4	3.25	6.3	< 0.3	0.38	70	134
	R6W	1	13.5	3.30	6.1	< 0.3	0.36	69	130

Margaret River	1654	1	14.2	3.36	6.6	0.4	0.38	48	106
	1654	2	14.4	3.36	6.5	0.4	0.41	53	98
	PT 15	1	14.4	3.51	5.7	0.6	0.33	46	78
	PT 15	2	14.6	3.52	5.7	0.6	0.33	56	96
	WA Sel'n	1	14.5	3.55	5.7	0.4	0.33	56	112
	WA Sel'n	2	14.6	3.51	5.7	0.5	0.3	53	107
	BVRC 12	1	15.4	3.51	5.8	0.5	0.4	59	96
	BVRC 12	2	16.3	3.48	6.5	0.2	0.19	54	86

Table 41. Wine analysis of 2015 Vintage Shiraz clones at bottling.

Region	Clone	Replicate	Alc. (% v/v)	pH	TA (g/L)	G+F (g/L)	VA (g/L)	FSO_2 (mg/L)	TSO_2 (mg/L)
Barossa	R6W	1	16.9	3.78	5.2	0.6	0.30	< 4	< 4
	R6W	2	18.0	3.60	6.8	0.6	0.32	20	58
	PT15	1	17.1	3.74	5.3	0.5	0.26	< 4	< 4
	PT15		17.1	3.83	5.0	0.5	0.27	< 4	< 4
	BVRC 30	1	17.0	3.69	5.8	0.4	0.26	29	60
	BVRC 30	2	17.0	3.68	5.7	0.4	0.24	30	59
	BVRC 12	1	17.2	3.40	7.3	0.5	0.25	20	52
	BVRC 12	2	17.2	3.46	6.9	0.5	0.25	19	52
	SARDI 7	1	16.5	3.73	5.6	0.3	0.34	< 4	< 4
	SARDI 7	2	16.4	3.78	5.3	0.3	0.28	24	45
	SARDI 4	1	16.8	3.65	6.4	0.4	0.26	24	55
	SARDI 4	2	17.1	3.65	6.5	0.5	0.27	21	52
	1654	1	17.1	3.63	6.1	0.5	0.21	27	59
	1654	2	17.0	3.61	6.2	0.4	0.22	27	58
Grampians	PT15	1	14.1	3.65	5.0	0.3	0.37	33	63
	1654	1	13.6	3.48	5.3	0.4	0.28	38	76
	1654	2	13.5	3.50	4.9	0.5	0.29	38	79
	PT 23	1	14.4	3.72	4.7	< 0.3	0.38	37	70
	PT 23	2	14.5	3.72	4.8	0.4	0.40	39	70
	BVRC12	1	14.1	3.61	4.8	0.4	0.37	42	68
	BVRC12	2	14.3	3.64	4.9	0.3	0.38	37	66
	BVRC30	1	14.3	3.65	4.9	< 0.3	0.38	46	80
	BVRC30	2	14.2	3.63	4.9	0.3	0.41	27	58
	R6W	1	14.5	3.54	5.2	0.6	0.35	53	105
	R6W	2	14.6	3.63	4.9	0.5	0.35	32	64
	BESTS	1	14.5	3.53	4.9	0.4	0.36	49	86
	BESTS	2	14.0	3.54	5.2	0.3	0.40	34	75
Margaret River	1654	2	13.4	3.57	5.3	0.4	0.30	41	85
	BVRC12	1	14.2	3.53	5.5	0.6	0.29	41	75
	BVRC12	2	14.5	3.57	5.4	0.7	0.29	42	75
	PT15	1	14.0	3.59	5.0	0.6	0.29	39	72
	WA SEL'N	1	14.8	3.63	5.3	0.6	0.30	41	69
	WA SEL'N	2	14.6	3.64	5.1	0.6	0.30	39	65
Riverland	R6W	1	16.8	3.94	6.1	0.6	0.52	< 4	< 4
	1654	1	16.7	3.86	6.0	0.5	0.49	< 4	< 4
	PT 23	1	16.4	3.86	6.1	0.4	0.47	< 4	< 4
	SARDI 7	1	16.3	3.87	5.9	0.4	0.23	25	55
	BVRC30	1	16.9	4.03	5.5	0.6	0.47	21	44

BVRC12	1	16.9	3.89	6.0	0.6	0.51	< 4	< 4
SARDI 4	1	16.5	3.87	5.7	0.4	0.31	27	57

Table 42. Wine analysis of 2016 Vintage Shiraz clones at bottling.

