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CSIRO

Enhanced varieties and clones to meet the challenges of climate change and deliver lower alcohol wines



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Enhanced varieties and clones to meet the challenges of climate change and deliver lower alcohol wines

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Table of Contents

		page
1.	**Abstract**	1
2.	**Executive Summary**	2-3
3.	**Background**	**4**-6
4.	**Project Aims and Performance Targets**	**7**
5.	**Method**	
	5.1 Climate	8
	5.2 The CSIRO Germplasm collection	8
	5.3 Phenology	9
	5.4 Growth characteristics	9
	5.5 Fruit composition	9-10
	5.6 Small-scale winemaking	10
	5.7 Wine analysis and assessment	10
	5.8 Data management	11
6.	**Results/Discussion**	
	6.1 Climate	12-15
	6.2 Phenology	16-33
	6.3 Growth characteristics	34-44
	6.4 Berry composition	45-81
	6.5 Wine evaluation	82-125
7.	**Outcome/Conclusion**	126-128
8.	**Recommendations**	129-130
9.	**Appendix 1: Communication**	131-132
10.	**Appendix 2: Intellectual Property**	133
11.	**.Appendix 3: References**	134-135
12.	**Appendix 4: Staff**	137
13.	**Appendix 5: Outputs/activities**	138-143
14.	**Appendix 6: Budget Reconciliation (lodged separately)**	

1. Abstract

Wine grape varieties originating from a diverse range of countries and regions, and advanced CSIRO breeding lines, have been assessed. The results demonstrate that there are significant opportunities to broaden the genetic base of varieties available to the Australian industry to enhance its capability to meet the challenges associated with climate change, limited water supply and drought and high alcohol content. Specifically, varieties have been identified with short seasonality to improve water use efficiency; small canopies to minimise transpiration and improve water use efficiency; long seasonality to ripen in cooler conditions; optimal pH and titratable acidity and unique aroma and flavour profiles.

2. Executive summary

The capability of the Australian wine industry to meet challenges associated with predicted climate change scenarios may be limited by the restricted number of winegrape varieties currently grown. These challenges include the consistent supply of quality product in a variable and changing environment; the effects of temperature on fruit composition and wine attributes; a compression of the seasonal cycle, leading to an inability to process fruit at optimum maturity and, adapting to limited water supply and drought. Furthermore, there is a need to address the issue of high alcohol content in many Australian wines. The potential to exploit genetic variability to meet these challenges through adoption of alternative varieties has been assessed. A systematic approach has been used to phenotype more than 500 varieties and specific clones (i.e. a total of 880 genotypes) in the CSIRO germplasm collection for traits, considered to be important to the Australian wine industry, for climate change adaptability. In addition, 10 advanced CSIRO breeding lines and 100 CSIRO 'Best selections' identified in previous small-scale winemaking studies were included.

The varieties, originating from a diverse range of countries and regions were assessed over four seasons in the Sunraysia region of North West Victoria, a major hot irrigated region. The study included close monitoring of vine phenology (i.e. budburst, flowering, veraison and harvest date); measurement of key growth characteristics (shoot fruitfulness, leaf area index, berry weight and estimates of yield); measurement of berry composition (total soluble solids, pH, titratable acidity, malic and tartaric acids, yeast assimilable nitrogen, mineral ion concentrations and in red varieties, total anthocyanins and phenolics) and, the production and evaluation of small- scale wines of selected varieties and CSIRO breeding lines. The information has been stored in a searchable form in FileMaker Pro13 database.

The project has demonstrated that there are significant opportunities to further broaden the genetic base and range of varieties with traits that will enable the Australian industry to adapt to future climate change scenarios and address the issue of high levels of alcohol. Adoption of enhanced varieties will enable the industry to maintain its production base in existing regions, despite the impacts of climate change, and minimise the significant economic, social and environmental costs of re-positioning and developing wine grape production and processing in new regions. The study has identified varieties, grown under hot conditions with:

- short seasonality to improve water use efficiency in hot irrigated regions. Such varieties may also be useful to diversify the production base in cooler regions
- smaller canopies to minimise transpiration, improve water use efficiency and improve production efficiencies, if used in high density plantings
- long seasonality to ripen in cooler conditions and extend the season
- optimal pH and titratable acidity levels which may enable crops to be harvested at lower maturity to produce lower alcohol wines
- improved composition (pH, organic acids, colour) and wine flavour and aroma which may provide opportunities for marketing at higher price points.

The study has described significant, but stable variation in key traits across the varieties driven by the genotype, despite varying environmental conditions (i.e. climate, site, vine age and management practices). These included a difference of six weeks in budburst, a two-fold difference in seasonality (i.e. budburst to harvest)

with harvest spread over a four month period, five-fold differences in fruitfulness and LAI, 15-fold differences in berry weight, 10-fold differences in berry mineral ion concentrations and large differences in key measurements of fruit composition (pH, titratable acidity, organic acid composition, yeast assimilable nitrogen and, in red varieties, total anthocyanins and phenolics). Very few of the imported varieties had low pH levels which would enable minimal acid addition for pH adjustment. In contrast, a number of the CSIRO breeding lines had excellent fruit composition with optimal pH and acid levels. Those selections showing good wine quality attributes warrant further development for release to industry.

Interrogation of the data has shown that varieties with the most optimal fruit composition for winemaking were those that ripened early in the season and had small berries. Late ripening varieties and those with large berries could be expected to have high pH with low levels of total soluble solids, titratable acidity and yeast assimilable nitrogen. The study also showed that the ability of a variety to achieve acceptable levels of maturity also had a strong genetic component. Ripening of some varieties appeared to cease at low maturities whereas in other varieties it increased rapidly, possibly due to wilting in hot conditions. Varieties with high TSS, would be expected to have higher tartrate and YAN levels and in some seasons, higher pH. The study has provided strong evidence, across the varieties, linking key measurements of berry composition used by industry (i.e. pH, titratable acidity, organic acid composition and yeast assimilable nitrogen) with berry mineral concentration, particularly K, S and Mg, canopy size (LAI) and berry weight. Further research is required to understand the genetic control of these processes and enhance the understanding of the relationships described. Of particular interest would be studies into uptake and transport of minerals into the berry and their role in pH buffering and ion balance. The potential to manipulate fruit composition of individual varieties through control of vine vigour by irrigation, pruning or canopy management and nutrition management warrants further research.

Small-scale winemaking has been used to identify a range of interesting varieties and CSIRO breeding lines that have potential for industry use. For red wine production, the strong relationship between berry anthocyanins and wine spectral properties is of particular interest as it shows that varieties with high levels of berry anthocyanins, a trait that was very stable across seasons, can be selected to produce wines with high colour for use as alternative varieties or for blending where existing varieties may be impacted by climate change. Furthermore, a small component of the project involving measurement of wine aroma and flavour compounds using GCMS has shown that wine of 11 varieties tested, displayed unique flavour and aroma profiles. Further research to assess the potential of the technology to identify wines from across a broader range of varieties; develop links with sensory profiling by trained panels; and describe relationships with flavour and aroma precursors in berries would have high scientific merit and value to the industry, particularly in developing objective measures of fruit quality for existing and alternative varieties.

3. Background

Major challenges for the Australian wine industry are the consistent supply of quality product in a variable and changing environment; adapting to limited water supply and drought; improving the economic sustainability of growers through increased production efficiency (i.e. higher yields for efficient use of natural resources) with reduced inputs (i.e. labour, fuel, water and chemicals) and a need to address the issue of the high alcohol content of many Australian wines, which has been steadily increasing over the last decade (Clingeleffer 2010). The capability of the wine industry to address these challenges, through adoption of vine management practices, is limited by the dominant effects of season to season variation, not only on productivity, but also on berry growth and development, fruit composition and final wine quality attributes (Clingeleffer 2010). The limited number of winegrape varieties grown commercially in Australia may restrict the capability of the wine industry to meet challenges associated with predicted climate change scenarios. These challenges include the consistent supply of quality product in a variable and changing environment; the effects of temperature on fruit composition and wine attributes; a compression of the seasonal cycle leading to an inability to process fruit at optimum maturity and adapting to limited water supply and drought (Clingeleffer and Davis 2011). Adoption of alternative varieties to broaden the genetic base of the Australian industry offers the potential to assist the industry to meet future challenges (Possingham et al. 1990; Clingeleffer and Davis 2011).

CSIRO established a grapevine germplasm collection of varieties, clones, *Vitis* species and rootstocks in the early 1960s with further introductions occurring in subsequent years to broaden the genetic base of material available in Australia. The collection, which contains more than 600 wine varieties and clones, was located at the former CSIRO Merbein research station in a hot irrigated region with a climate similar to regions which supply more than 60% of the Australian wine industry. It has now been relocated to the CSIRO Irymple property. The CSIRO variety collection has been an important source of material for distribution to all states, vine improvement groups and industry (Smith and Antcliff 1975); used in studies to identify alternative varieties and clones suited to hot irrigated regions (Antcliff 1973, Antcliff 1976, Clingeleffer and Davis 2011 and references therein); varietal identification (Antcliff 1976, Thomas et al. 1994) and to provide genetic material for winegrape breeding purposes which commenced in 1964 (Antcliff 1972, Antcliff 1980, Clingeleffer 1985, Clingeleffer et al. 1985). The winegrape variety collection has been an important resource used to describe both the major and minor varieties grown in Australia under standard conditions (Antcliff 1976, 1979, 1983, Kerridge and Antcliff 1996, Kerridge and Gackle, 2005, Possingham and Antcliff 1980). The performance of the varieties in the collection and breeding lines has been assessed in a standard manner with the use of small-scale winemaking (Antcliff and Kerridge 1975, Kerridge 1983). For breeding purposes, emphasis was placed on the use of varieties having distinctive flavour, high acidity, low pH and late maturity in the expectation that they may impart these characters to their progeny (Kerridge et al. 1987). Winegrape varieties adopted from the breeding program include Tarrango (Antcliff 1979), suited to a light red wine style (Kerridge et al. 1992); Taminga (Antcliff, 1982), suited to an aromatic white wine style (Kerridge et al. 1992); Tyrian and Rubienne which are grown for full bodied red wines and Cienna, which is currently grown for the production of wines with low alcohol (Clingeleffer 2008).

The comparative studies across the wine grape varieties in the collection have contributed significantly to the identification of alternative varieties which have performed better than standard varieties with respect to yield, berry composition, wine flavour and wine quality attributes (Clingeleffer et al. 1987, Kerridge et al. 1987a,b,c,d, Kerridge et al. 1988). A number of these varieties are now grown in Australia for commercial wine production. Alternative varieties of interest for the production of full bodied red wines with good yields were Cabernet Franc, Calzin, Ruby Cabernet, Tinta Molle and Touriga (Kerridge et al. 1987a). Others of interest from a wine perspective, but lower yielding were Abouriou, Barbera, Egiodola, Fresia, Lagrein, Lambrusco, Malbec, Marzemino, Petit Verdot, Raboso Piave, Saperavi, Souzao, St Macaire, Tannat, Teroldego and Ughetta. Varieties identified for the production of light bodied reds (Kerridge et al. 1987b) with good yields were Carignan, Mavronemeas, Mondeuse, Negro Amaro, Poerinha, Sangiovese, Sumoll and Tarrango together with the lower yielding varieties, Gamay, Grignolino and Valdigue.

Alternative varieties identified for the production of aromatic white wines (Kerridge et al.1987c) with good yields were Bacchus, Canada Muscat, Malvasia Moscato, Sauvignon Blanc, Taminga, Traminer and Verdelet together with the lower yielding varieties, Irsay Oliver, Montils, Morio Muskat, Muscat Ottenel, Muscat a Petits Grains Rouge, Siegerrebe, Viognier and White Muscat. For delicate white wines (Kerridge et al. 1987d) the promising varieties with good yields were Merbein Seedless, Rieslina and Solvorino and those with relatively low yields, Emerald Riesling, Gouais, Muller Thurgau and Rotgifler. Varieties identified for full bodied white wines (Kerridge et al. 1988) with good yields were Bianco d'Alessano, Chenin Blanc, Colombard, Goyura and Trebbiano and those with relatively lower yields were Ehrenfelser, Mtsvane and Fetyaska.

More recent collaborative studies between CSIRO and a major wine company (1998-2005) aimed to identify varieties suited to Asian market wine styles, with an emphasis on distinct flavour characteristics. This project also enabled the assessment of introductions not available in the earlier studies. The most promising white wine varieties identified were Bacchus, Bianca, Early Muscat, Ezerfurtu, Fiano, Flora, Slankamenka, Harslevelu, Marsanne, Malvasia Moscato, Orange Muscat, Petit Manseng, Verdejo Bianco and Vermentino. The most promising red varieties were Graciano, Lagrein, Montepulciano, Sangiovese, Saperavi, Tannat and Tempranillo (Clingeleffer and Davis 2011).

In this project, a systematic approach was used to phenotype winegrape varieties in the CSIRO germplasm collection and determine genetic diversity of traits considered to be important to enable the industry to meet the future challenges identified above (Clingeleffer and Davis 2011). It aimed to deliver varieties and clones with optimal berry composition, good colour and flavour when grown under hot conditions; varieties with high water use efficiency based on short seasonality and high fruit to leaf ratios; varieties suited to extend the harvest intake period to minimise the effects of compressed seasons and varieties suited to production of wine with lower alcohol content. Given that climate change is compressing phenological events within the seasonal cycle, the study included phenological developmental stages (ie. budburst, flowering, veraison and harvest date at a moderate sugar level, 22 ^{o}Brix). It also included growth characteristics such as fruitfulness (bunches/shoot), maximum canopy size, berry weight, bunch weight, yield estimates and fruit composition (total

soluble solids, titratable acidity, pH, organic acids, yeast assimilable nitrogen, total anthocyanins and phenolics, and targeted measurement of anthocyanin profiles). Small-scale winemaking was also undertaken on selected genotypes to supplement the collection of data on key phenological, growth and production characteristics.

The systematic phenotyping across the extensive germplasm has contributed to measurement of diversity and distinctness across the varieties, clones and advanced breeding lines. Such information will underpin future research in varietal improvement involving advanced scientific fields of molecular physiology, genomics and metabolomics and accurate assessment using modern technologies of fruit and wine composition (i.e. flavour, aroma, colour and phenolics).

From an industry perspective, the adoption of enhanced varieties will contribute to an economically sustainable future wine industry which meets the challenges associated with a variable and changing climate, drought and limited water supply and a requirement to produce lower alcohol wines. This can be achieved in existing regions and minimises the significant economic, environmental and social costs of re-positioning and developing in new regions with respect to winegrape production and processing (i.e. irrigation, vineyards, wineries, bottling and packaging and transport infrastructure). Adoption of enhanced varieties identified in the project should enable the industry to maintain its position as a major wine exporter, contribute to Australia's wealth and provide opportunities to produce wines for marketing at higher price points. The identification of varieties and clones for improvements in water use efficiency (i.e. short season varieties to reduce seasonal water requirements and varieties with a high crop water use index) will also contribute a positive environmental benefit. Furthermore, production from varieties suited to lower alcohol wine production will facilitate the industry's ability to address the issue of high alcohol in many Australian wines and in the longer term, provide a basis for attitudinal change within the Australian community toward consumption of wines with excellent flavour and aroma and lower alcohol.

4. Project Aims and Performance targets

The aims of the project were to:

1. Phenotype varieties, clones and advanced breeding lines under hot conditions in the CSIRO winegrape germplasm collection for key phenological, growth and compositional characteristics relevant to meeting future industry challenges.

2. Use the phenotypic information together with detailed targeted assessment of fruit and wine composition of the promising types (ie. for organic acid composition and anthocyanins) to:
   - identify varieties and clones and advanced breeding lines suited to hot climate winegrape production which will allow the industry to meet the challenges of wine production in a changing and variable climate including higher temperatures
   - identify varieties and clones with high water use efficiency based on short seasonality and/or high fruit to leaf ratios as a surrogate for crop water use index (crop yield to water transpired)
   - identify varieties suited to production of wines with lower alcohol contents.

3. Provide underpinning research knowledge for ongoing genetic diversity research and future varietal enhancement based on flavour, aroma, colour, phenolics and tannin analysis incorporating the advanced scientific fields of molecular physiology, genomics and metabolomics.

The detailed planned outputs and performance targets from the original application (2009-2012) and variations (2012- 2015) are presented in Appendix 5. An extension of the project was also approved in December 2014 to provide another season of data for the 'Best Selections' (see below) to facilitate identification of those with potential for further development and evaluation under semi-commercial conditions; assess the performance of four advanced selections in the Riverland and undertake ICP mineral analyses of berry samples collected in 2010 and 2014. The latter was used to establish relationships between berry potassium concentration, organic acids and pH. The project extension also provided further opportunity for consultation with industry in relation to outcomes of the AGWA WGG 1401 project, "A case study for the oversight of Australian Grapevine Foundation Assets".

5. Method

5.1 Climate

Weather records of maximum temperature, minimum temperature and rainfall for Mildura were sourced from the Bureau of Meteorology. The recording station at Mildura airport is situated within 3 km of both the former CSIRO Merbein research station where phenotyping was conducted in the 2009/10 and 2010/11 seasons and the CSIRO Irymple site, used in subsequent seasons (2011/12 to 2014/15).

5.2 The CSIRO germplasm collection

The CSIRO germplasm collection was established as own rooted vines in three vine plots with a 3.3 x 1.8 m (row x vine) spacing in Northwest Victoria, at the former CSIRO Merbein Research Station site (34^{o} 13'41''S, 142^{o} 2' 38''E) in a hot irrigated region with a climate similar to regions that supply more than 60% of the Australian wine industry. The collection of varieties, clones, *Vitis* species and rootstocks was first established in the early 1960's with further introductions occurring in subsequent years to widen the genetic base of material available in Australia. The varietal materials used initially in this study (seasons 2009/10 and 2010/11) were 20-40 years old. At the Merbein site, the vines were trained on 1.4 m high, single or narrow T-trellis (0.3m) and managed without cultivation using undervine herbicide application and mowing of the mid-row, mechanically hedged without shoot positioning and irrigated with a moderate irrigation regime (i.e. an application of 5 ML/ha) using undervine sprinklers. Due to the impending closure of the Merbein site, the entire germplasm collection was relocated to the CSIRO Irymple site between 2008 and 2011 with some vines producing a small crop in 2012. At the CSIRO Irymple site the three vine plots are planted with a 3.0 x 1.8 m vine spacing and managed on a high 1.6 m trellis, mechanically hedged and irrigated by drip irrigation with an annual application of 5 ML/ha.

Germplasm available to the project included:

1. 566 wine varieties (including 300 not held elsewhere in Australia), clonal material, some with unique characteristics for a number of key wine varieties and a number of table and dried grape varieties that were assessed for potential use as a winegrape or included for comparative purposes. In total 880 varietal entries were included in the study. The varietal entry details listed in this report represent the best information available at the time of undertaking the project.
2. 100 selections from CSIRO's breeding program which were identified with potential through small-scale winemaking assessment in preceding seasons (2006-2008). These selections will be referred to as 'Best Selections'.
3. Ten 'advanced' selections, five white and five red varieties also developed by CSIRO which had been shown to have superior wine characteristics compared to standard varieties. The potential of these lines was identified in tastings with wine companies. During the course of the project six of these advanced lines (three white and three red) were established in 1 ha plantings in Victoria and grafted on 140 Ruggeri rootstock. The other four selections

(two white and two red) were established on Ramsey and 1103 Paulsen rootstocks in the Riverland of South Australia.

5.3 Phenology

Key phenological developmental stages (budburst, flowering, veraison and predicted harvest date at 22 ^{o}Brix) were recorded across the varieties. This was achieved by visual weekly monitoring of all varieties from the commencement of each stage, and in the case of harvest date, weekly collection of berry samples to assess maturation post veraison. The data were then used to determine the date for 50% budburst of the final shoot number, 50% of the total bunches flowering and 50% of berries through veraison. Predicted harvest date was determined at 22 ^{o}Brix, based on fruit maturation curves collected over the course of ripening. For analysis and comparative purposes, the dates were converted to numbers with 1 July of each year equal to zero.

5.4 Growth characteristics

Key growth characteristics assessed for all varieties were:

1. Shoot fruitfulness (bunches/shoot), determined for 10 representative shoots per variety in spring.
2. Maximum leaf area index (LAI), measured prior to harvest using a LiCor canopy meter.
3. Yield, estimated visually using the following categories: very low (<2 kg/vine), low (2-7 kg/vine), medium (7-15 kg/vine), high (15-25 kg/vine) and very high (>25 kg/vine).
4. Tolerance of disease, particularly to downy mildew, was also determined visually in the wet 2010/11 season by observing canopy and fruit condition.

5.5 Fruit composition

At harvest in each season, samples of 100 berries were frozen and retained to measure berry composition. Berry samples were gently crushed in a plastic bag to extract juice. The juice samples were then centrifuged at 4^{o}C (Beckman J25i; Beckman Coulter Inc., Fullerton, CA, USA) for 15 min. @ 5930 g. The clear juice was decanted and used for assessments of juice composition and frozen for later analysis of ions. Compositional measurements included:

1. Total soluble solids (^{o}Brix) analysed with a hand-held digital refractometer (Atago Co, Ltd, Japan).

2. Titratable acidity and pH determined by autotitration (Metrohm Ltd., Herisau, Switzerland).
3. Organic acids (tartrate and malate) and yeast assimilable nitrogen (YAN) determined by FTIR techniques (Oenofoss^{TM})

4. Total berry anthocyanins and phenolics (red varieties) determined using spectral techniques (Iland et al. 2000), following preparation of berry samples that were ground under liquid Nitrogen.
5. Targeted assessment of berry anthocyanin profiles (red varieties) by HPLC (Downey and Rochfort 2008) following preparation of berry samples ground under liquid Nitrogen.
6. Mineral element analyses of cations, phosphorus and sulphur by inductively coupled plasma-optical emission ICP spectrometry (Spectro ARCOS, Spectro Analytical Instruments, Kleve, Germany, and Thermo Scientific iCAP 6000 Series, Thermo Electron Limited, Cambridge, United Kingdom) following acid digestion of centrifuged juice samples.

Measures of TSS, pH, TA, malic acid, tartaric acid, YAN, berry anthocyanins, berry total phenolics and all mineral elements were made on frozen/thawed berry samples except for TSS, pH and TA in 2010 and 2011 from Merbein.

5.6 Small scale winemaking

Each season, small-scale wine lots were made from selected varieties and CSIRO breeding lines with 10-30 kg of fruit at CSIRO Merbein (seasons 2009/10 and 2010/11), DEPI Victoria at Irymple (seasons 2011/12 to 2014/15) and by AWRI at the University of Adelaide Hickinbotham Roseworthy Wine Science Laboratory winemaking facility, Waite Campus, Adelaide (2014/15). In all cases must samples were taken for pH, titratable acidity and total soluble solids readings. The standard protocols involved cooling the fruit to approximately 1^{o}C prior to crushing and fermenting, the use of EC118 yeast, pH adjustment through the winemaking process using tartaric acid, aiming for levels of 3.4 - 3.5 pH, free sulphur adjustment to 30 ppm using SO_2, and the judicious use of $CuSO_4$ to prevent and address problems with reductive characters (i.e. H_2S), and addition of diammonium phosphate (DAP) to minimise issues with stuck ferments. Red wine ferments were conducted on skins until they were pressed off at approximately 2 ^{o}Brix. All ferments were conducted at 18-20 ^{o}C until they reached dryness (<2 g/L residual sugar), then cold stabilised at 0-1 ^{o}C and racked twice to remove yeast and potassium bi-tartrate lees. All wines were sterile filtered using Millipore equipment prior to bottling in 375 mL screw capped bottles with N_2 used in the ullaged headspace. Wines were stored at 16 ^{o}C until required.

5.7 Wine analysis and assessment

Prior to bottling, assessment was made of the pH, total acidity and free sulphur levels. The total addition of tartaric acid for pH adjustment at the various stages of the winemaking process was also determined. For red wines, spectral characteristics of the red wines were evaluated according to the methods of Sommers and Evans (1977), about two months after bottling using a GBC 918 UV/Vis spectrophotometer (GBC Scientific Equipment Pty. Ltd., Dandenong Australia). The assessment of 74 key wine aroma and flavour compounds was also conducted on a limited number of targeted wines using solid-phase micro-extraction (SPME) gas chromatography mass spectrometry (GCMS) techniques according to the methodology described by Boss et al. (2014). The future potential of varietal wines and those from CSIRO

breeding lines have been assessed over the course of the study through integration of the results from assessments by CSIRO staff, key industry stakeholders, industry groups and commercial wine companies.

5.8 Data management

FileMaker Pro 13 was used for storage and management of the data generated in the project. Interrogation of these data was largely undertaken using Excel for sorting and classification. The database also contains background information from the literature on origins, regional use and wine style; vine health status and data from previous CSIRO small-scale winemaking evaluations. For the varieties assessed in this project, digital images of CSIRO photographic records relating to ampelographic characteristics have been included where available in the data base. Digital images of each variety growing in the field at the CSIRO Irymple property were also recorded in season 2014/15.

6. Results/Discussion

6.1 Climate

An overview of the daily climatic conditions recorded over the period of the phenotyping study is presented in Figure 6.1.1 and as monthly means in Figure 6.1.2. The monthly means are also tabulated in Tables 6.1.1, 6.1.2 and 6.1.3 for the five seasons in which vine phenology data were collected. Significant differences in climatic conditions were recorded over the six years of the study. In particular there was a wide range in total rainfall, ranging from 184 mm in 2012/13 to 924 mm in 2010/11 when significant rain was recorded in most months (Figure 6.1.1, 6.1.2, Table 6.1.3). The variation in mean monthly maximum temperature between seasons was highest in November, ranging from a monthly mean of 32.5 ^{o}C in 2009/10 to 26.2 ^{o}C in 2010/11 although differences of more than 4 ^{o}C were also recorded in September, December, February and March (Table 6.1.1). Similarly, the variation in mean monthly minimum temperatures was also highest in November, ranging from 17.3 ^{o}C in 2009/10 to 10.9 ^{o}C in 2013/14 (Table 6.1.1).

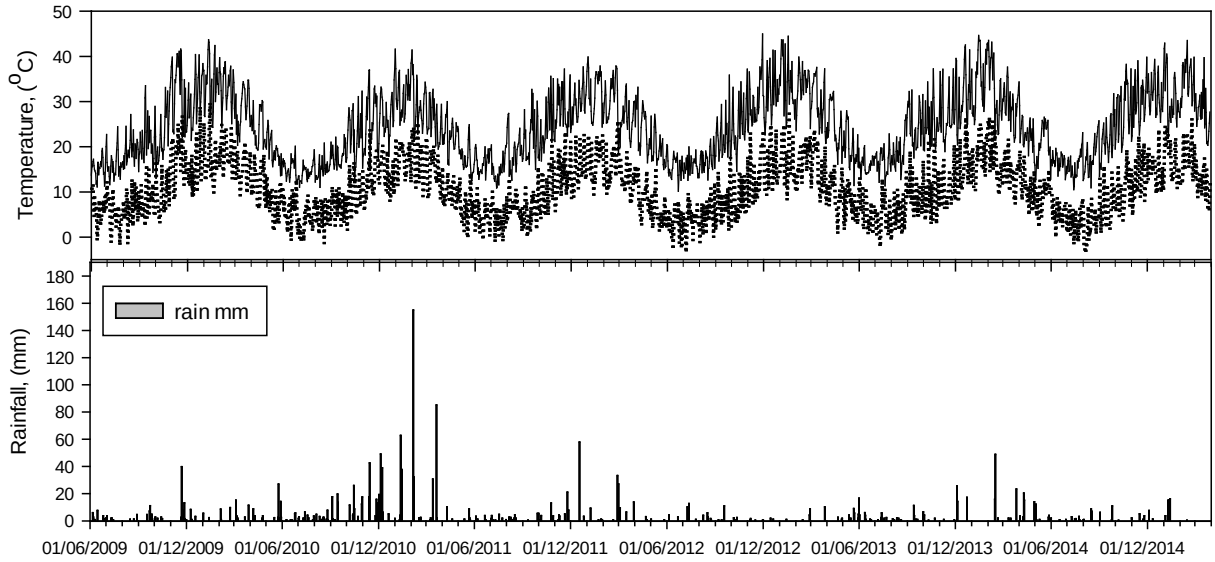


Figure 6.1.1. Daily maximum temperature (^{o}C), minimum temperature (^{o}C) and rainfall (mm) for Mildura, July 2009 to March 2015 (source: Bureau of Meteorology). Solid lines are maximum temperature. Dotted lines are minimum temperature.

The 2009/10 season was relatively hot and dry with a total rainfall of 289 mm, associated with significant rain events in November, March and May (Table 6.1.3). In the 2009/10 season, mean monthly maximum temperatures were equal to, or exceeded the five year mean, particularly in August and November (Table 6.1.1) while the mean monthly minimum temperatures were higher than the five year mean in all months except January, particularly in July, November, February and April (Table 6.1.2). In contrast, the weather conditions in the 2010/11 season were cool and very wet with a total rainfall of 924 mm, with significant rainfall events in all months, particularly over the growing season (August- March) (Table 6.1.3). In

2010/11 mean monthly maximum temperatures were lower than in all other seasons in all months, except June (Table 6.1.1) and mean monthly minimum temperatures were equal to or lower than the five year mean in all months except October (Table 6.1.2). The total rainfall in season 2011/12 of 304 mm occurred mainly in August, October, November, December and March (Table 6.1.3). Mean monthly maximum temperatures in 2011/12 were higher than the five year mean early in the season (i.e. August, September and October) but cooler in summer (December-March) (Table 6.1.1). Mean monthly minimum temperatures in 2011/12 were significantly higher than the five year mean in August and October, but lower in September and for the period from February to June (Table 6.1.2). Season 2012/13 was the driest of all the seasons in the study with 184 mm, recorded mainly outside the growing season in July and June (Table 6.1.3). It was a very hot season with mean monthly maximum temperatures exceeding the five year mean in all months except August and June, particularly in October, February, March and April (Table 6.1.1). In contrast, mean monthly minimum temperatures were generally lower than the five year mean in the early part of the season July-November and in January and April but higher in February and March. The total rainfall in season 2013/14 of 301 mm occurred mainly in December, February, March, April and May (Table 6.1.3). The 2013/14 season was also very hot with the mean monthly maximum temperature being exceeded in all months except November and April, but particularly in July, January and May. Similarly mean monthly minimum temperatures were higher for most months, except for the exceptionally low value recorded for November 2013.

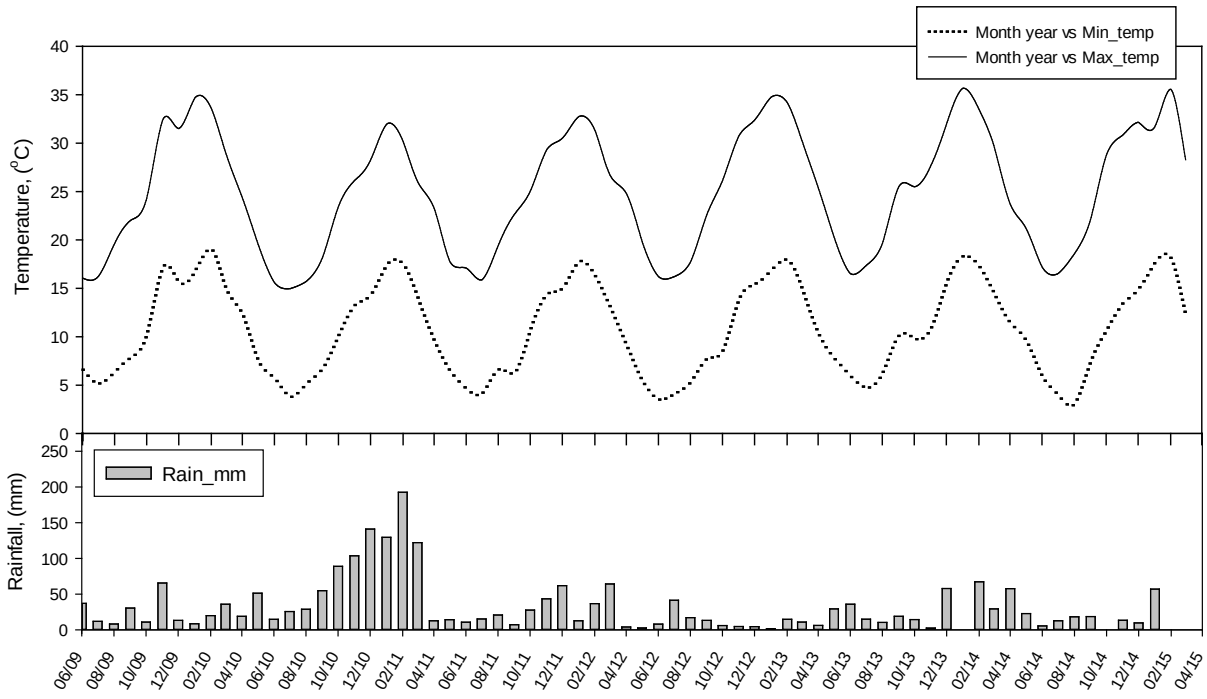


Figure 6.1.2. Mean monthly maximum temperature (°C), minimum temperature (°C) and rainfall (mm) for Mildura, July 2009 to March 2015 (source: Bureau of Meteorology).

Table 6.1.1. Mean monthly maximum temperature (^{o}C) for Mildura, July 2009 - June 2014 (source: Bureau of Meteorology). The five year mean and range are also included. Values highlighted in blue and red indicate exceptionally low and high monthly values across the seasons, respectively.

Season	**2009/10**	**2010/11**	**2011/12**	**2012/13**	**2013/14**	**mean**	**range**
July	16.2	15.0	15.9	16.2	17.3	16.1	2.3
August	19.6	15.7	19.4	17.7	19.6	18.4	3.9
September	22.1	18.3	22.7	22.6	25.5	22.2	4.4
October	24.3	23.5	25.1	26.1	25.5	24.9	2.6
November	32.5	26.2	29.3	30.8	27.7	29.3	6.3
December	31.5	28.3	30.5	32.4	32.0	30.9	4.1
January	34.7	32.0	32.7	34.7	35.7	34.0	3.7
February	33.6	30.2	31.3	34.2	33.5	32.6	4.0
March	28.9	26.0	26.7	30.3	29.8	28.3	4.3
April	24.3	23.2	24.8	25.4	23.7	24.3	2.2
May	19.5	17.7	19.8	20.3	21.2	19.7	3.5
June	15.6	17.1	16.2	16.5	17.2	16.5	1.6

Table 6.1.2. Mean monthly minimum temperature (^{o}C) for Mildura, July 2009 - June 2014 (source: Bureau of Meteorology). The five year mean and range are also included. Values highlighted in blue and red indicate exceptionally low and high monthly values across the seasons, respectively.

Season	**2009/10**	**2010/11**	**2011/12**	**2012/13**	**2013/14**	**mean**	**range**
July	5.2	3.8	4.2	4.1	4.7	4.4	1.4
August	6.4	5.2	6.6	5.3	6.2	5.9	1.4
September	7.9	6.8	6.3	7.7	10.1	7.8	3.8
October	10.3	10.2	10.8	8.6	9.8	9.9	2.2
November	17.3	13.3	14.4	13.9	10.9	14.0	6.4
December	15.6	14.4	15.1	15.5	15.6	15.2	1.2
January	16.9	17.5	17.8	16.9	18.3	17.5	1.4
February	19.0	17.5	16.3	18.0	17.3	17.6	2.7
March	14.9	13.9	13.1	15.0	14.6	14.3	1.9
April	12.3	9.6	9.1	10.4	11.5	10.6	3.2
May	7.5	6.4	5.5	7.8	9.6	7.4	4.1
June	5.7	4.6	3.5	5.9	5.9	5.1	2.4

Table 6.1.3. Mean monthly rainfall (mm) for Mildura July 2009 - June 2014 (source: Bureau of Meteorology). Values highlighted in blue and red indicate exceptionally low and high monthly values across the seasons, respectively.

Season	**2009/10**	**2010/11**	**2011/12**	**2012/13**	**2013/14**
July	11.8	25.6	15.2	41.4	14.8
August	8.2	28.8	20.8	17.0	10.4
September	30.4	54.8	7.2	13.2	18.8
October	10.8	88.8	27.6	6.0	14.4
November	65.6	103.6	43.4	4.6	2.4
December	13.2	141.0	61.8	4.4	57.8
January	8.4	129.4	12.6	1.2	0.6
February	19.8	192.6	36.6	14.6	67.2
March	35.8	122.0	64.2	10.8	29.2
April	18.8	12.6	4.0	6.2	57.6
May	51.2	14.2	2.6	29.2	22.8
June	14.6	10.6	8.0	35.8	5.4
Total	**288.6**	**924.0**	**304.0**	**184.4**	**301.4**

6.2 Phenology

6.2.1 Overview

Key phenological stages were assessed for the 566 wine varieties in the CSIRO Merbein collection in the 2009/10 and the 2010/11 seasons and at the CSIRO Irymple site in 2012/13 (veraison and predicted harvest dates only) and for all stages in 2013/14 when vines in the re-established collection were fully developed. Budburst was also recorded in 2015. It should be noted that extreme weather conditions in the cool, wet 2010/11 season (Tables 6.2.1.1, 6.2.1.2, 6.2.1.3) with record breaking rainfall events and high humidity led to significant issues with excessive canopy growth, fungal diseases (downy and powdery mildew, fruit splitting and development of bunch rots), compounded by significant leaf loss and delayed maturation. In that season many varieties did not achieve adequate levels of maturity for winemaking, even at the end of the season; hence it was difficult to determine predicted harvest date.

An overview of the distribution of phenological stages in the three seasons with complete data sets (2009/10, 2010/11 and 2013/14) for the 566 varieties, common to all years, is presented in Figures 6.2.1.1, 6.2.1.2, 6.2.1.3. In general, both the pattern and period of 50% budburst was reasonably consistent across the seasons ranging from 18 August through to 3 October in 2009/10; from 9 September through to 11 October in 2010/11 and from 22 August to 3 October in 2013/14. In all seasons, the peak of 50% budburst for the majority of varieties occurred in the second week of September (i.e. week 11). Highly significant correlations between seasons for 50% budburst date ($r = 0.47 - 0.68$) indicate a strong influence of genotype, accounting for 22 - 46% of the seasonal variation despite being planted at different locations, differences in vine age and different climatic conditions between seasons.

Across the varieties, the period and pattern of 50% flowering varied between seasons and appeared to be linked to climatic conditions (Figures 6.2.1.1, 6.2.1.2., 6.1.2.3). In the 2009/10 season, the flowering period ranged from 15 October through to 6 November, with a high proportion of the varieties flowering in week 18 following a period of high temperatures in late October and early November (Table 6.2.1.1). In contrast, in the cooler 2010/11 season (Table 6.2.1.1), flowering occurred between 25 October and 11 November and was more spread with a significant number of varieties flowering in weeks 17 and 18 with a peak in 19. The commencement of flowering in 2013/14 was very early, following high temperatures in September (Table 6.2.1.1), but spread over a more extended period than in the other seasons, ranging from 30 September to 7 November with a peak in flowering in week 16 with a significant numbers of varieties flowering in weeks 17 and 18. Highly significant correlations between seasons for 50% flowering date ($r = 0.50 - 0.62$) indicate a strong influence of genotype, accounting for 22-46% of the seasonal variation despite being planted at different locations, differences in vine age and different climatic conditions between seasons.

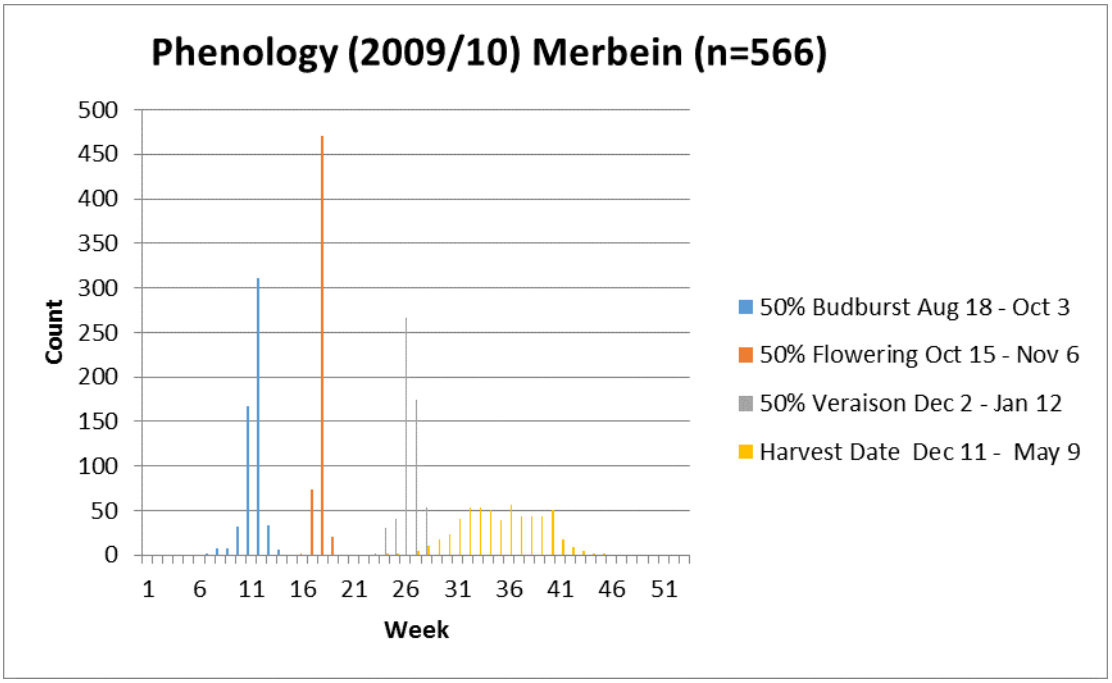


Figure 6.2.1.1. Distribution of the occurrence of key phenological stages (50% budburst, 50% flowering, 50% veraison and predicted harvest date at 22 ^{o}Brix) across the varieties established at the CSIRO Merbein site in the 2009/10 season, commencing 1 July. Count = n^{o} of varieties.

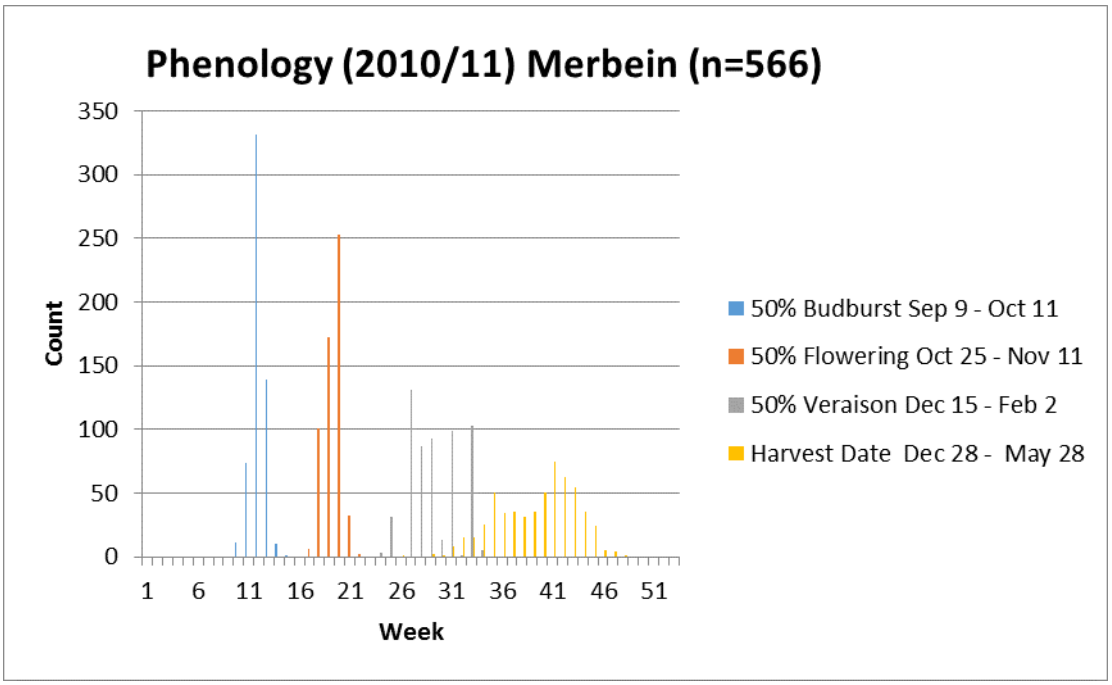


Figure 6.2.1.2. Distribution of the occurrence of key phenological stages (50% budburst, 50% flowering, 50% veraison and predicted harvest date at 22 ^{o}Brix) across the varieties established at the CSIRO Merbein site in the 2010/11 season, commencing 1 July. Count = n^{o} of varieties.