Region	Clone	Replicate	Alc. (% v/v)	G+F (g/L)	pH	TA (g/L)	FSO_2 (mg/L)	TSO_2 (mg/L)	VA (g/L)
Riverland	SARDI 7	1	12.1	< 0.3	3.55	6.0	< 4	30	0.44
	SARDI 7	2	12.5	< 0.3	3.57	6.0	7	27	0.42
	BVRC 12	1	14.4	0.6	3.65	5.4	9	22	0.43
	BVRC 12	2	13.4	0.4	3.58	5.6	< 4	28	0.43
	BVRC 30	1	13.2	< 0.3	3.58	6.2	< 4	27	0.51
	BVRC 30	2	12.6	< 0.3	3.55	6.1	< 4	29	0.50
	R6W	1	14.3	0.6	3.66	5.9	< 4	23	0.44
	SARDI 4	1	15.6	0.3	4.02	5.4	21	43	0.38
	SARDI 4	2	15.4	0.7	3.98	5.5	23	47	0.43
	1654	1	14.6	0.6	3.9	5.5	17	47	0.42
	1654	2	15.0	0.7	4.06	5.4	< 4	18	0.42
	PT 23	1	15.3	0.6	4.02	5.4	26	48	0.44
	PT 23	2	15.1	0.6	3.96	5.4	23	46	0.43
Barossa	BVRC 30	1	13.2	0.4	3.65	5.1	< 4	37	0.43
	BVRC 30	2	12.6	< 0.3	3.68	5.1	< 4	35	0.39
	SARDI 4	1	13.2	0.4	3.73	6.1	13	27	0.47
	SARDI 4	2	13.7	0.4	3.68	5.8	< 4	36	0.39
	SARDI 7	2	14.6	0.6	3.69	5.5	< 4	20	0.44
	1654	2	13.5	0.4	3.69	5.2	6	19	0.41
	PT 15	1	13.4	< 0.3	3.87	5.2	22	49	0.37
	PT 15	2	13.4	0.3	3.83	5.3	19	53	0.38
Grampians	BVRC 12	1	14.1	0.5	3.49	5.3	5	23	0.5
	BVRC 12	2	14.2	0.6	3.52	5.3	7	49	0.5
	BVRC 30	1	14.0	0.5	3.54	5.2	4	20	0.51
	BVRC 30	2	14.1	0.4	3.53	5.2	4	22	0.51
	R6	2	13.9	0.4	3.56	5.1	< 4	57	0.51
	1654	1	12.6	< 0.3	3.47	5.4	18	46	0.46
	1654	2	13.5	0.5	3.5	5.4	7	52	0.48
	PT 23	1	14.4	0.5	3.49	5.2	< 4	20	0.51
	BESTS	1	14.1	0.4	3.5	5.3	< 4	21	0.52
	BESTS	2	13.8	0.5	3.49	5.3	< 4	22	0.5
Margaret River	BVRC 12	1	14.1	0.7	3.55	5.1	33	66	0.36
	BVRC 12	2	13.9	0.7	3.55	5.1	37	77	0.36
	1654	1	14.2	0.5	3.66	4.9	39	77	0.36
	1654	2	14.2	0.6	3.63	5.1	40	79	0.37
	PT 15	1	14.6	0.7	3.52	5.4	39	72	0.36
	PT 15	2	14.5	0.8	3.5	5.3	39	72	0.37
	WA SEL'N	1	14.1	0.7	3.51	5	35	67	0.36
	WA SEL'N	2	14.1	0.7	3.52	5	36	70	0.35