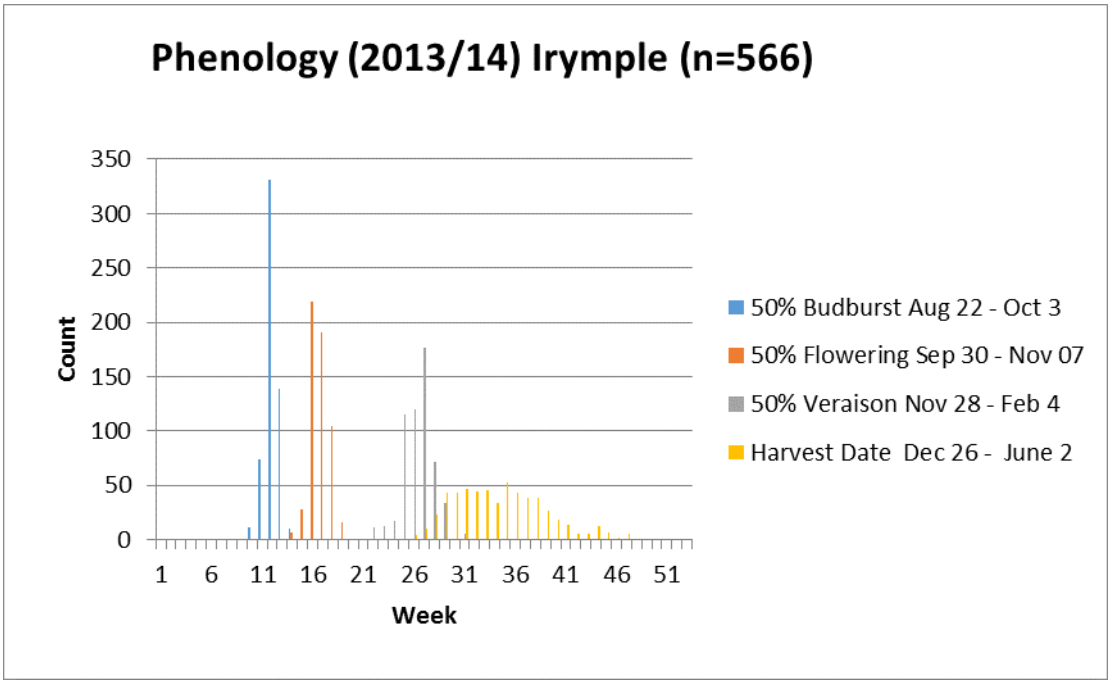


Figure 6.2.1.3. Distribution of the occurrence of key phenological stages (50% budburst, 50% flowering, 50% veraison and predicted harvest date at 22 ^{o}Brix) across the varieties established at the CSIRO Irymple site in the 2013/14 season, commencing 1 July. Count = n^{o} of varieties.

The period and pattern of 50% veraison varied between seasons, and as with flowering, appeared to be linked to climatic conditions (Figures 6.2.1.1, 6.2.1.2, 6.2.1.3). In the 2009/10 season, which had high maximum temperatures in November and December (Table 6.2.1.1), veraison across the varieties occurred over a relatively short period from 2December to 12 January with a peak period occurring in week 26. In contrast, in the cooler 2010/11 season (Table 6.2.1.1), veraison was more extended, ranging from 15 December to 2 February with a significant spread between weeks 26 and 32. In the 2013/14 season, which had a relatively cool November but a hot December and January (Table 6.2.1.1), veraison also occurred over an extended period from 28 November to 4 February with a peak occurring in the 27th week. Significant correlations between seasons for 50% veraison date (r = 0.20 - 0.58) indicate an influence of genotype, accounting for up to 34% of the seasonal variation despite being planted at different locations, differences in vine age and different climatic conditions between seasons.

In all seasons, the predicted date of harvest across the varieties extended over several months, from December to May (Figures 6.2.1.1, 6.2.1.2, 6.2.1.3). In the 2009/10 season the predicted harvest occurred between 11 December and 9 May, with most varieties reaching 22 ^{o}Brix between weeks 32 and 39. In contrast, harvest in the cool 2009/10 season was much later, extending from 28 December to 28 May with the majority of varieties reaching desired levels of maturity between week 34 and week 44 with a peak in week 41. In the 2013/14 season, the predicted harvest date ranged from 26 December to 6 June with most varieties ripe between the 29th

and 38th week. Highly significant correlations between seasons for the predicted harvest date (r = 0.56) indicate a strong influence of genotype, accounting for more than 30% of the seasonal variation, despite being planted at different locations, differences in vine age, different climatic conditions and different crop loads between seasons. However, correlations between predicted harvest date in each season and 50% budburst (r = 0.28 - 0.48), 50% flowering (r = 0.34 - 0.42) or 50% veraison (r = 0.13 - 0.44) were quite low suggesting that harvest date is only weakly linked to the timing of other key phenological events that occur earlier in the seasons. This was not unexpected taking into consideration the wide spread in predicted harvest dates in all seasons compared to other phenological events. It also suggests that ripening for each variety is unique in its response to environmental cues and potentially crop load.

6.2.2 Time of Budburst

Early and late bursting varieties were identified through interrogation of the phenology data collected over four seasons for varieties planted at the CSIRO Merbein site (2009/10 and 20010/11) and the CSIRO Irymple site (2013/14 and 2014/15). Selection was based on the mean date of 50% budburst over the four seasons and consistency of the results across the seasons, represented by the standard error value for each mean. Mean 50% budburst date for the selected early ripening white varieties ranged from 27 August (day 57) through to 10 September (day 71) (Table 6.2.2.1). Apart from the hybrid varieties from the USA (Leanoy and Canada Muscat) and Fernao Pires from Portugal, the origins of the early bursting white varieties are the Northern European wine producing countries and the North of France and Italy. Mean 50% budburst date for the selected early bursting red varieties covered a similar time frame (Table 6.2.2.2). As with the white varieties, the origins of most of the early bursting red varieties are in Northern Europe. The three GM selections (Table 6.2.2.1) are unnamed genotypes from the Geisenheim breeding program in Germany. The origins of Best's R3V47, an unidentified variety found in an old vineyard planted in Western Victoria from material collected in Europe, before *Phylloxera* caused extensive loss of plantings and varieties in the mid-late 1800s, is unknown. From an adaptive point of view, it is likely that early budburst provided an advantage to extend the season in the cooler, more Northern regions of Europe with shorter grower seasons, hence enabling growers to attain adequate maturity levels for wine production. From an Australian industry perspective it is possible that a number of the early bursting white and red varieties could provide useful alternatives in cooler regions. Budburst of most of the white varieties listed was earlier or equal to Chardonnay. For the red varieties, budburst was similar to Pinot Noir. In the warmer regions, the early bursting varieties could be used to extend the season, depending on their harvest date, although care in site selection would be important to avoid frost prone areas. Furthermore, a potential increase in irrigation requirements should also be considered if the length of the season from budburst to harvest is extended (i.e. seasonality, see section below).

Mean 50% budburst date for the selected late bursting white varieties ranged from 19 September (day 80) to 1 October (day 92) (Table 6.2.2.3). The origins of the late bursting white varieties tended to be more the Mediterranean regions of Europe with one variety from Hungary (Harslevelu) and one from central Asia (Agadaj). The

origins of three of the late bursting white varieties which were sourced from old vineyards planted in Western Victoria from material collected in Europe, before *Phylloxera* caused extensive loss of plantings and varieties in the mid-late 1800s, is unknown. Mean 50% budburst date for the selected late bursting red varieties ranged from 19 September (day 80) to 7 October (day 98) (Table 6.2.2.4). Budburst for a large number of these varieties was equal to or later than Cabernet Sauvignon. As with the white varieties, the origins of most of the late bursting varieties were the Mediterranean regions of Europe, the exceptions being Kardarka from Hungary and Cereza from Argentina and two hybrid varieties from the USA. The unidentified, three Australian sourced varieties were from vineyards in Western Victoria and the Yarra Valley established with material from pre-phylloxera vineyards in Europe. From an Australian industry perspective late bursting alternative varieties offer potential to overcome issues of compressed seasons associated with climate change if they ripen later than varieties currently grown. They may also be useful for planting in areas prone to early spring frosts. Depending on the length of their growing season (seasonality), varieties with delayed budburst could also contribute to savings in water as they offer potential to delay the commencement of irrigation.

Table 6.2.2.1. Early bursting white varieties, selected on mean date of budburst between 27 August and 10 September and consistency between seasons over four seasons (2009/10, 2010/11, 2013/14 and 2014/15). Data are presented as the mean number of days from 1 July with the standard error in brackets.

Variety	Mean Days (SE)	Country of origin
Banatski Muscat	57 (4.3)	Serbia
Grociana	63 (2.9)	Italy
GM 649-3	64 (2.9)	Germany
Radmilovaski Muscat	64 (3.3)	Serbia
Chardonnay Muscat	66 (4.9)	France
Baufrac	66 (2.8)	Italy
Demir Kapija	67 (4.2)	Macedonia
Leanoy	67 (2.6)	USA
Bianca	68 (5.6)	Hungary
Rabigato	69 (3.5)	Portugal
Ezerjo	69 (2.3)	Hungary
Fernao Pires	69 (2.3)	Portugal
Bacchus	69 (4.9)	Germany
GM 647-2	69 (2.0)	Germany
Traminer	69 (2.3)	France
Muller Thurgau	69 (2.3)	Germany
Canada Muscat	69 (2.0)	USA
GM 6495-1	69 (2.0)	Germany
Gyongyrizling	70 (2.3)	Hungary
Melon	70 (2.5)	France
Morio Muscat	70 (2.5)	Germany
Lignan Blanc	71 (3.5)	France
Arbois	71 (1.0)	France
Aucarot	71 (1.1)	France
Orange Muscat	71 (2.9)	France
Grey Riesling	71 (2.9)	Germany
Chardonnay	71 (2.9)	France
Siegrrebe	71 (2.9)	Germany
Beogradska Rana	71 (2.6)	Serbia

Table 6.2.2.2. Early bursting red varieties, selected on mean date of budburst between 27 August and 10 September and consistency between seasons over four seasons (2009/10, 2010/11, 2013/14 and 2014/15). Data are presented as the mean number of days from 1 July with the standard error in brackets. * 'Heritage' variety of unknown origin.

Variety	Mean Days (SE)	Country of origin
Opuzensia Rana	68 (3.0)	Serbia
Limberger	68 (1.7)	Austria
Dunkelfelder	69 (2.0)	Germany
Pinot Noir	69 (2.3)	France
Vespolina	69 (3.3)	Italy
Nebbiolo	69 (2.3)	Italy
Marzemino	70 (2.3)	Italy
Rabose Piave	70 (2.5)	Italy
Nebbiolo Chiavenas	70 (2.5)	Italy
Brachetto	70 (2.5)	Italy
Best's R3V47	71 (4.0)	Australia *
Sereksiya Black	71 (3.7)	Russia
Muscat a Petits Grains Rouge	71 (1.1)	France
Sangiovese	71 (2.9)	Italy
Aramon	71 (2.9)	France
Bastardo	71 (2.9)	Portugal
Nebbiolo Lampia	71 (2.6)	Italy

Table 6.2.2.3. Late bursting white varieties, selected on mean date of budburst between 19 September and 1 October and consistency between seasons over four seasons (2009/10, 2010/11, 2013/14 and 2014/15). Data are presented as the mean number of days from 1 July with the standard error in brackets. * 'Heritage' varieties of unknown origin.

Variety	Mean Days (SE)	Country of origin
Malvasia di Candia	92 (2.5)	Italy
Trebbiano	89 (1.1)	Italy
Duchess of Buccleuch	88 (1.2)	United Kingdom
Bianca d' Alessano	87 (1.9)	Italy
Best's R17V87A	86 (1.4)	Australia*
Monbadon	85 (1.1)	France
Seppelts #4	85 (1.1)	Australia*
La Reina	83 (4.8)	Spain
Harslevelu	83 (3.7)	Hungary
Tradura	83 (4.2)	Italy
Best's K	82 (3.8)	Australia*
Agadaj	80 (2.9)	Daghestan
Slankamenka	80 (3.4)	Serbia

Table 6.2.2.4. Late bursting red varieties, selected on mean date of budburst between 19 September and 7 October and consistency between seasons over four seasons (2009/10, 2010/11, 2013/14 and 2014/15). Data are presented as the mean number of days from 1 July with the standard error in brackets. * 'Heritage' varieties of unknown origin.

Variety	Mean Days (SE)	Country of origin
Semi de Goes	98 (4.6)	Spain
Montepulciano	94 (4.3)	Italy
Best's R1V8	92 (1.4)	Australia*
Uva di Troia	90 (1.2)	Italy
Negro Amaro	87 (2.1)	Italy
Danugue	87 (1.9)	France
Graytown R3#2	86 (4.4)	Australia*
Monastrell	86 (85)	Spain
Croatina	86 (0.5)	Italy
Mataro	83 (2.8)	France
Corvinon	84 (1.3)	Italy
Cinsaut	84 (0.7)	France
Marocain Noir	83 (2.3)	France
Graciano	83 (4.3)	Spain
Souzao	83 (4.8)	Portugal
Best's R4V14	83 (3.7)	Australia*
Kardaka	82 (4.2)	Hungary
Cereza	82 (3.5)	Argentina
Cabernet Sauvignon	82 (3.5)	France
Lindley	81 (3.8)	USA
Pescatore	80 (2.9)	Argentina
Marzemino	80 (2.7)	Italy
Urbana	80 (2.9)	USA
Negro Amaro	87 (2.1)	Italy
Caino	80 (2.9)	Spain
Best's R2V73	80 (3.4)	Australia*

6.2.3 Predicted harvest

Early and late ripening varieties were identified through interrogation of the phenology data collected over three seasons for varieties planted at the CSIRO Merbein site (2009/10 and 20010/11) and the CSIRO Irymple site (2013/14). Selection was based on the mean predicted harvest (i.e. the date when total soluble solids reached 22 ^{o}Brix, calculated from maturation data collected during ripening over the three seasons) and consistency of the results across the seasons, represented by the standard error value for each mean. In general, because of significant seasonal effects on the timing of harvest date described above (Figures 6.2.3.1, 6.2.3.2, 6.2.3.3), the variability between seasons was higher than that described for budburst above.

The early ripening white varieties listed in Table 6.2.3.1 reached the predicted harvest date between 7 and 30 January, significantly earlier than the benchmark variety, Chardonnay which had a mean predicted harvest date of 220 ±16.4 days (i.e. 4 February). Interestingly, the variability in predicted harvest date between seasons for four varieties, (i.e. Siegerrebe, Verdelho, Bianca and Bacchus) was very low despite the variability in climatic conditions during berry growth and ripening (Tables 6.2.1.1, 6.2.1.2, 6.2.1.3. and Figures 6.2.1.1. and 6.2.1.2). Apart from Seneca, a species hybrid from the USA, and Verdelho from Portugal, most of the early ripening varieties originate in the cooler Northern regions of Europe. The early ripening red varieties listed in Table 6.2.3.2 reached the predicted harvest date between 4 and 29 January. The predicted harvest date for the benchmark variety, Pinot Noir was the 25th of January. Apart from New York Muscat, a species hybrid from the USA, most of the earlier ripening red varieties originated in the cooler, more Northern regions of Europe.

From an adaptive point of view, early ripening in the cooler regions would enhance the ability to consistently reach adequate levels of maturity during the growing season. From an Australian industry perspective, adoption of varieties which ripen earlier than the benchmark varieties, Chardonnay and Pinot Noir, will enable extension of the harvest period and potentially reduce the effects of compressed seasons associated with climate change. Furthermore, early ripening varieties provide a potential opportunity to reduce the irrigation requirement and improve water use efficiency as the water requirements of vines in the post-harvest period is likely to be lower than those carrying a crop. A number of the early ripening varieties may provide useful alternatives for wine production in cooler regions.

Table 6.2.3.1. Early ripening white varieties, selected on mean predicted harvest date (22 ^{o}Brix) between 7 January and 30 January and consistency between seasons over three seasons (2009/10, 2010/11 and 2013/14). Data are presented as the mean number of days from 1 July with the standard error in brackets.

Variety	Mean Days (SE)	Country of origin
Seneca	191(9.9)	USA
Siegerrebe	197 (2.9)	Germany
Radmilovaski Muskat	200 (9.1)	Serbia
Petit Meslier	201 (9.9)	France
Verdelho	201 (6.5)	Portugal
Bianca	202 (4.9)	Hungary
Lignan Blanc	204 (6.0)	Italy
Gyongyrizling	206 (16.8)	Hungary
Zala Gyongye	206 (17.8)	Hungary
Grocanica	208 (8.9)	Italy
Bacchus	214 (2.9)	Germany
Precose de Malingre	214 (16.3)	France

Table 6.2.3.2. Early ripening red varieties, selected on mean predicted harvest date (22 ^{o}Brix) between 4 January and 29 January and consistency over three seasons (2009/10, 2010/11 and 2013/14). Data are presented as the mean number of days from 1 July with the standard error in brackets.

Variety	Mean Days (SE)	Country of origin
Marechal Foch	188 (16.0)	France
Leon Millot	198 (15.3)	France
Comtessa	203 (10.5)	Germany
Opuzensia Rana	205 (6.4)	Serbia
New York Muscat	206 (11.2)	USA
Pinot Precose	207 (10.0)	France
Muscat a Petits Grains Rouge	208 (8.2)	France
Pinot Noir	209 (12.1)	France
Abouriou	211 (12.7)	France
Medea	212 (13.3)	Hungary
Brachetto	213 (8.5)	Italy

The mean predicted harvest dates for the late ripening white varieties listed in Table 6.2.3.3 ranged from 30 March to 30 April. A significant number of these varieties were later ripening than the current commercial varieties, Doradillo (10 April) and Palamino (12 April). Interestingly, the variability in predicted harvest date between seasons for Doradillo was very low despite the variability in climatic conditions during berry growth and ripening (Tables 6.2.1.1, 6.2.1.2, 6.2.1.3. and Figures 6.2.1.1. and 6.2.1.2.). While a number of the late ripening varieties have their origins in the Mediterranean regions of Spain, France and Italy, the list also includes four varieties from Hungary and one variety from Daghestan in central Asia. The two unidentified varieties sourced in Australia were from vineyards in Western Victoria established with material from pre-phylloxera vineyards in Europe. The mean predicted harvest dates for the late ripening red varieties listed in Table 6.2.3.4 ranged from 2 to 23 April. All ripened later than commercial varieties grown for red wine production in Australia. The majority of these varieties originated in the Mediterranean regions of France, Italy, Portugal and Greece. The five unidentified varieties sourced in Australia were from vineyards in Western Victoria and the Yarra Valley that were established with material from pre-phylloxera vineyards in Europe.

Adoption of late ripening varieties to extend the wine grape production season and ripen in cooler conditions offers the industry a strategy to combat hotter harvest conditions and the issue of compressed seasons associated with climate change. However, it is likely that such varieties may have a higher irrigation water requirement due to the extended seasons, although from a water use efficiency perspective this may be off-set if such varieties are capable of ripening larger crops.

Table 6.2.3.3. Late ripening white varieties, selected on mean predicted harvest date (22 ^{o}Brix) between 30 March and 30 April and consistency over three seasons (2009/10, 2010/11 and 2013/14). Data are presented as the mean number of days from 1 July with the standard error in brackets. * 'Heritage' varieties of unknown origin.

Variety	Mean Days (SE)	Country of origin
La Reina	304 (11.4)	Spain
Gros Meslier	303 (6.7)	France
Catarratto	298 (8.4)	Italy
Putzscheere	296 (6.0)	Hungary
Agadaj	296 (6.5)	Daghestan
Monbadon	291(8.5)	France
Furmint	291 (22.6)	Hungary
Best's A	291 (8.3)	Australia*
Mantua de Pilas	289 (13.5)	Spain
Slankamenka	289 (7.7)	Serbia
Seppelt's #4	287 (11.4)	Australia*
Palamino	284 (16.1)	Spain
Doradillo	282 (1.67)	Spain
Trajadura	282 (8.9)	Italy
Keknyelu	281 (17.1)	Hungary
Naza Valenciana	279 (11.9)	Spain
Canocazo	278 (7.8)	Hungary
Gouais	278 (12.1)	France
White Vernaccio	278 (14.7)	Italy
Malvasia di Candia	276 (8.8)	Italy
Malvasia Istria	272 (6.7)	Italy

Table 6.2.3.4. Late ripening red varieties, selected on mean predicted harvest date (22 ^{o}Brix) between 2 April and 23 April and consistency over three seasons (2009/10, 2010/11 and 2013/14). Data are presented as the mean number of days from 1 July with the standard error in brackets. * 'Heritage' varieties of unknown origin.

Variety	Mean Days (SE)	Country of origin
Graytown R3#2	297 (14.2)	Australia*
Mavro Romeico	295 (4.6)	Greece
Best's R1V54	295 (13.1)	Australia*
Uva di Troia	290 (11.3)	Italy
Best's R4V14	289 (10.5)	Australia*
Best's R1V12	289 (14.5)	Australia*
Jurancon Noir	287 (9.0)	France
Aspiran	285 (13.8)	France
Grec Rose	285 (16.5)	France
Cionoria	285 (11.3)	Italy
Montepulciano	283 (13.3)	Italy
Corvinon	283 (6.0)	Italy
Best's 22	282 (5.0)	Australia*
Aubun	282 (6.1)	France
Negro Amaro	281 (3.4)	Italy
Caino	279 (7.6)	Portugal
Molinara	279 (14.2)	Italy
Mavro Naussis	278 (7.5)	Greece
Pescatore	277 (10.4)	Italy
Tinta Carvalha	277 (11.0)	Portugal
Kavadarski Drenak	276 (3.1)	Portugal

6.2.4 Seasonality

Interrogation of the database was also used to identify varieties with short and long seasonality, defined as the period between budburst and predicted harvest date. Highly significant correlations between seasons for seasonality across the varieties ($r = 0.50$) indicate a strong influence of genotype, accounting for 25% of the seasonal variation despite being planted at different locations, differences in vine age and different climatic conditions between seasons. The results are presented in Tables 6.2.4.1 - 6.2.4.4.

Overall, the mean values over three seasons for seasonality across the varieties shows a two-fold difference, ranging from 111 days to 226 days for the white varieties, Perle de Csaba and Gros Meslier respectively and 114 days to 216 days for the red varieties, Marechal Foch and for the unidentified Australian sourced variety, Best's R1V54 (Tables 6.2.7 - 6.2.12.). The respective distributions of seasonality across the white and red varieties, presented in Figures 6.2.4.1 and 6.2.4.2.for each of the three seasons, describe the influence of season on seasonality. For the white varieties in 2009/10, the distribution was almost normal, with seasonality ranging from 14 weeks to 33 weeks, with the majority of varieties

falling in the range from 20 - 30 weeks and a peak at 21 - 22 weeks (Figure 6.2.4.1). In contrast, in the cool, wet 2010/11 season, the pattern of distribution for the white varieties was skewed toward longer seasonality ranging from 15 - 35 weeks with the majority of varieties falling in the range from 22 - 32 weeks with a peak at 29 - 30 weeks. In 2013/14 the distribution was skewed toward short seasonality ranging from 15-36 weeks with the majority of varieties falling in the range from 18-26 weeks with a peak at 21 weeks. Similar patterns of distribution in seasonality were also recorded for the red varieties (Figure 6.2.4.2). In 2009/10, the distribution was almost normal with seasonality ranging from 12 weeks to 33 weeks with the majority of varieties falling in the range from 19 - 28 weeks and a peak at 23 weeks. In contrast, in the cool, wet 2010/11 season, the pattern of distribution for the red varieties was skewed toward longer seasonality ranging from 18-35 weeks with the majority of varieties falling in the range from 23 - 30 weeks with a peak at 28 - 30 weeks. In 2013/14 the distribution was slightly skewed toward short seasonality ranging from 13-37 weeks with the majority of varieties falling in the range from 18-28 weeks with a peak at 24 - 25 weeks.

White and red varieties with short seasonality are listed in Tables 6.2.4.1 and 6.2.4.2, respectively. No commercial varieties that are currently grown in Australia, were identified with short seasonality (Table 6.2.4.1). In contrast, the list for red varieties with short seasonality includes a number of commercial varieties, i.e. Pinot Noir, Muscat a petits grains rouge, Cabernet Sauvignon and Gamay (Table 6.2.4.2). Apart from the USA varieties, Seneca (white) and New York Muscat (red), most of the varieties with short seasonality originate from the cooler, more northern regions of Europe. From an adaptive perspective, varieties with short seasonality offer distinct advantages in these cooler regions enabling growers to adequately and consistently ripen the fruit in cooler regions. From an Australian industry perspective, varieties with short seasonality could provide useful alternatives for cooler regions, provide opportunities to reduce water consumption in warmer irrigated regions and reduce inputs for pest and disease control.

White and red varieties with long seasonality are listed in Tables 6.2.4.3 and 6.2.4.4, respectively. More than half of white the varieties identified had longer seasonality than the commercial benchmark varieties, Doradillo (203 days) and Palamino (207 days) (Table 6.2.4.3). There were no commercial red Australian varieties identified with long seasonality (Table 6.2.2.4). With the exception of three Hungarian varieties, (the white varieties Keknyelu and Furmint and the red variety, Cegled Szepe), the majority of the varieties listed with long seasonality originated in the Mediterranean regions of France, Italy, Spain, Portugal and Greece. There was one unidentified white variety and seven unidentified red varieties sourced in Australia from vineyards in Western Victoria and the Yarra Valley that were established with material from pre-phylloxera vineyards in Europe. From an adaptive perspective, the varieties with long seasonality may have been selected because they ripened when conditions at harvest were cooler and possibly because they were able to adequately ripen large crops. Given predicted temperature scenarios associated with climate change in Australia, adoption of varieties with long seasonality may be useful to both extend the harvest period and ripen the crop under cooler conditions in late autumn. However, issues of extended periods required for irrigation and pest and disease management must also be taken into account.

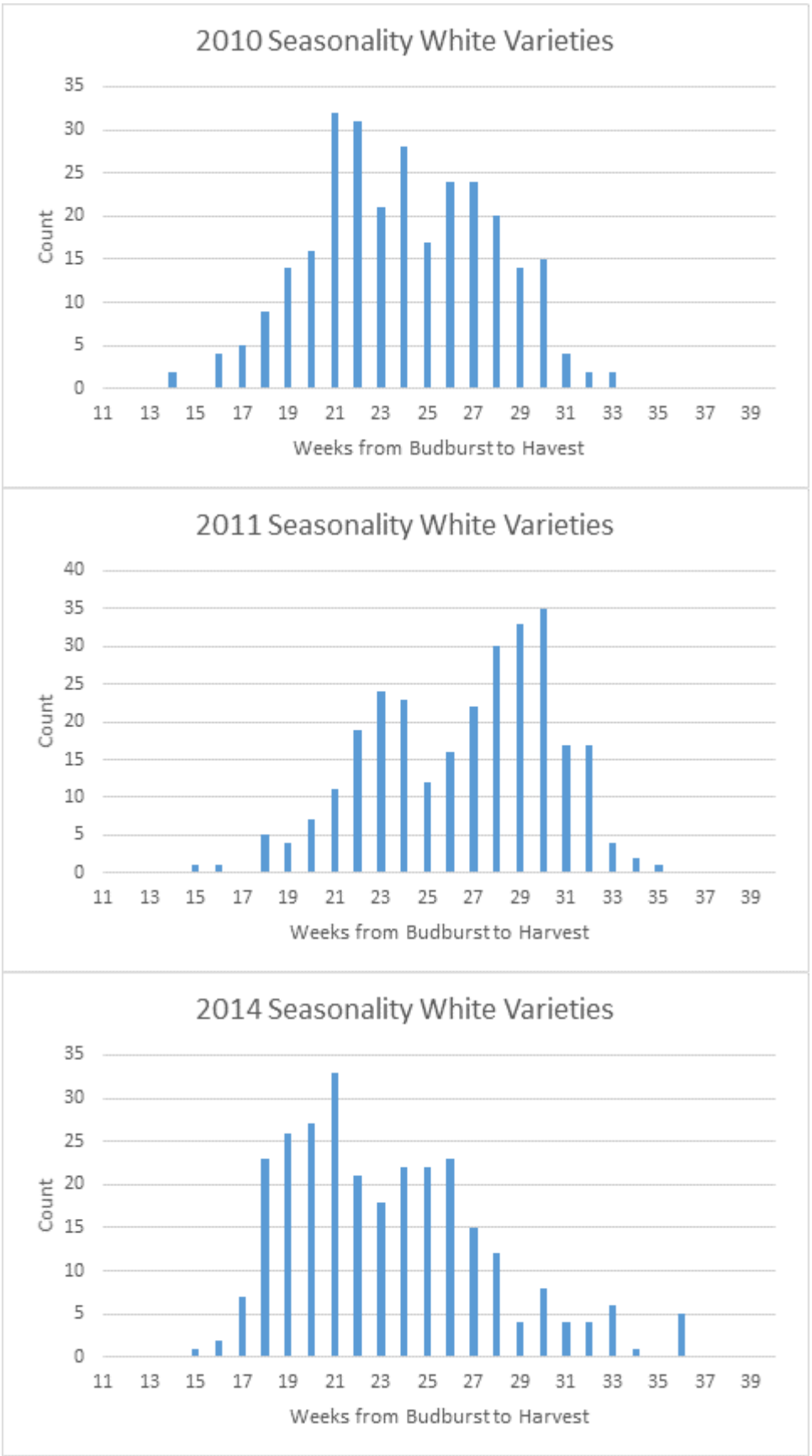


Figure 6.2.4.1. Distribution in seasonality (i.e. the period from budburst to predicted harvest date at 22 ^{o}Brix) for white varieties across three seasons, 2009/10, 2010/11 and 2013/14 (N=284). Count = n^{o} of varieties.

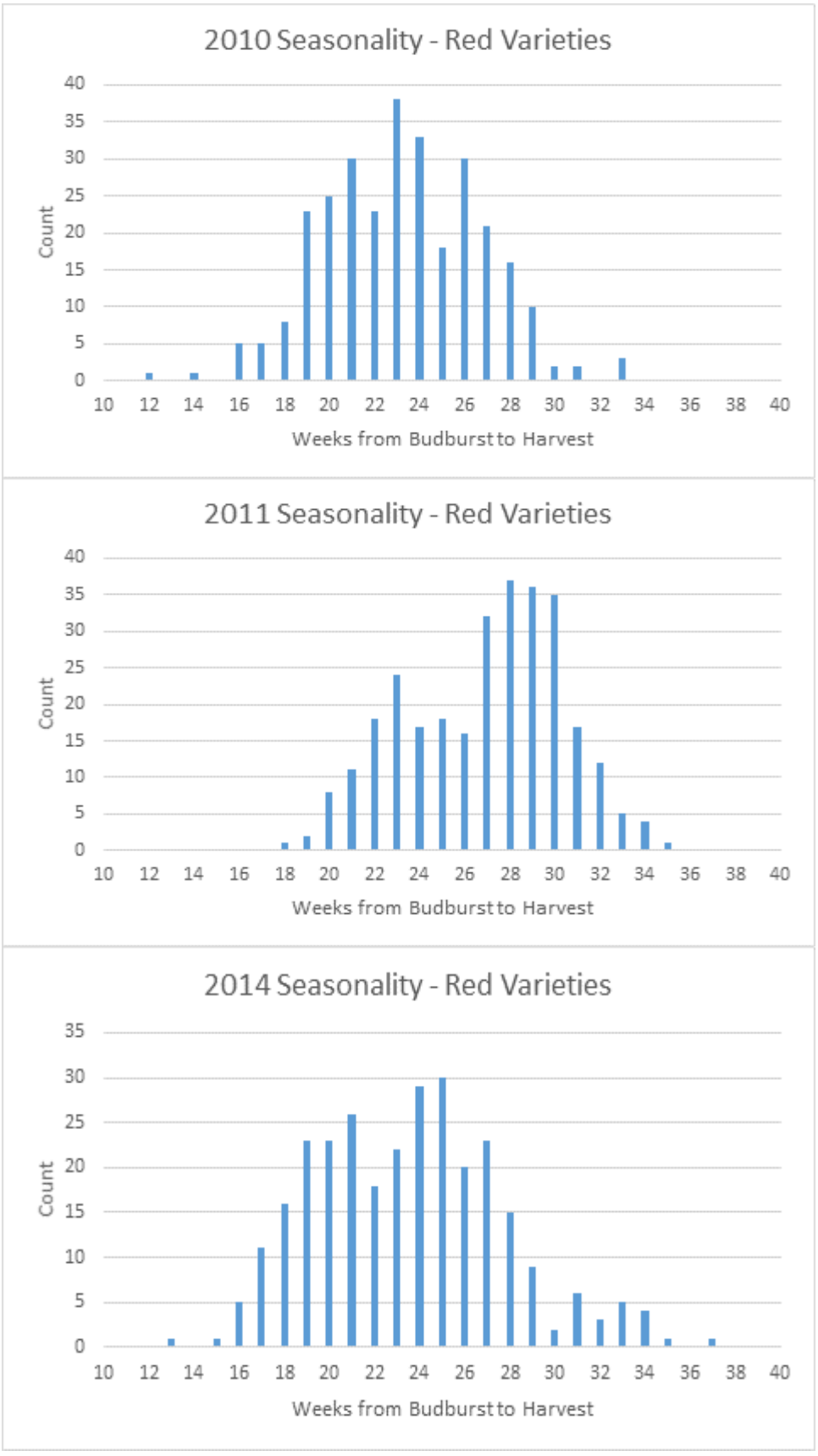


Figure 6.2.4.2. Distribution in seasonality (i.e. the period from budburst to predicted harvest date at 22 ^{o}Brix) for red varieties across three seasons, 2009/10, 2010/11 and 2013/14 (N=294). Count = n^{o} of varieties.

Table 6.2.4.1. White varieties with short seasonality (days from budburst to predicted harvest date) selected on the mean value and consistency over three seasons (2009/10, 2010/11 and 2013/14). Data are presented as the mean number of days from budburst to predicted harvest date with standard errors in brackets.

Variety	**Days (s.e.)**	**Country of origin**
Perle de Csaba	111(4.2)	Hungary
Seneca	119 (12.0)	USA
Verdelho	121 (7.8)	Portugal
Petit Meslier	122 (5.2)	France
Siegerrebe	126 (2.2)	Germany
Ezerfurtu	134 (3.8)	Hungary
Sauvignon	135 (11.5)	France
Bianca	136 (5.5)	Hungary
Auxerrois	140 (7.9)	France
Muscat Ottonel	140 (14.6)	France
Riesling Italico	141 (9.3)	Italy
Schonburger	142 (7.1)	Germany
Precose de Malingre	143 (15.2)	France
Bacchus	143 (4.0)	Germany
Luglienga	144 (11.4)	Italy
Ehrenfelser	146 (12.6)	German
Grocanica	146 (11.1)	Italy

Table 6.2.4.2. Red varieties with short seasonality (days from budburst to predicted harvest date) selected on the mean value and consistency over three seasons (2009/10, 2010/11 and 2013/14). Data are presented as the mean number of days from budburst to predicted harvest date with standard errors in brackets.

Variety	**Days (s.e.)**	**Country of origin**
Marechal Foch	114 (12.9)	France
Leon Millot	121 (13.3)	France
New York Muscat	130 (8.1)	USA
Pinot Precose	135 (7.8)	France
Pinot Noir	135 (7.1)	France
Muscat a petits grains rouge	137 (6.7)	France
Abouriou	139 (7.0)	France
Delaware	140 (12.5)	USA
Comtessa	139 (10.8)	Germany
Medea	134 (9.2)	Hungary
Opuzensia Rana	139 (3.3)	Serbia
Grignolino	147 (19.4)	Italian
Cabernet Sauvignon	150 (1.2)	France
Gamay	150 (13.1)	France
Egiodola	150 (10.8)	France

Table 6.2.4.3. White varieties with long seasonality (days from budburst to predicted harvest date) selected on the mean value and consistency over three seasons (2009/10, 2010/11 and 2013/14). Data are presented as the mean number of days from budburst to predicted harvest date with standard errors in brackets. * ‘Heritage’ variety of unknown origin.

Variety	**Date**	**Country of origin**
Naza Valenciana	200 (7.7)	Spain
Canocazo	201 (5.2)	Spain
White Vernaccio	202 (16.1)	Italian
Gouais	202 (8.8)	France
Keknyelu	202 (20.0)	Hungarian
Seppelts#4	202 (12.9)	Australia*
Doradillo	203 (3.8)	Spain
Palamino	207 (14.2)	Spain
Furmint	209 (23.8)	Hungary
Monbadon	209 (8.1)	France
Mantua de Pilas	211 (16.2)	Spain
Slankamenka	213 (13.6)	Serbia
Catarratto	214 (9.8)	Italy
Agadaj	217 (9.9)	Daghestan
Putzcheere	218 (5.4)	Hungary
La Reina	224 (15.9)	Spain
Gros Meslier	226 (7.8)	France

Table 6.2.4.4. Red varieties with long seasonality (days from budburst to predicted harvest date) selected on the mean value and consistency over three seasons (2009/10, 2010/11 and 2013/14). Data are presented as the mean number of days from budburst to predicted harvest date with standard errors in brackets. * 'Heritage' varieties of unknown origin.

Variety	Date	Country of origin
Corvinon	199 (5.8)	Italy
Caino	200 (9.2)	Portugal
Uva di Troia	201 (12.1)	Italy
Cegled Szepe	202 (16.8)	Hungary
Best's 22	203 (4.0)	Australia*
Best's R2V20	203 (20.1)	Australia*
Molinara	204 (11.2)	Italy
Gueche Noir	206 (15.0)	France
Aspiran	206 (13.1)	France
Best's R24V14	207 (12.70)	Australia*
Cionoria	208 (14.0)	Italy
Grec Rose	209 (14.2)	France
Jurancon Noir	210 (5.9)	France
Best's R2V73	211 (16.0)	Australia*
Graytown R3#2	213 (15.6)	Australia*
Best's R1V12	213 (13.5)	Australia*
Mavro Romeico	213 (22.5)	Greece
Best's R1V54	216 (15.5)	Australia*

6.2.5 Conclusions from phenology data

A systematic approach has been used to collect data on the timing of key phenological stages over three seasons for more than 500 wine varieties, originating from a diverse range of countries and regions, growing in a hot region. In any season, there were no or very weak correlations between predicted harvest date and the timing of budburst, flowering or veraison, an indication that events prior to harvest had little influence on the timing of harvest and that the ripening process is under strong genetic control. Based on phenology, the results show that there is significant varietal diversity to meet the future challenges associated with climate change. These include early and late ripening varieties to extend the harvest period and reduce the impacts of compressed harvest periods and, in the latter case, ripen in cooler conditions. Furthermore, varieties with short seasonality may offer potential to reduce irrigation requirements and improve water use efficiency. Early ripening varieties with short seasonality may also be useful to diversify the production base in cooler regions.

6.3 GROWTH CHARACTERISTICS

6.3.1 Shoot fruitfulness

Shoot fruitfulness measures of varieties and clones (n = 808) were recorded in spring 2009/10 and 2010/11 for mechanically hedged vines located at the CSIRO Merbein site, with spurs retained varying in length from 1 - 6 nodes and in 2013 for more tightly mechanically pruned vines located at the CSIRO Irymple site. The distribution of fruitfulness across the varieties in each season is presented in Figure 6.3.1. In 2009/10 there was a wide range in shoot fruitfulness, ranging from 0.4 to 2.4 bunches per shoot, although most varieties were in the 1.2 to 2.0 range. In 2010/11, shoot fruitfulness ranged from 0.0 to 2.8, with most varieties in the 0.8 to 1.8 range. In the 2013/14 season, younger vines at the CSIRO Irymple site tended to have higher fruitfulness, ranging from 0 to 3.5 bunches per shoot, with most in the 1.0 to 2.0 range. While there was a significant correlation for fruitfulness between seasons 2009/10 and 2010/11 ($r = 0.41$) for vines located at the same site, the correlations between 2009/10 and 2013/14 and between 2010/11 and 2013/14 were lower ($r = 0.14$ and 0.31, respectively). The low r values indicate differing varietal responses to environmental cues impacting fruitfulness (climate and site).

Varieties with low fruitfulness were generally seedless table and dried grape varieties which would normally be cane pruned. Winegrape varieties with consistent low fruitfulness across the 3 seasons (i.e. mean < 1.0) included Chali Sar, Malvasia Rioja, Bobal, Grec Rose, Lignan, Semis de Goes, Doradillo, Cereza, Refosco Pedunclo Rosso, Miguel de Arco, Danugue, Bonvedro, Raboso Piave and Gros Vert. It is likely that varieties with low fruitfulness at the basal nodes would have production problems and would require either cane or minimal pruning to improve fruitfulness using longer fruiting units. Varieties with high fruitfulness (mean > 2.0) included Varousset, Crinto, Picolit, Aurora, Raffiat de Moncade, Chancellor, Gueche Noir, Gamay, Troyen, Muller Thurgau, Furmint, Arnsburger, Riesling and Aligote. Interestingly, mean fruitfulness for clones of the same variety were generally quite close. For example, fruitfulness of 14 Riesling clones ranged from 1.6 (Neustadt 90 clone) to 2.5 (GM239 clone).

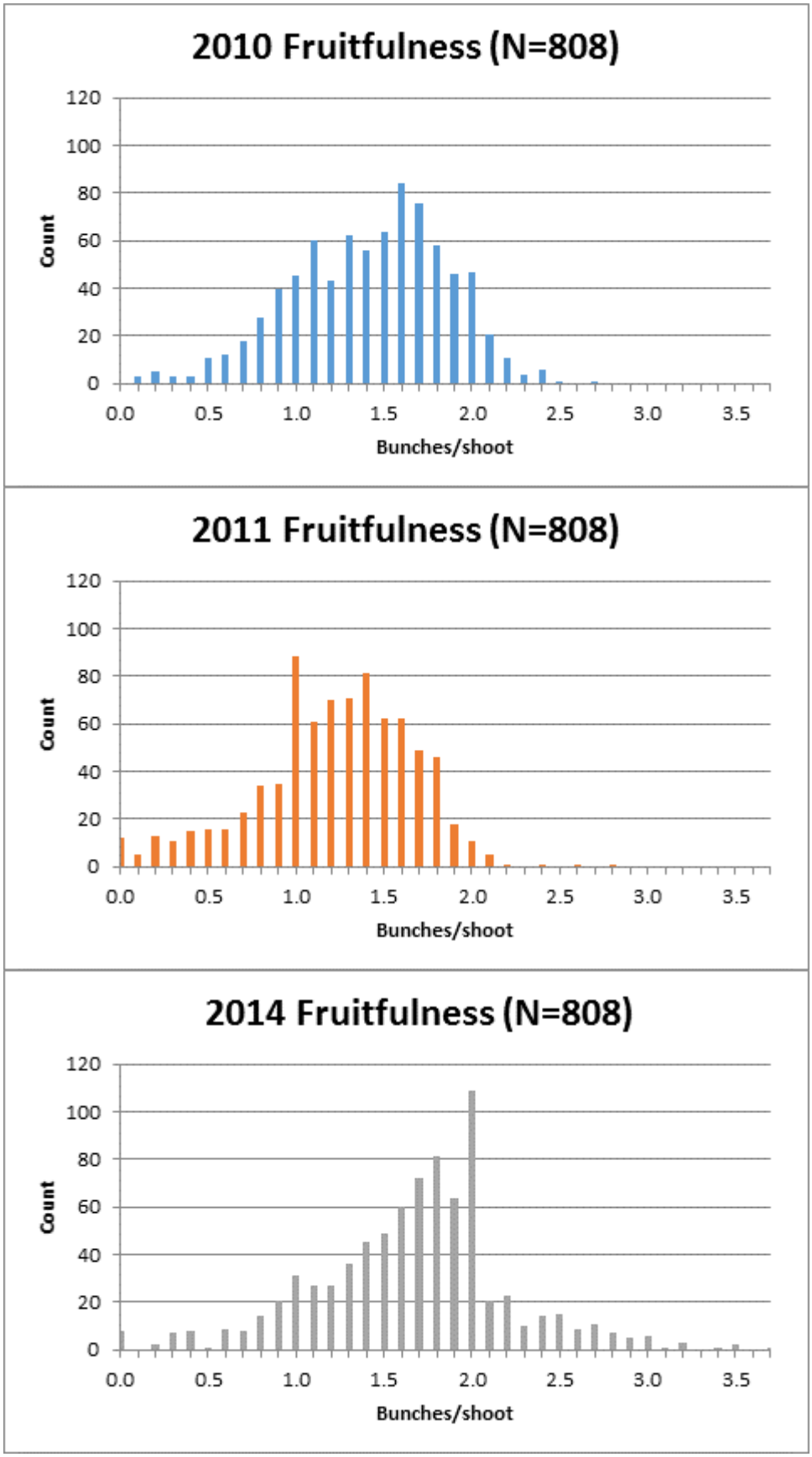


Figure 6.3.1. Distribution of fruitfulness (bunches per shoot) across all varieties and selected clones in the CSIRO variety collection, across seasons 2009/10, 2010/11 and 2013/14. Count = n^{o} of varieties and clones.

6.3.2 Leaf area

The distribution of the leaf area index (LAI) collected in December/January is provided for the three seasons (2009/10, 2010/11 and 2013/14) in Figure 6.3.2 Across the varieties there was up to a 40-fold difference in LAI, ranging from 0.2 - 5.5 m^2/m^2 in the 2009-10 season when growth was impacted by hot conditions and the enforced deficit irrigation treatment; 0.2 to 8.0 m^2/m^2 in the 2010-11 season when the cool, wet conditions favoured vegetative growth and, 0.2 to 9.5 m^2/m^2 for the young vines located at the CSIRO Irymple site. While there was a significant correlation for LAI between seasons 2009/10 and 2010/11 (r = 0.53) for vines located at the same site, the correlations between 2009/10 and 2013/14 and between 2010/11 and 2013/14 were lower (r = 0.16 and 0.15 respectively). The low r values indicate differing varietal responses to environmental cues impacting canopy development (climate, site and management). Wine grape varieties with consistently low LAI values over the seasons (i.e. mean LAI <1.0) included Jurancon Noir, Rauschling, Gyongyrizling, Arinto, Pinot Nori, Arbois, Ondenc, Pinotage, Flora, Muscat Gordo Blanco and Riesling. Wine grape varieties with consistently high LAI values (mean LAI > 4) included Shiraz, Leon Millot, Demir Kapija, Baresana, Trajadura, Pignoletto, Villa Nueva, Bastardo, Chardonnay, Bastardo, Malbec, Viosinho, Albana, Tinta Cao, Jacquez and Antao Vaz.

The maximum LAI provides an estimate not only of canopy size and hence photosynthetic capacity, but also provides a surrogate measure of vine transpiration based on 1 L/m^2/day (Walker et al. 2005). Consequently, the results indicate potential to select varieties with smaller canopies to minimise transpiration and improve water use efficiency and also to improve production efficiencies if used in high density plantings, provided vine yield and fruit composition are acceptable.

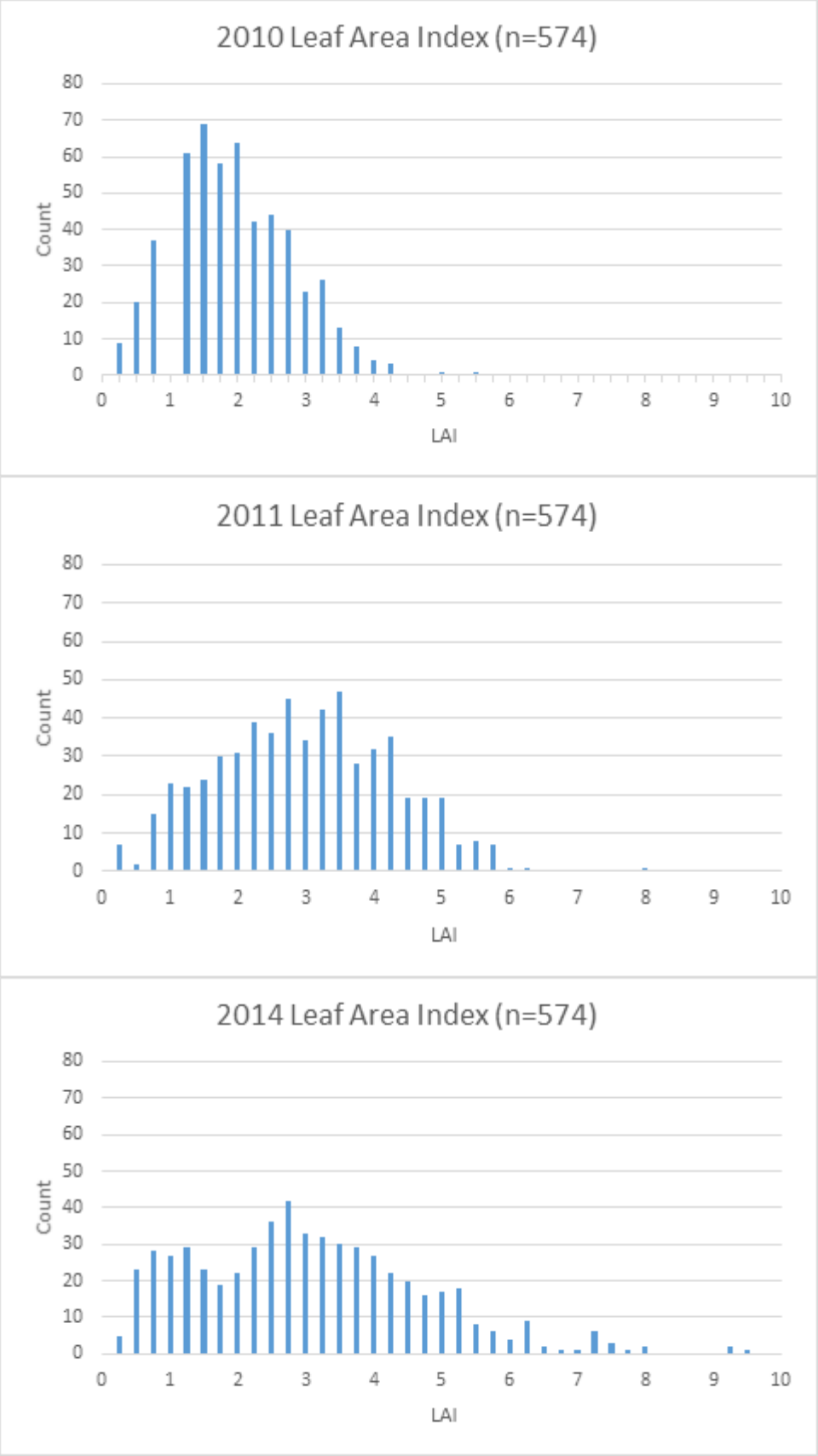


Figure 6.3.2. Distribution of leaf area index (LAI) of varieties in the CSIRO variety collection, across seasons 2009/10, 2010/11 and 2013/14. Count = n^{o} of varieties.

6.3.3 Estimated yield

Yields were estimated across the varieties and clones in the CSIRO collection in the 2009/10, 2010/11 and 2013/14 seasons by visual assessment and categorization of the potential crop. The results presented in Figure 6.3.3 show that the majority of varieties and clones fell in the moderate yield potential class (class 5, 7-15 kg/vine) in 2009/10 whereas in 2010/11 a larger proportion were classified in the low to moderate class (class 3, 2 - 7 kg/vine). This was most likely associated with losses due to an increased incidence of disease in the very wet, cool season as fruitfulness was similar in both seasons (Figure 6.3.1). There was a wider spread in yield potential of the young vines established at the CSIRO Irymple site, in season 2013/14 reflecting both the higher levels of fruitfulness (Figure 6.3.1) and the wider range in canopy size (LAI, Figure 6.3.2) although most of the varieties and clones were classified in the moderate yield potential class (5). Relationships for estimated yields between seasons were low ($r < 0.17$), an indication of differing varietal responses to environmental cues (climate, site and management) directly (e.g. losses due to rots) or indirectly (e.g. fruitfulness) impacting yield. Nonetheless, a number of varieties were classified in low or high potential yield classes across the seasons. Winegrape varieties with consistent low yield potential (mean = class 3, 2 - 7 kg/vine) were Cegled Szepe, Crinto, Arinto, Arbane, Cabernet Sanzey, Fer, Lignan Blanc, Montepulciano, Perle de Csaba, Ondenc, Precose de Malingre and Dunkelfelder. Winegrape varieties with consistent high yield potential (mean >6.2, 15 - 25 kg/vine) were Furmint, Mourisco Branco, Clairette, Feher Szagos, Marsanne, Malbec, Peloursin, Smederevka, Cionoria, Malvasia Moscato, Farana, Carignan, Cinsaut, Varousset, Trebbiano, Tinta Amarella, Bourboulenc, Verdelet, Palamino and Jaen.

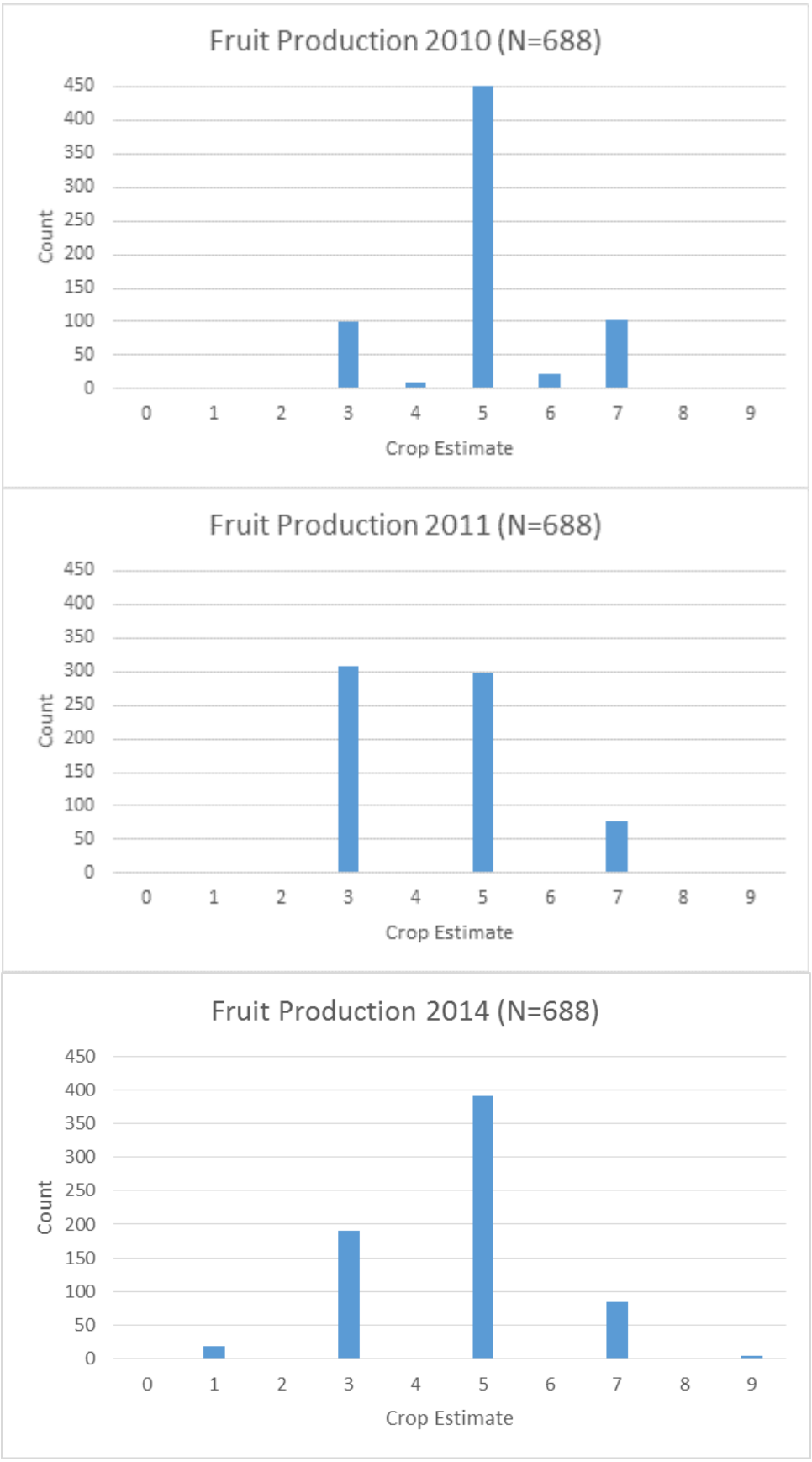


Figure 6.3.3. Distribution of estimated yield of varieties and selected clones in the CSIRO collection, seasons 2009/10, 2010/11 and 2013/14. Categories (Classes) of

yield potential range from 1 (very low yield) through to 9 (very high yield). Count = n^{o} of varieties.

6.3.4 Leaf area index / estimated yield ratio

The ratio of leaf area index to yield was calculated from the data of LAI and yield estimates provided above (Figures 6.3.2 and 6.3.3). The ratio, not only provides an indication of the efficiency of each variety to convert photosynthetic capacity to harvestable crop but also provides a surrogate for crop water use efficiency (vine transpiration/yield) based on an indicative value of 1 L/m^2/day for transpiration (Walker et al. 2005). The results presented in Figure 6.3.4.1 show a ten-fold range in the ratio (LAI/estimated yield) across the varieties and clones. While there was a significant but weak correlation for the ratio between 2009/10 and 2010/11 ($r = 0.22$) the correlations between 2009/10 and 2013/14 and between 2010/11 and 2013/14 were non- existent ($r < 0.03$). Nonetheless, a number of varieties were consistently classified as inefficient varieties (mean ratio > 1) and with high efficiency (mean ratio < 0.2) across the seasons. Wine grape varieties classified as inefficient (i.e. those with low yield and large canopies) included Jacquez, Corvina Veronese, Bastardo, Fer, Tinta Cao, Lignan, Leon Millot, Mavronemeas, Nebbiolo Chiavenas, Villa Nueva and Mavro Romeico. Varieties classified with high efficiency included Gyongyrizling, Pinotage, Pinot Noir, Uva di Troia, Medea, Limberger, Aubun, Muscat Ottonel, Bequignol, Troyen, Gamay and Jaen. Consequently, the results indicate potential to select varieties to improve water use efficiency provided they are capable of achieving adequate maturity levels with acceptable fruit composition.

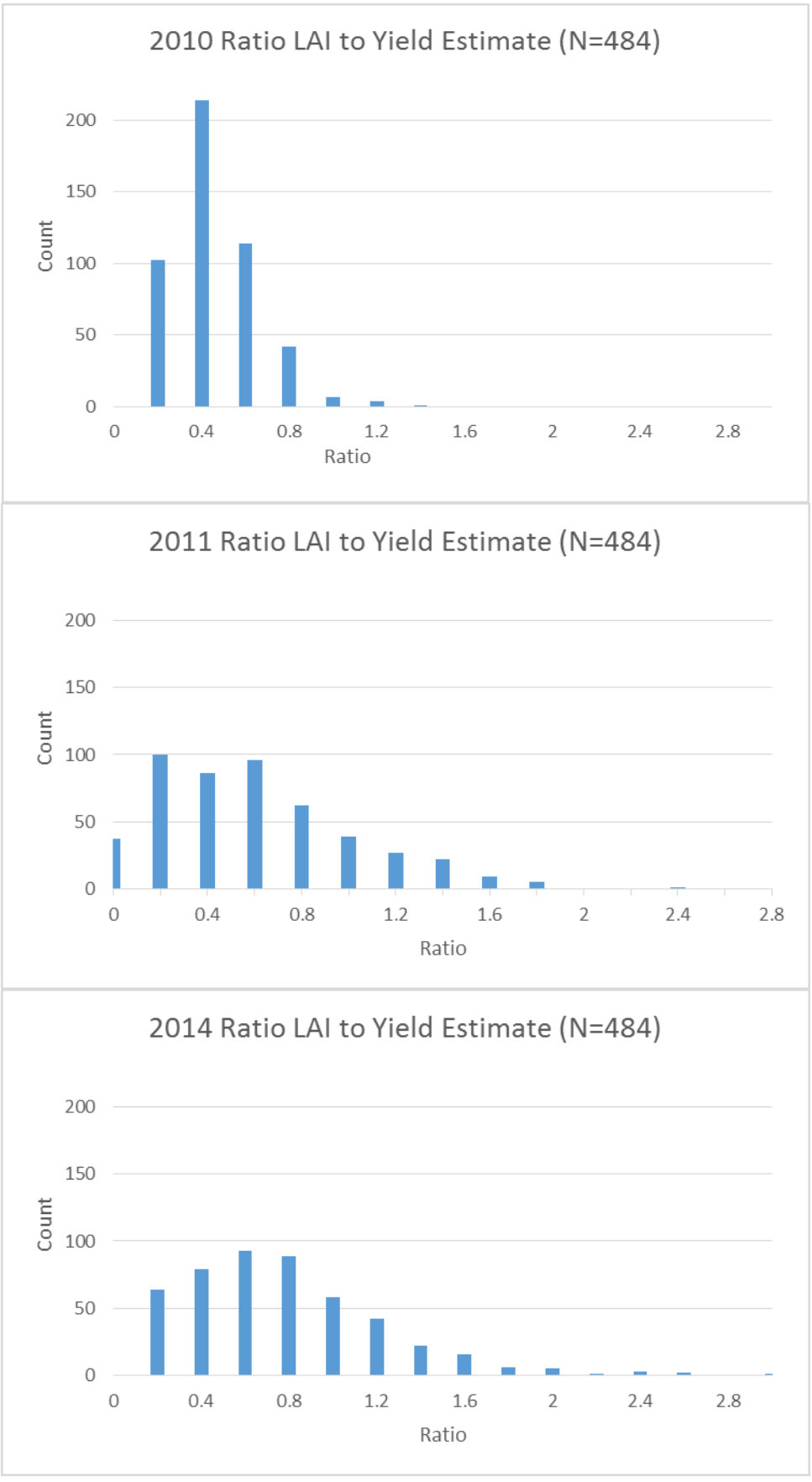


Figure 6.3.4. Distribution of the leaf area index/estimated yield ratio of varieties in the CSIRO variety collection across seasons 2009/10, 2010/11 and 2013/14.

6.3.5 Berry weight

Berry weights were determined for samples collected for fruit composition studies from vines located at the CSIRO Merbein site in 2009/10 and 2010/11 and for the young vines located at the CSIRO Irymple site in seasons 2012/13 and 2013/14. The results presented in Figure 6.3.5 show large differences in berry weight, ranging from 0.5 to 8.5 g. Those with very small berries were seedless currant varieties while those with large berries were seeded table grape varieties. For the winegrape varieties there was a six-fold difference in berry weight, ranging from 0.6 to 3.8 g. Strong relationships for berry weight between seasons (r values 0.81 - 0.86) indicate that 66% to 75% of the variation in berry weight from season to season could be accounted for by the variety despite the significant effects of climate, irrigation and vine management practices across the seasons. Examples of these relationships are provided below for comparisons between 2009/10 and 2010/11 (a) between 2009/10 and 2012/13 (b) and between 2009/10 and 2013/14 (c), respectively.

(a) 2010/11 vs. 2009/10 $Y= 1.174x + 0.254$ ($R^2 = 0.75$)

(b) 2012/13 vs. 2009/10 $Y= 0.843x + 0.461$ ($R^2 = 0.66$)

(c) 2013/14 vs. 2009/10 $Y= 0.848x + 0.490$ ($R^2 = 0.66$)

The regression between berry weight in 2010/11 and 2009/10 (a) indicates that varieties with an average berry weight of 1.0 g and 2.0 g respectively in 2009/10 would produce significantly larger berries of 1.43 g and 2.60 g respectively in 2010/11, a result associated with the impact of the cool, wet season in 2010/11 compared to the hot, dry season with limited water supply in 2009/10. The regression between berry weight in 2010/13 and 2009/10 (b) indicates that varieties with an average berry weight of 1.0 g and 2.0 g respectively in 2009/10 would produce larger berries of 1.43 g and 2.15 g respectively in 2012/13. Similarly, the regression between berry weight in 2010/13 and 2009/10 (c) indicates that varieties with an average berry weight of 1.0 g and 2.0 g respectively in 2009/10 would produce larger berries of 1.34 g and 2.19 g respectively in 2013/14. These latter results most probably are due to a combination of site, vine age, the more severe pruning and less restricted irrigation management at the Irymple site.

Winegrape varieties which consistently produced small berries (i.e. mean <1.0 g) across the 4 seasons were Petit Verdot, Gamay de Bouze, Marechal Foch, Pinot Noir, Ehrenfelser, Dunkelfelder, Fernao Pires, Verduzzo, Gros Manseng, Jacquez, Gamay and Graciano. Winegrape varieties which consistently produced large berries (i.e. mean between 3 and 3.75 g) were Baresana, Semis de Goes, Osicka, Antigona, Trajadura, Feher Szagos, Boglarka, Koshu Sanjaku, Kavadarski Drenak, Beogradska Besemena, Marocain Noir, Smederevka, Doradillo and Farana.

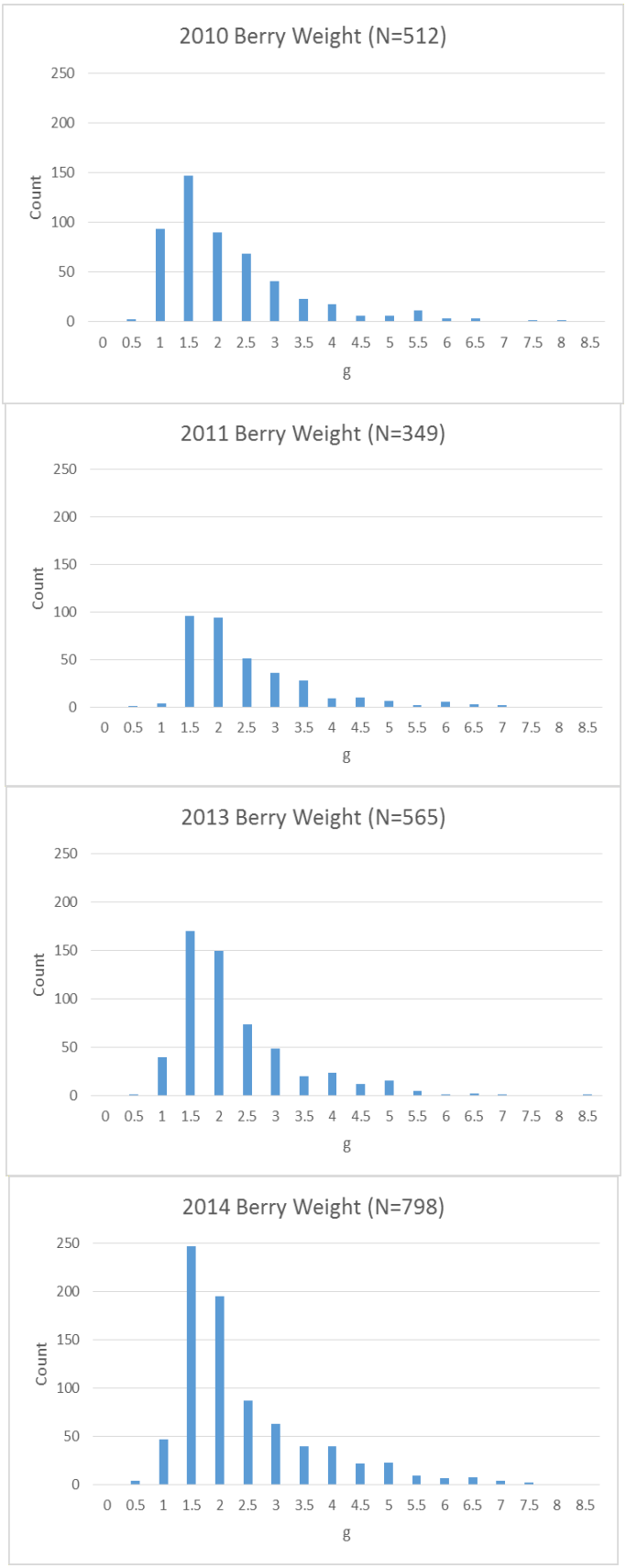


Figure 6.3.5. Distribution of berry weight across varieties and selected clones in the CSIRO germplasm collection across seasons 2009/10, 2010/11, 2012/13 and 2013/14.

6.4.6 Disease tolerance (2010/11)

The extreme weather conditions in the cool, wet 2010/11 season (Tables 6.1.1, 6.1.2, 6.1.3), with record breaking rainfall events and high humidity, led to significant issues with excessive canopy growth, fungal diseases (downy and powdery mildew, fruit splitting and development of bunch rots), compounded by significant leaf loss and delayed maturation. This exceptional season provided an opportunity to score varieties for their susceptibility or tolerance to downy mildew infection. The overall results presented in Figure 6.3.6 show that about 20% of the varieties had very low susceptibility to infection while a further 20% had high or very high susceptibility to infection. Highly susceptible winegrape varieties included the standard variety, Pinot Noir and surprisingly the species hybrid Royalty as well as Arinarnoa, Mavro Romeico, Solvorino and Corvinon. The varieties with very low susceptibility to infection included many standard *Vitis vinifera* varieties as well a number of disease resistant species hybrids. It is likely that such results may have been associated with variability across the vineyard with pockets of infection at different locations. However, the high number of varieties with low susceptibility to downy mildew infection under such high disease pressure indicate potential to identify alternative varieties with downy mildew tolerance.

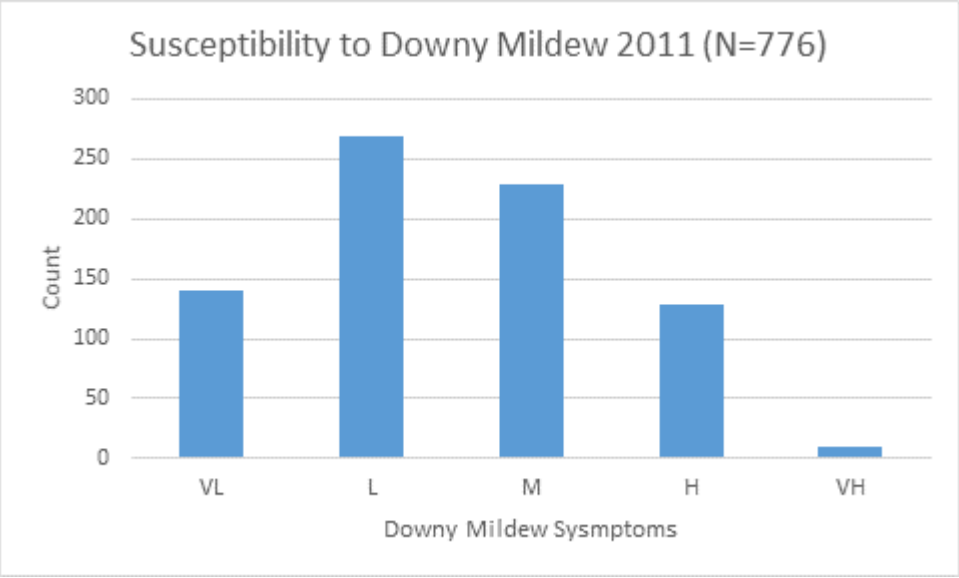


Figure 6.3.6. Distribution of the susceptibility of varieties and selected clones in the CSIRO variety collection in season 2010/11. Count = n^{o} of varieties.

6.4 BERRY COMPOSITION

6.4.1 Total soluble solids

Over four seasons, 2009/10, 2010/11 and 2012/13 and 2013/14 fruit maturity was monitored, usually on a weekly basis, with the aim to collect samples for processing for berry composition studies. White varieties were sampled in the 20-22 ^{o}Brix range and red varieties were sampled in the 22-24 ^{o}Brix range. In general, this was achieved for both the red and white varieties (Figure 6.4.1.1 and 6.4.1.2). However, it was noted that there were some varieties where ripening stalled and the desired levels of total soluble solids (TSS) were not achieved, while in other varieties TSS increased rapidly, in part due to berry wilting leading to higher than desired TSS values.

For established vines, located at the CSIRO Merbein site in the 2009/10 season, the TSS of most white varieties fell between 18 ^{o}Brix and 24 ^{o}Brix with a peak at 21 ^{o}Brix (Figure 6.4.1.1). In the wet, difficult ripening 2010/11 season, the TSS of most varieties fell between 17 ^{o}Brix and 23 ^{o}Brix with a peak at 19 ^{o}Brix. For the young vines located at the CSIRO Irymple site, in the 2012/13 season the TSS of most varieties fell between 20 ^{o}Brix and 24 ^{o}Brix with a peak around 22 – 23 ^{o}Brix. In the 2013/14 season the TSS of most varieties fell between 18 ^{o}Brix and 24 ^{o}Brix with a peak at 21 ^{o}Brix. Despite the fact that ripening was monitored with the aim to collect samples in a narrow TSS range (20-22 ^{o}Brix), and the significant effects of season on ripening, there were highly significant correlations ($r = 0.30 - 0.34$, $r < 0.001$) between seasons across the varieties for TSS, an indication of a relatively strong effect of genotype. This indicates that some varieties consistently had difficulties in achieving desired maturity while others consistently had high TSS, presumably associated with rapid increases in TSS associated with berry wilting. As a consequence, it was possible to identify white wine varieties which consistently had low TSS (mean < 18.2 ^{o}Brix). In general these were late ripening varieties and included Gros Meslier, Furmint, Ondenc, Putzscheere, Monbadon, Minnella Bianca, Loureiro, Catarratto, La Reina, Agadaj and Solvorino. Similarly it was possible to identify varieties which consistently had high TSS (mean > 24.2 ºBrix). These included Sauvignonasse, White Muscat, Duchess of Buccleuch, Verdelho, Aurelia, Trajadura, SV39-639, July Muscat and Agostenga.

For the red varieties located at the CSIRO Merbein site, the TSS of most varieties fell between 19 ^{o}Brix and 24 ^{o}Brix with a peak at 20 ^{o}Brix in 2009/10 and between 18 ^{o}Brix and 23 ^{o}Brix with a peak at 20 ^{o}Brix in the wet 2010/11 season. For red varieties located at the CSIRO Irymple site, the TSS of most varieties fell between 20 ^{o}Brix and 25 ^{o}Brix with a peak at 23 ^{o}Brix in 2012/13 and between 19 ^{o}Brix and 24 ^{o}Brix with a peak at 21 ºBrix in 20113/14 season. As with the white varieties, highly significant correlations between seasons ($r = 0.30 - 0.34$, $r < 0.001$) indicated a relatively strong effect of genotype. Red wine varieties which consistently had low TSS (mean < 19 ^{o}Brix) included Mavro Romeico, Montepulciano, Rossignola, Molinara, Prokupac, Bobal, Corvinon, Gueche Noir and Negro Amaro. Red varieties which consistently had high TSS included Bastardo, Jacquez, Tannat, Gascon, Gamay, Brachetto, Flora, Pinot Precose and Marechal Foch.

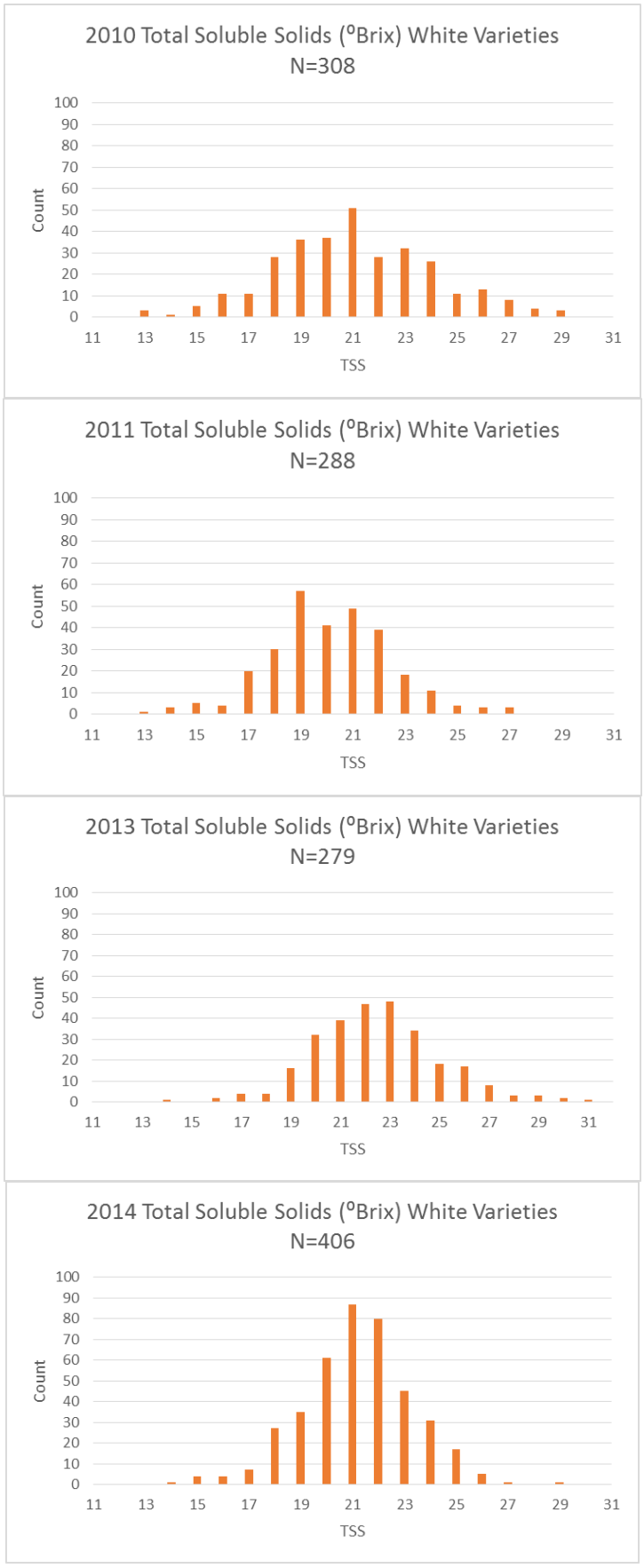


Figure 6.4.1.1. Distribution of total soluble solids (°Brix) of berry samples collected over 4 seasons (2009/10, 2010/11, 2012/13 and 2013/14) from white varieties and selected clones in the CSIRO germplasm collection. Count = n° of varieties.

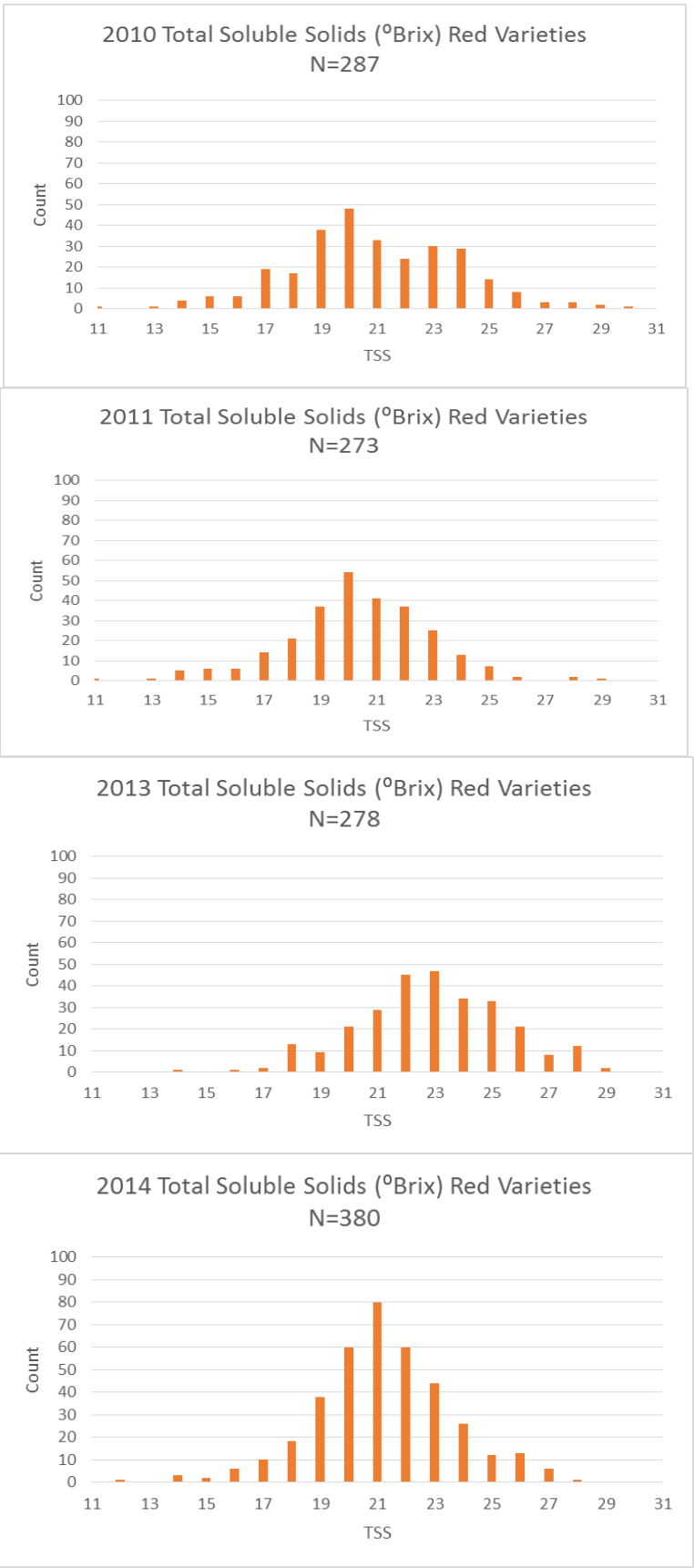


Figure 6.4.1.2. Distribution of total soluble solids (°Brix) of berry samples collected over 4 seasons (2009/10, 2010/11, 2012/13 and 2013/14) from red varieties and selected clones in the CSIRO germplasm collection. Count = n° of varieties.

6.4.2 Juice pH

Juice pH is a critical quality parameter as it determines requirements for acid addition treatments to adjust pH to between 3.45 and 3.55 in the winemaking process to enhance wine stability and minimise microbial spoilage. For white varieties established at the CSIRO Merbein site, the pH ranged from 3.4 to 4.7 with a peak at 3.9 in the 2009/10 season and from 3.1 to 4.6 with a peak at 3.9 in 2010/11 (Figure 6.4.2.1). For white varieties located at the CSIRO Irymple site the pH ranged from 3.6 to 5.2 with a peak at 4.4 in 2012/13 and from 3.1 to 5.2 with a peak at 4.3 in 2013/14. The results indicate that for most varieties, pH levels were much higher in 2012/13 and 2013/14 than in the earlier seasons. The reasons for this are unclear but it could be related to the site, a young vine response, higher TSS at sampling (Figures 6.4.1) or possibly the fact that it was necessary to freeze berries for transport and analyses in Adelaide. A small increase in pH was expected with the frozen samples as in a previous rootstock study with Shiraz as the scion, a small increase of 0.15 pH was found when comparing fresh and frozen samples across 60 rootstock genotypes (Clingeleffer 1996). Highly significant correlations for pH across seasons ($r = 0.22 - 0.45$, $p<0.001$) indicate a significant effect of genotype despite the different seasonal conditions, the use of different sites, the range in berry maturity and the potential issue with the change in methodology from fresh to frozen berries.

Overall, very few white varieties had low pH which would indicate a minimal requirement for pH adjustment in winemaking. Those which consistently had low pH over the seasons (mean < 3.70, the mean pH of the benchmark variety, Riesling) included GM 7116-2, Savagnin, GM 6495-3, Fiano, Petit Meslier, Helena, Perdea, Cortese, GM 318-57, Verdelho and Albana. It is of interest to note that 3 were unnamed selections from the breeding program in Germany. White varieties which had very high pH (mean > 4.25) included Farana, Demir Kapija, Schonburger, Palamino, Feher Szagos, Leanoy, Pollux, Baresana, Mantua de Pilas, Beogradska Rana, Jaen, Marsanne, Ondenc, Precose de Malingre, Favorit, Canocazo, Verdelet, Mourisco Branco, Muscat de St.Vallier and Doradillo.

For red varieties established at the CSIRO Merbein site, the pH ranged from 3.1 to 4.6 with a peak at 3.9 in the 2009/10 season and from 3.1 to 4.4 with a peak at 3.8 in 2010/11 (Figure 6.4.2.2). For red varieties located at the CSIRO Irymple site the pH ranged from 3.3 to 5.3 with a peak at 4.4 in 2012/13 and from 3.3 to 5.1 with a peak at 4.2 in 2013/14. As with the white varieties, highly significant correlations for pH across seasons ($r = 0.24 - 0.38$, $p<0.001$) indicate a significant effect of genotype despite the different seasonal conditions, the use of different sites, the range in berry maturity and the potential issue with the change in methodology from fresh to frozen berries. As with the white varieties and for the same reasons, the results indicate that for most red varieties, pH levels were much higher in 2012/13 and 2013/14 than in the earlier seasons, particularly in 2012/13. Red varieties which consistently had low pH (mean < 3.6) over the seasons included Rossignola, Raboso Piave, Scarlet, Crinto, Aglianico, Mavro Naussis, Gamay and Alvarelhao. Those with high pH (mean > 4.25) included Cinsaut, Tempranillo, Comtessa, Molinara, Kavadarski Drenak, Miguel de Arcon, Cesanese, Garonnet, Mavro Romeico, Bequignol, Incrocio Bruni, Cascade, Durif, Semis de Goes, Cereza and Frankenthal.

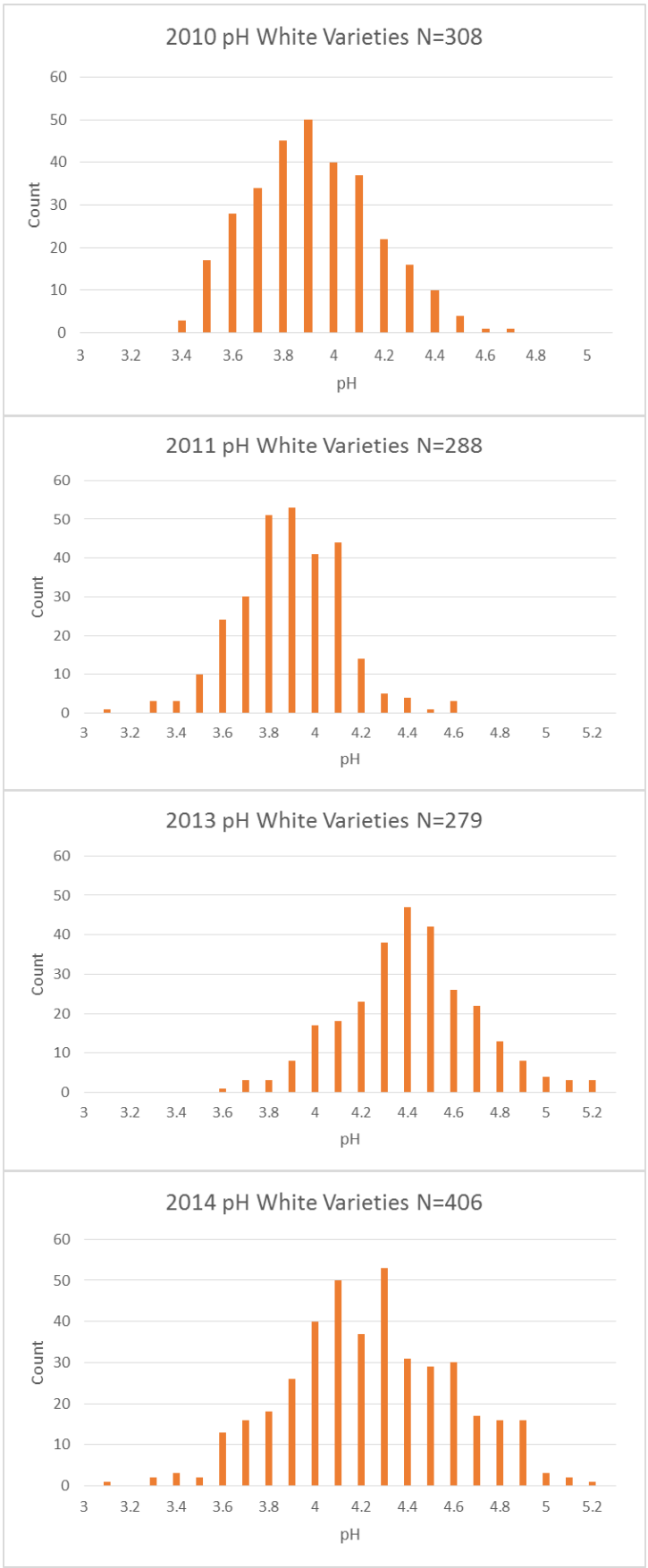


Figure 6.4.2.1. Distribution of pH of berry samples collected over four seasons (2009/10, 2010/11, 2012/13 and 2013/14) from white varieties and selected clones in the CSIRO germplasm collection. Count = n^{o} of varieties.

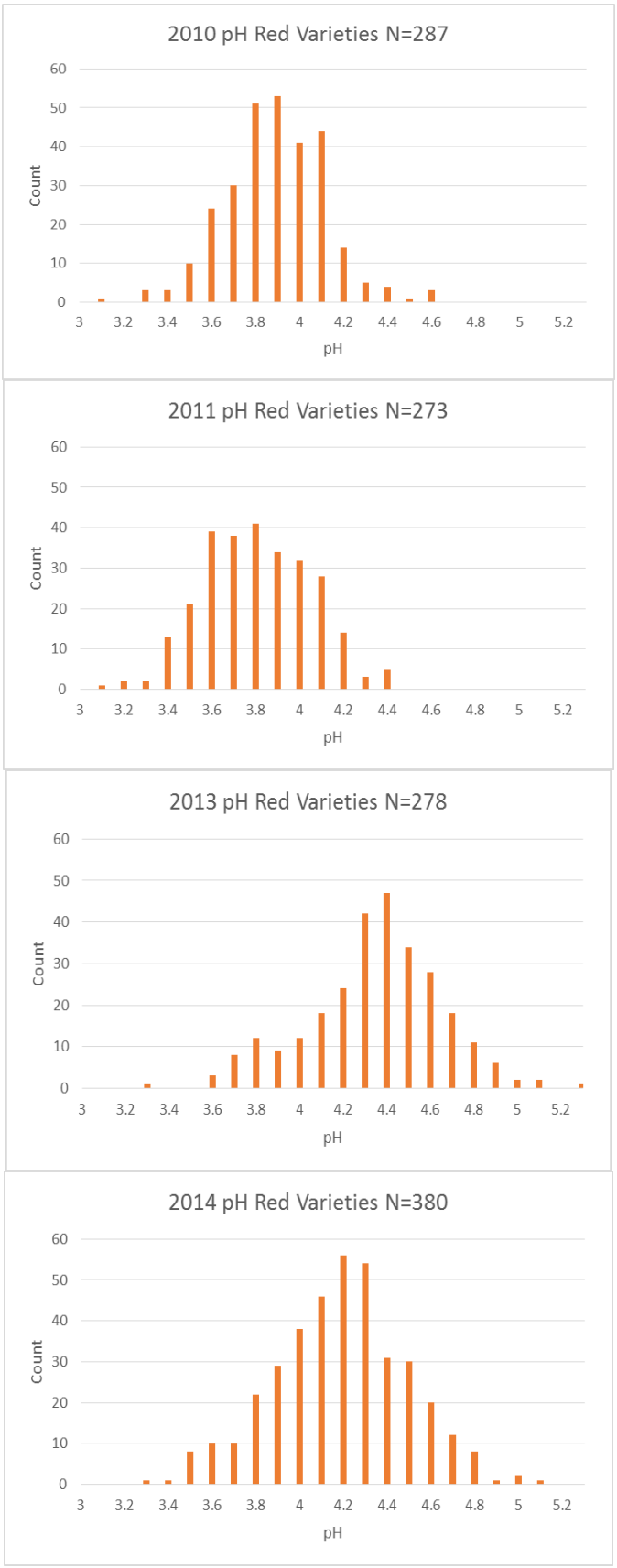


Figure 6.4.2.2. Distribution of pH of berry samples collected over four seasons (2009/10, 2010/11, 2012/13 and 2013/14) from red varieties and selected clones in the CSIRO germplasm collection. Count = n^{o} of varieties.

6.4.3 Juice titratable acidity

Titratable acidity is measured regularly in musts as it is related to pH buffering and hence requirements for acid adjustment of pH in winemaking and the taste of the wine. Acceptable levels of acidity in the must generally fall between 6.0 and 8.0 g/L. Excessive levels can contribute to a tart wine taste. For white varieties established at the CSIRO Merbein site, the TA ranged from 2 to 9 g/L with a peak at 5 g/L in the 2009/10 season and from 2 to 10 g/L with a peak at 4 g/L in 2010/11 (Figure 6.4.3.1). For white varieties located at the CSIRO Irymple site, the TA ranged from 2 to 7 g/L with a peak at 3 g/L in the 2012/13 season and from 2 to 16 g/L with a peak at 3 g/L in the 2013/14 season. The proportion of varieties with TA levels greater than 6 g/L was lower in 2012/13 and 2013/14 than in the earlier seasons. This result could be related to the site, a young vine effect and the higher TSS levels, particularly in 2012/13 (Figure 6.4.1.1). For the white varieties, highly significant correlations for TA between seasons (r = 0.23 - 0.44) indicate a significant effect of genotype despite the different seasonal conditions, the use of different sites and the different levels of maturity. White varieties which consistently had the highest levels of TA (mean > 5 g/L) included GM 7116-2, Helena, Sauvignon Blanc, Chenin Blanc, Gros Manseng Blanc, Sunmuscat , Aucarot, Ehrenfelser, GM 318-57, Fiano, Savagnin, Sauvignon, Chardonnay, Raffiat de Moncade, GM 6495-1, Verdelho, Fiano, GM 6495-3, Petit Meslier and Albana. White varieties which consistently had the lowest levels of TA (mean < 3g/L) included Mourisco Branco, Ondenc, Palamino, Canocazo, Doradillo, Mantua de Pilas, Ezerfurtu, Feher Szagos, GM 6414-11, Marsanne, Muscat de Samur, Favorit, Sylvaner, Mauzac, La Reina, Ortrugo, Cesanese, Traminer, Rauschling, Rotgipfler, Morio Muskat, Precose de Malingre, Muscat Ottonel, Montils and Green Veltliner.

For red varieties established at the CSIRO Merbein site, the TA ranged from 3 to 13 g/L with a peak at 5 g/L in the 2009/10 season and from 2 to 10 g/l with a peak at 5 g/L in 2010/11 (Figure 6.4.3.2). For red varieties located at the CSIRO Irymple site, the TA ranged from 2 to 10 g/L with a peak at 3 - 4 g/L in 2012/13 and from 2 to 9 g/L with a peak at 3 g/L in 2013/14. As with the white varieties, the proportion of varieties with TA levels greater than 6 g/L was lower in 2012/13 and 2013/14 than in the earlier seasons. As with the white varieties this could be related to the site, a young vine effect and the higher TSS levels, particularly in 2012/13 (Figure 6.4.1.2). For the red varieties, highly significant correlations for TA between seasons (r = 0.25 - 0.44) indicates a significant effect of genotype despite the different seasonal conditions, the use of different sites and the different levels of maturity. Compared to the white varieties, a greater proportion of red varieties had TA levels that were greater than 6/g/L. Those that consistently had higher levels (mean >5.6 g/L) included Royalty, Varousset, Cienna, Mantey, Chambourcin, Brachetto, Marechal Foch, Petit Verdot, Teroldego, Tinta Cao, Rubired, Mavro Naussis, Jacquez and Raboso Piave. Red varieties with low levels of TA (mean < 3 g/L) included Incrocio Bruni, Cegled Szepe, Piros Slanka, Malbec, Sangiovese, Semis de Goes, Mondeuse, Kavadarski Drenak, Tempranillo, Gamay, Durif, Cereza, Pinot Gris, Cinsaut, Mavro Romeico, Rondinella, Carmenere, Grand Noir de la Calmette and Comtessa.

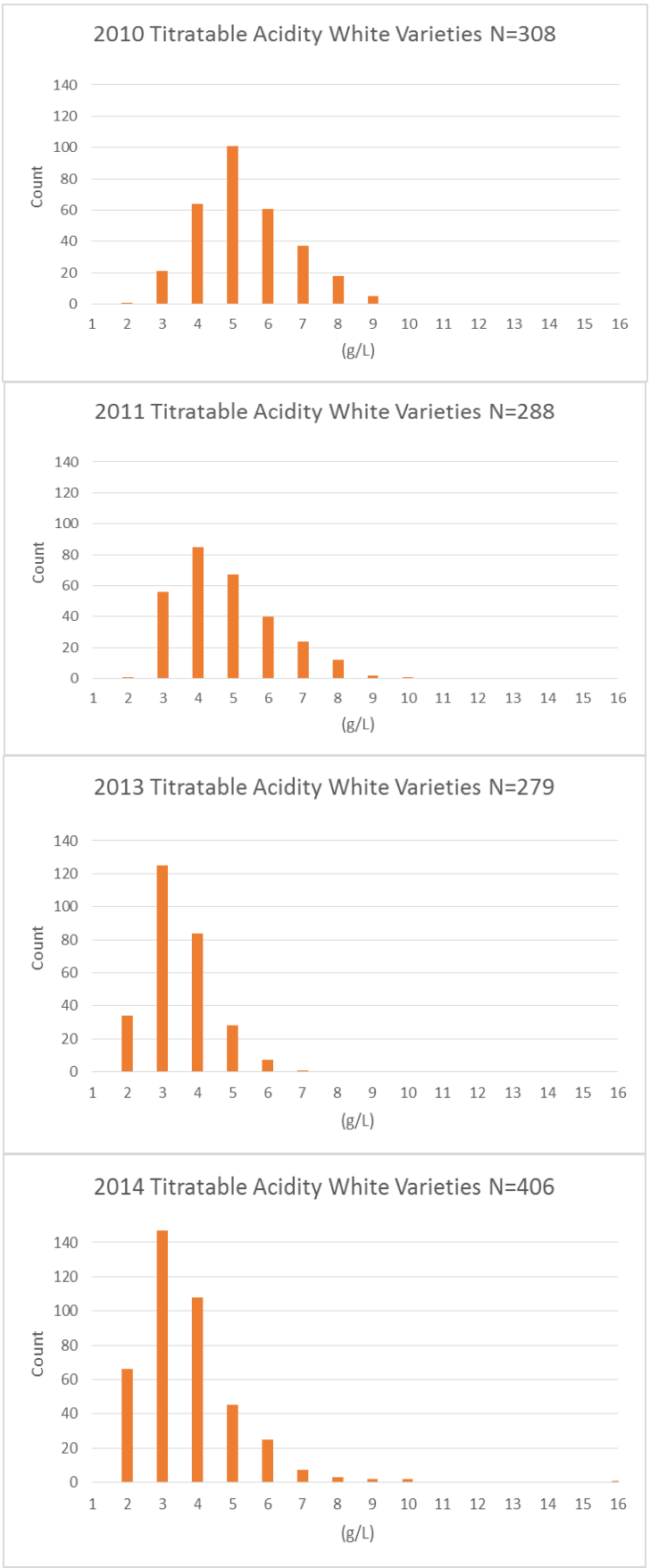


Figure 6.4.3.1. Distribution of titratable acidity (g/L) of berry samples collected over four seasons (2009/10, 2010/11, 2012/13 and 2013/14) from white varieties and selected clones in the CSIRO germplasm collection. Count = n^{o} of varieties.

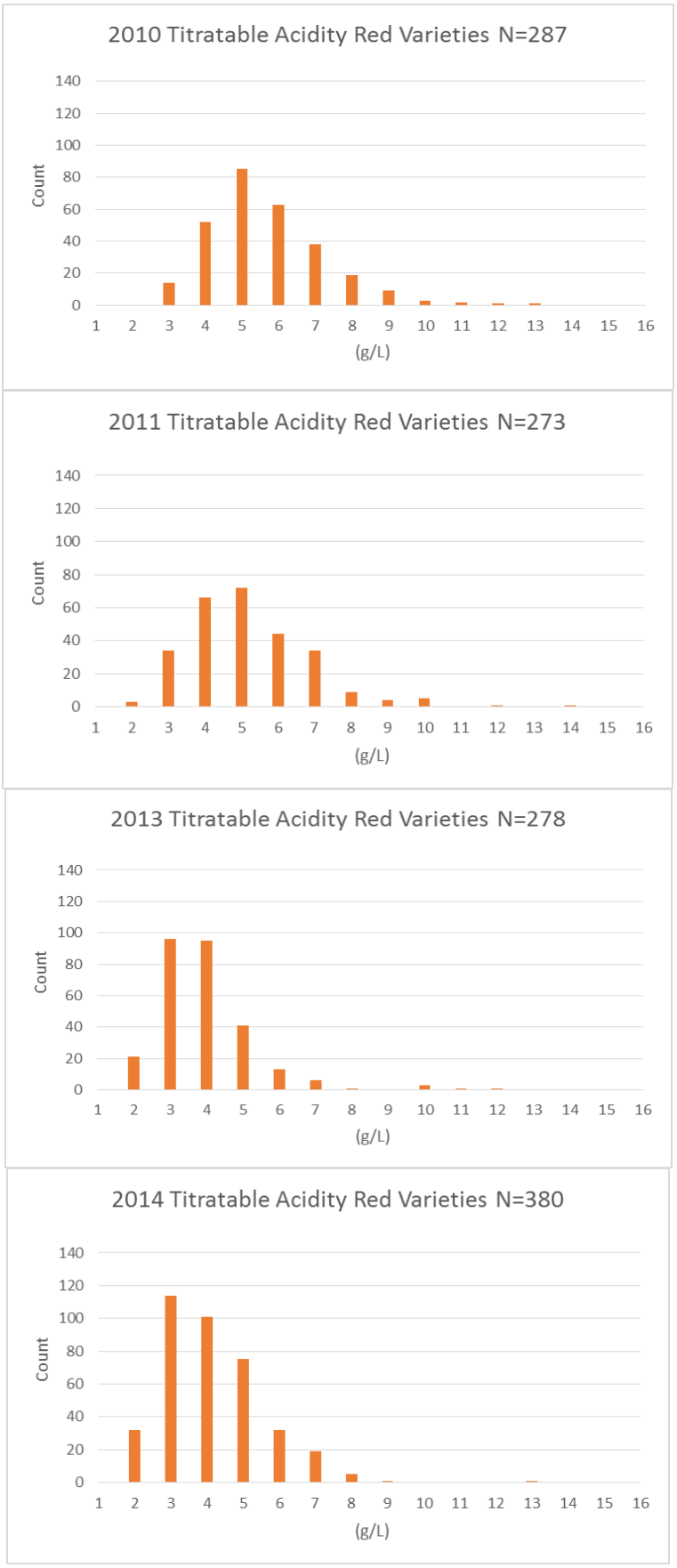


Figure 6.4.3.2. Distribution of titratable acidity (g/L) of berry samples collected over 4 seasons (2009/10, 2010/11, 2012/13 and 2013/14) from red varieties and selected clones in the CSIRO germplasm collection. Count = n^{o} of varieties.

6.4.4 Malic acid

Malic acid and tartaric acid are the main organic acids found in grape berries. For many wine styles, malic acid is the least preferred as it is a weaker acid than tartaric. High levels of malic acid may require controlled secondary bacterial fermentation of the wine, where it is converted to lactic acid. If this process is not controlled in winemaking, spontaneous fermentation may occur in storage leading to spoilage. The pH of the wine also increases when malic acid is converted to lactic acid leading to instability.

For white varieties established at the CSIRO Merbein site, the distribution in malic acid ranged from 1 to 6 g/L with a peak at 3 g/L in the hot 2009/10 season and from 2 to 10 g/L with a peak at 4 g/L in 2010/11 (Figure 6.4.4.1). For white varieties located at the CSIRO Irymple site, malic acid ranged from 0.5 to 8 g/L with a peak at 3 g/L in 2012/13 and from 1 to 11.5 g/L with a peak at 3.5 - 4 g/L in 2013/14. For the white varieties, highly significant correlations for malic acid between seasons ($r = 0.18 - 0.49$) indicate a significant effect of genotype despite the different seasonal conditions, the use of different sites and the different levels of maturity. The white varieties which consistently had high levels of malic acid (> 5 g/L) included Bianca and Verdelho. White varieties which consistently had the lowest levels of malic acid (< 2.5 g/L) included Ortrugo, Cayuga White, Bourboulenc, Catarratto, Reichensteiner, Sangiovese, Len de L'El, Arbane and Auxerrois.

For red varieties established at the CSIRO Merbein site, malic acid concentrations ranged from 1 - 6 g/L with a peak at 3 g/L in the 2009/10 season and from 2 - 10 g/L with a peak at 4 g/L in 2010/11 (Figure 6.4.4.2). For red varieties located at the CSIRO Irymple site, the malic acid ranged from 0.5 to 8 g/L with a peak at 3 - 4 g/L in 2012/13 and from 1 to 11.5 g/L with a peak at 3.5 - 4 g/L in 2013/14. For the red varieties, the correlation coefficients for the relationships between seasons were much higher and more consistent than for the white varieties (i.e. 0.50 - 0.69), indicating very strong control of the malic acid levels by the genotype despite the different seasonal conditions, the use of different sites and the different levels of maturity. The red varieties which consistently had high levels of malic acid (> 5.5 g/L) included Lambrusco, Gropello Gentile, Negrette, Tinta Cao, Marechal Foch, Bastardo, Cinsaut, Jacquez and Caino. Red varieties which consistently had the lowest levels of malic acid (< 2.0 g/L) included Cegled Szepe, Calzin, Kadarka, Gamay, Grand Noir de la Calmette, Piquepoul, Salvador and Incrocio Bruni.

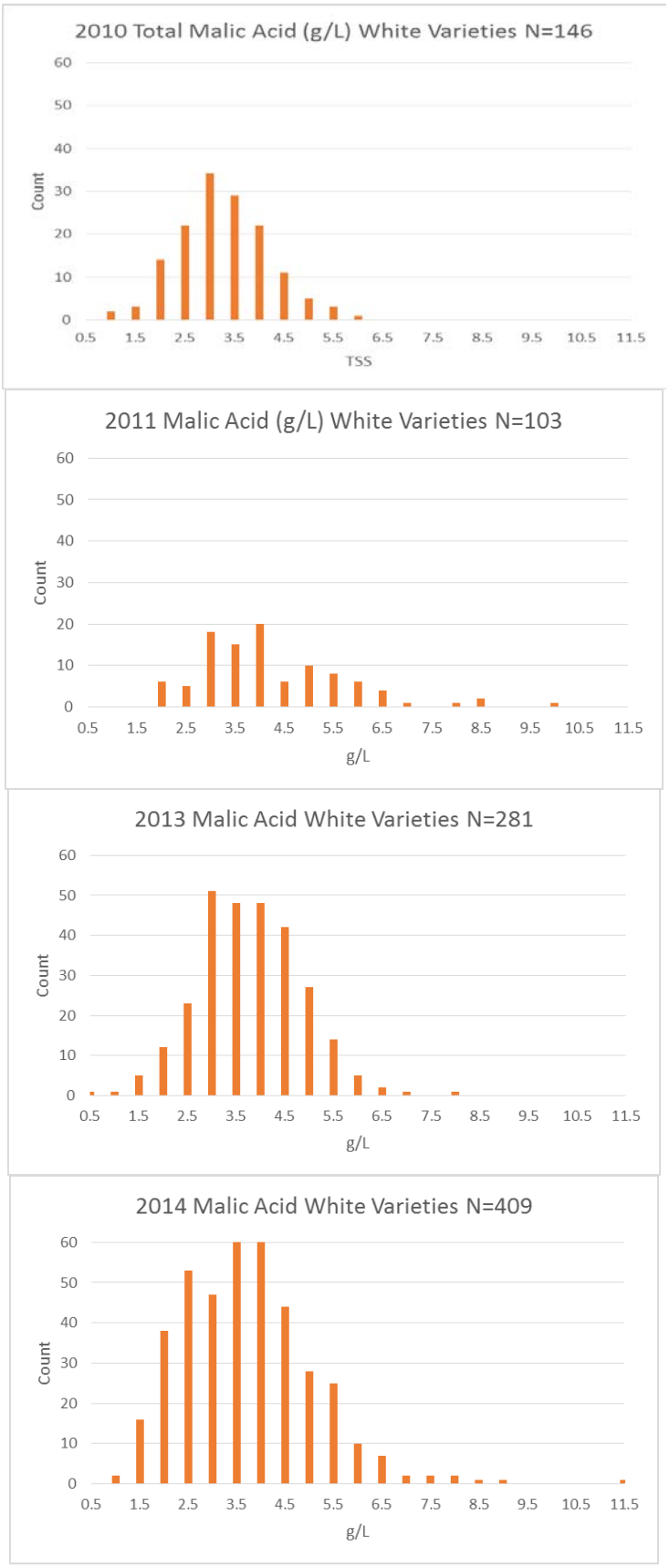


Figure 6.4.4.1. Distribution of malic acid (g/L) of (frozen/thawed) berry samples collected over four seasons (2009/10, 2010/11, 2012/13 and 2013/14) from white varieties and selected clones in the CSIRO germplasm collection. Count = n^{o} of varieties.

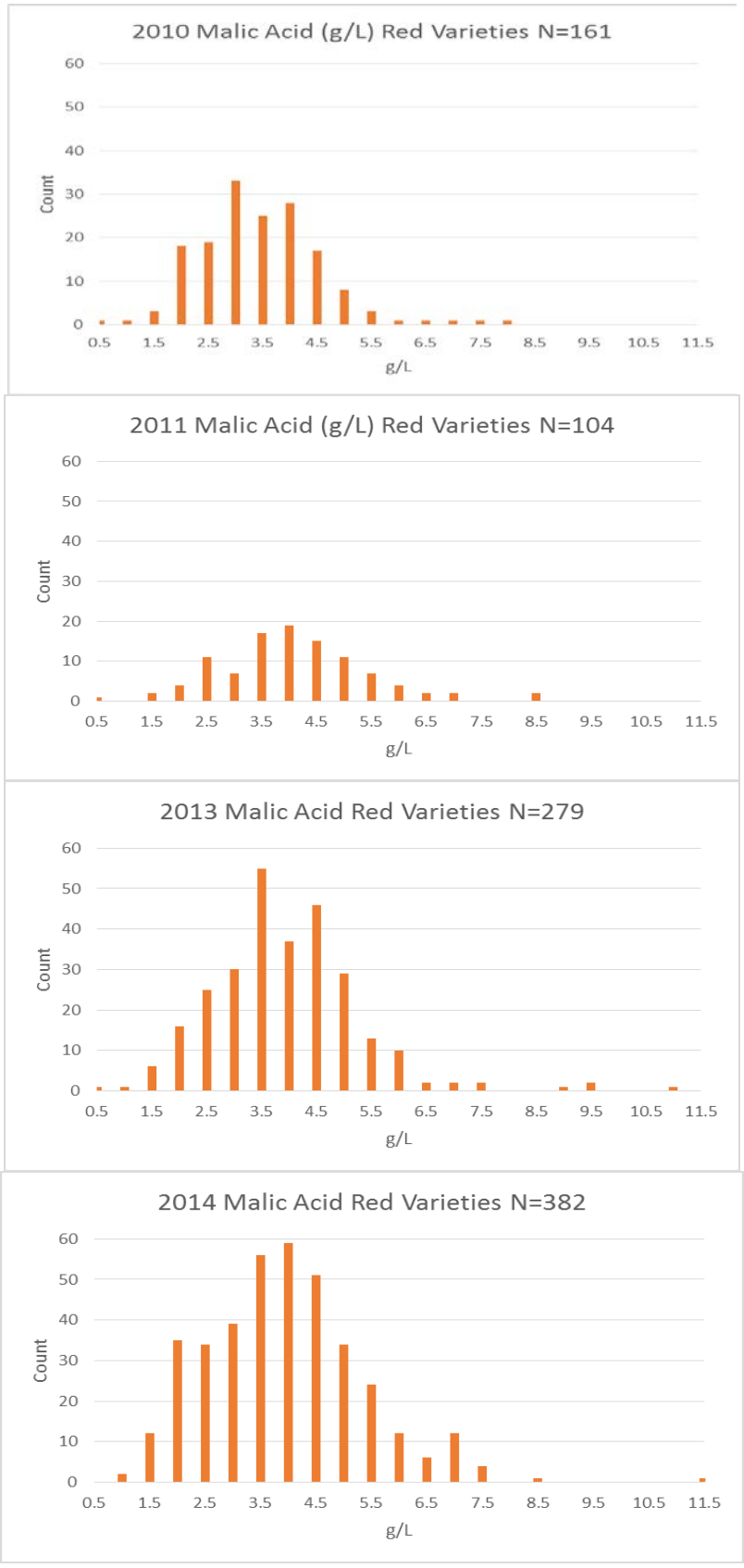


Figure 6.4.4.2. Distribution of malic acid (g/L) of (frozen/thawed) berry samples collected over four seasons (2009/10, 2010/11, 2012/13 and 2013/14) from red varieties and selected clones in the CSIRO germplasm collection. Count = n^{o} of varieties.

6.4.5 Tartaric acid

For white varieties established at the CSIRO Merbein site, the tartaric acid concentration ranged from 2 to 8.5 g/L with a peak at 6.5-7 g/L in the 2009/10 season and from 2 to 7 g/L with a peak at 4.5 g/L in 2010/11 (Figure 6.4.5.1). For white varieties located at the CSIRO Irymple site the tartaric acid concentration ranged from 2 to 8.5 g/L with a peak at 5 g/L in 2012/13 and from 1 to 8 g/L with a peak at 5.5 g/L in 2013/14. Correlations between seasons for tartaric acid were low and rarely significant (r = -.08 to 0.26) indicating that tartaric acid levels are more influenced by seasonal conditions and site than by the genotype. Consequently there were no white winegrape varieties which consistently had low levels of tartaric acid. In contrast, there were a number that consistently had high levels of tartaric acid (> 6 g/L). These included Chardonnay, Muscadelle, Himrod, Sauvignon, Schonburger, Albana, Malvasia Rioja and Fiano.

For red varieties established at the CSIRO Merbein site, the tartaric acid concentration ranged from 1 to 9 g/L with a peak at 7 g/L in the 2009/10 season and from 0.5 to 8.5 g/l with a peak at 6. 5 g/L in 2010/11 (Figure 6.4.5.2). For red varieties located at the CSIRO Irymple site the tartaric acid concentration ranged from 2 to 9 g/L with a peak at 5.5 g/L in 2012/13 and from 2 to 8 g/L with a peak at 5.5 g/L in 2013/14. As with the white varieties, correlations between seasons for tartaric acid were low and rarely significant (r = -.08 to 0.26) for the red varieties indicating that tartaric acid levels are more influenced by seasonal conditions and site than by the genotype. Consequently there were no red winegrape varieties which consistently had low levels of tartaric acid. In contrast, there were a number that consistently had high levels of tartaric acid (> 6 g/L). These included Mavronemeas, Grosse Blaue, Villa Nueva, Grignolino, Teroldego, Saint Laurent, Pinot Noir, Rubired, Meunier, Gropello Gentile, Vespolina, Marechal Foch and Bastardo.

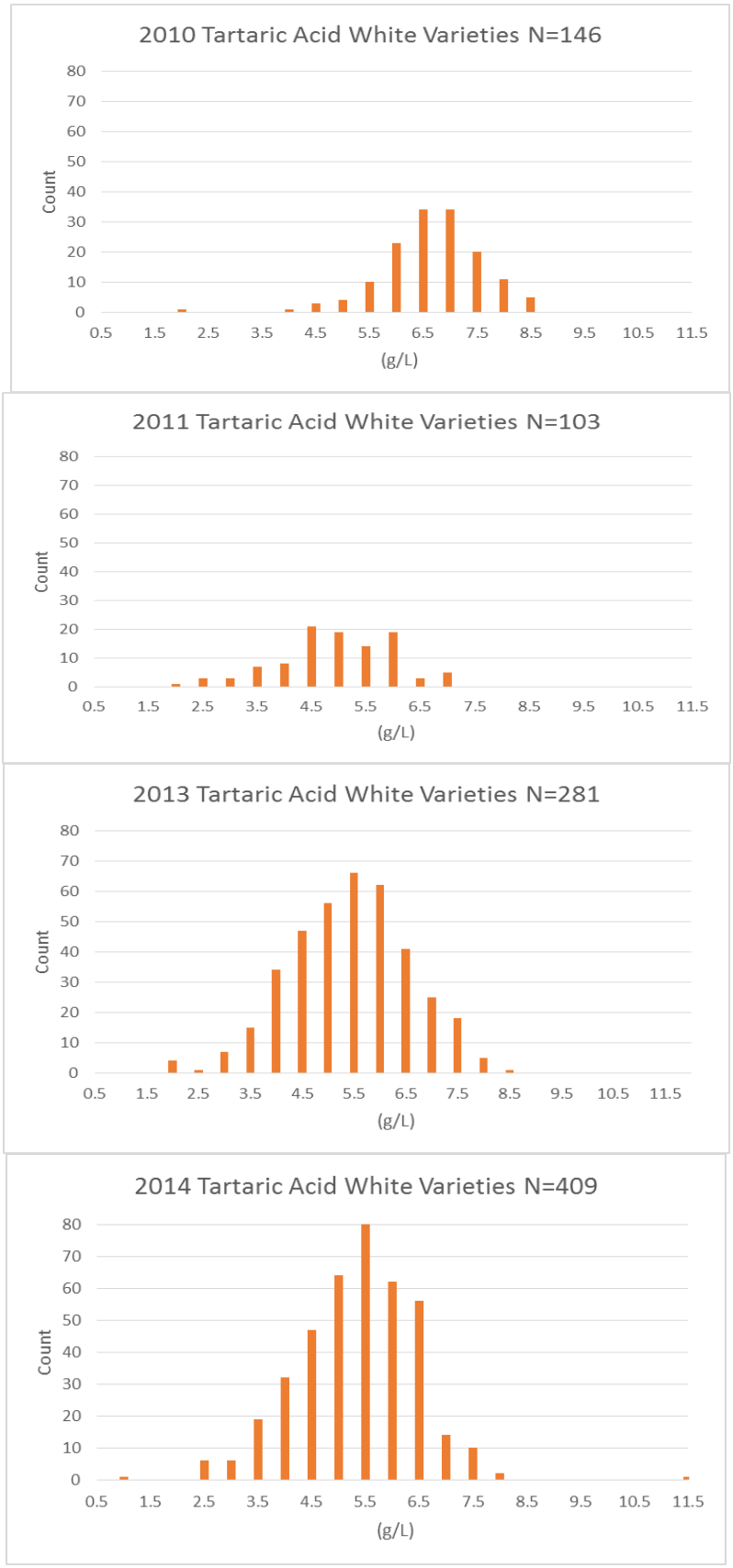


Figure 6.4.5.1. Distribution of tartaric acid (g/L) of (frozen/thawed) berry samples collected over four seasons (2009/10, 2010/11, 2012/13 and 2013/14) from white varieties and selected clones in the CSIRO germplasm collection. Count = n^{o} of varieties.

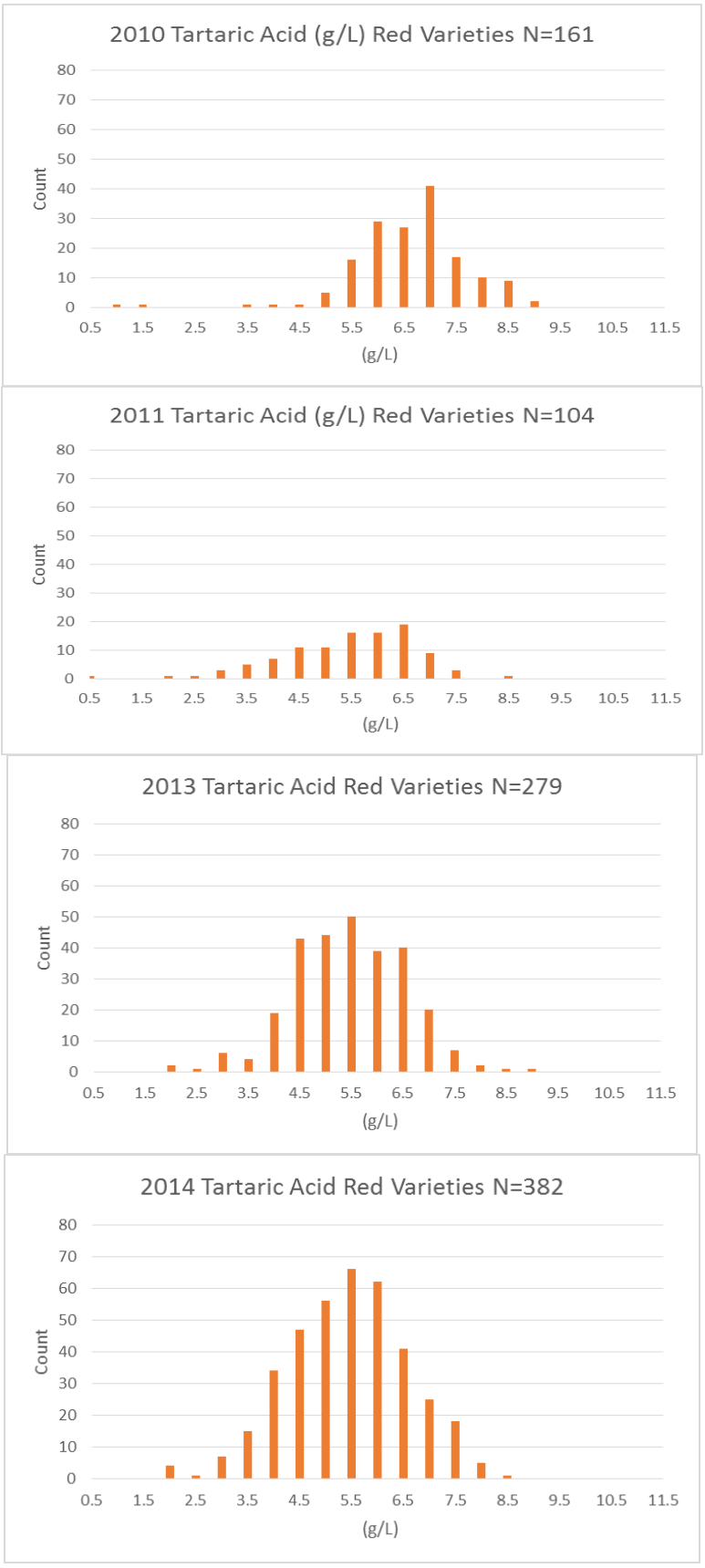


Figure 6.4.5.2. Distribution of tartaric acid (g/L) of (frozen/thawed) berry samples collected over four seasons (2009/10, 2010/11, 2012/13 and 2013/14) from red varieties and selected clones in the CSIRO germplasm collection. Count = n^{o} of varieties.

6.4.6. Yeast assimilable nitrogen

Successful fermentation is reliant on sources of nitrogen being available in the must for consumption by yeasts, i.e. yeast assimilable nitrogen. It is generally considered that a level of 150 mg/L is essential to minimise the risk of delayed or 'stuck' fermentation during winemaking and prevent the formation of hydrogen sulphide (Iland et al. 2000). Diammonium phosphate (DAP), an added expense, may be added to the must or during fermentation as an additional source of N for consumption by yeasts to stimulate fermentation and minimise these problems.

The distribution of YAN of the white varieties located at both the CSIRO Merbein and Irymple sites was reasonably consistent across the seasons, ranging from 50 - 700 g/L with a peak around 250 - 300 g/L (Figure 6.4.6.1). For the white varieties, highly significant correlations for YAN between seasons (r = 0.26 - 0.69) indicate a very strong effect of genotype, despite the different seasonal conditions, the use of different sites and the different levels of maturity. White varieties which consistently had YAN levels below the critical value of 150 mg/L included Picolit, Malvasia di Candia, White Vernaccio, Slankamenka, Doradillo, Feher Szagos, Seyval, Ortrugo, Verduzzo, Verduzzo Friulano, Pollux, Albillo and Fiano. These varieties would require addition of DAP to minimise the risk of problems with fermentation. The very few white varieties that consistently had very high levels of YAN (mean > 400 mg/L) included Salvador, Delizia di Vaprio, Aurora and Verdelho.

The distribution of YAN of the red varieties located at both the CSIRO Merbein and Irymple sites was reasonably consistent across the seasons, ranging from 100 - 850 g/L with a peak around 250 - 300 mg/L (Figure 6.4.6.2). For the red varieties, highly significant correlations for YAN between seasons (r = 0.24 - 0.57) indicate a significant effect of genotype despite the different seasonal conditions, the use of different sites and the different levels of maturity. Red varieties which consistently had YAN levels below the critical value of 150 mg/L included Tyrian, Rondinella, Cabernet Sanzey, Piquepoul, Portugais Bleu, Ughetta, Kadarka, Grey Riesling, Kavadarski Drenak, Mataro, Siderites and Uva di Troia. These varieties would require addition of DAP to minimise the risk of problems with fermentation. The very few red varieties that consistently had very high levels of YAN (mean > 400 g/L) included Bonarda, Royalty, Marechal Foch, Cascade and Cinsaut.

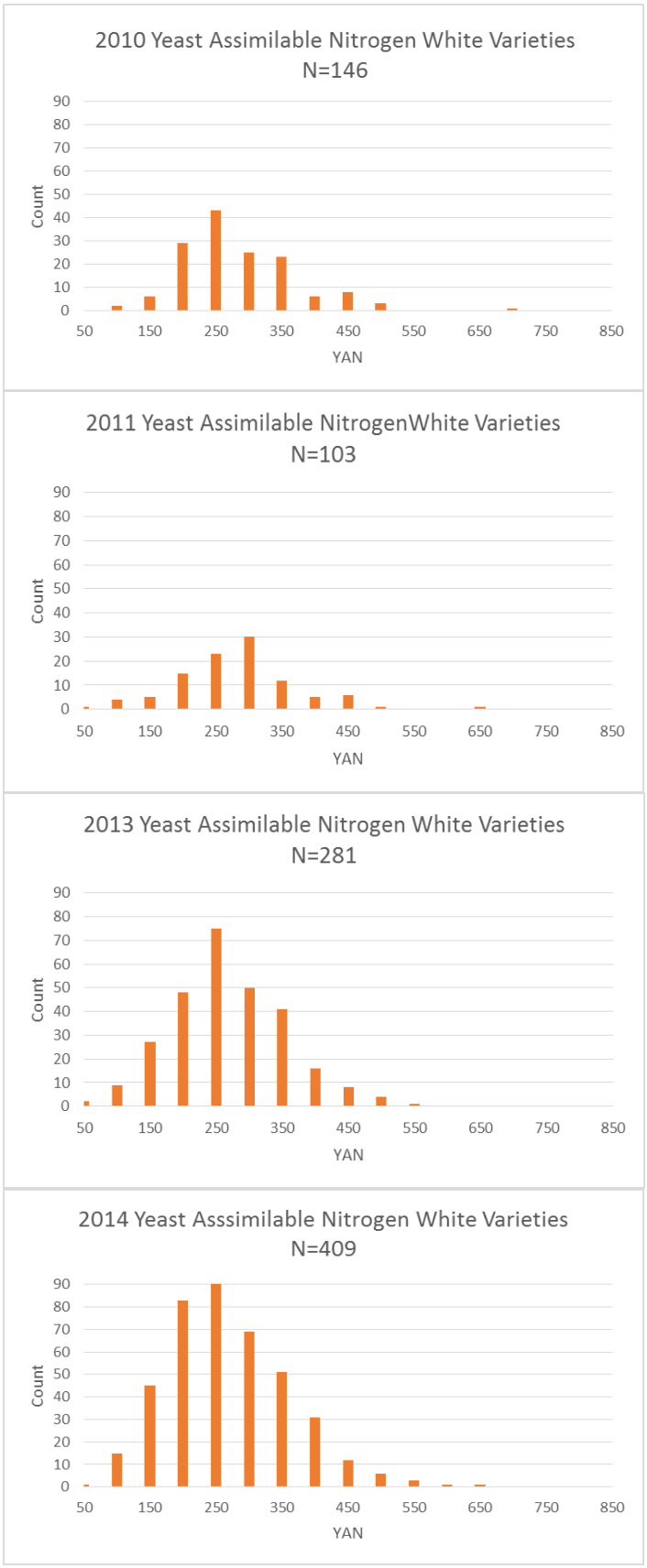


Figure 6.4.6.1. Distribution of yeast assimilable nitrogen (YAN, mg/L) of (frozen/thawed) berry samples collected over four seasons (2009/10, 2010/11, 2012/13 and 2013/14) from white varieties and selected clones in the CSIRO germplasm collection. Count = n^{o} of varieties.

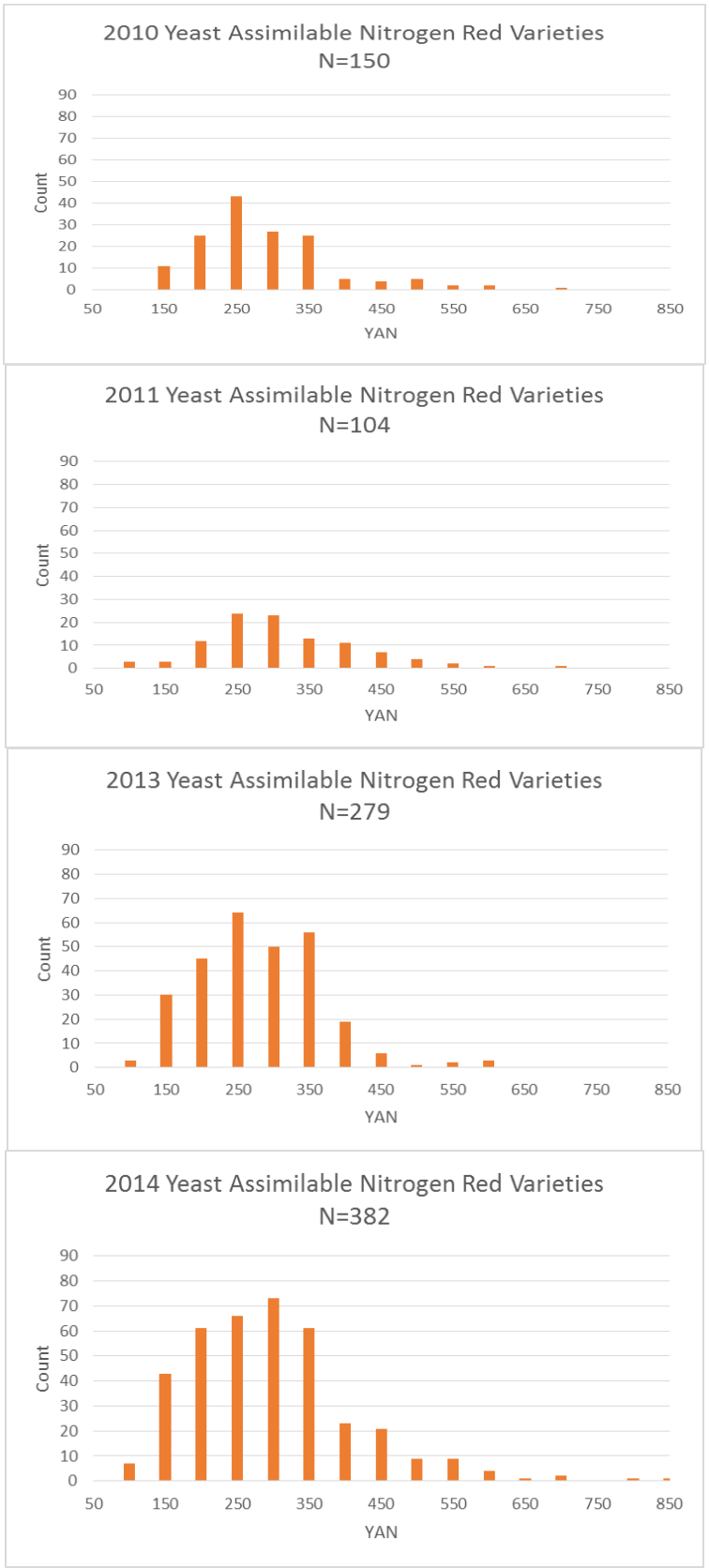


Figure 6.4.6.2. Distribution of yeast assimilable nitrogen (YAN) of (frozen/thawed) berry samples collected over four seasons (2009/10, 2010/11, 2012/13 and 2013/14) from red varieties and selected clones in the CSIRO germplasm collection. Count = n^{o} of varieties.

6.4.7. Relationships between key variables of fruit composition

Correlation coefficients describing relationships between sampling date, berry weight and measurements of berry composition (total soluble solids, pH, titratable acidity, malic acid, tartaric acid and yeast assimilable nitrogen) are provided for each season in Table 6.4.7.1. Leaf area index has also been included because preliminary analyses across the dataset indicated relationships with some of the key variables. Despite the different climatic conditions and sites and issues of maturity at sampling, a number of consistent, highly significant relationships ($P<0.001$) are described, many for the first time, which have significant implications for the selection of varieties for future wine production and selection of criteria for inclusion in targeted breeding studies.

The highly significant relationships with sampling date (Table 6.4.7.1) indicate that later ripening varieties were likely to have larger berries in all seasons, lower levels of total soluble solids (in 20012/13 and 2013/14), higher pH (all seasons), lower levels of titratable acidity (all seasons) and lower levels of YAN (all seasons). There were also trends for the later ripening varieties to have lower malic acid (2013/14) and tartaric acid (2012/13 and 2013/14). Such results indicate compositional benefits and potential reductions in winemaking costs associated with pH adjustment, from the adoption of early ripening rather than later ripening varieties to extend the harvest season and ripen in cooler conditions.

The highly significant relationships with berry weight (Table 6.4.7.1) indicate that varieties with larger berries are likely to have significantly lower TSS (2009/10 and 2010/11), higher pH (all seasons), lower TA (all seasons except 2010/11) and lower tartaric acid (all seasons). There was no relationship between berry weight and malic acid or YAN in any season. At the CSIRO Merbein site with older vines (seasons 2009/10 and 2010/11) there was also a significant relationship between berry weight and LAI suggesting a link to vine vigour. These results indicate compositional benefits from adoption of varieties with smaller berries, particularly in regard to costs associated with pH adjustment.

The highly significant relationships with TSS (Table 6.4.7.1) indicate that varieties with higher TSS at sampling would have higher pH (2009/10, 2012/13) and higher tartrate and YAN (all seasons). There was no association between TSS and TA or malate in any season. While the association with pH is not unexpected, the very positive relationships between TSS and tartaric acid or YAN were unexpected and difficult to explain. They suggest either a strong linkage with ripening processes in the accumulation of TSS, tartaric acid and YAN across the varieties or the possibility that increases in both TSS, TA and YAN may be associated with berry shrivel. While the latter argument may hold true for TSS and tartrate due to the negative associations with berry weight, it does not explain the YAN association as there was no relationship between berry weight and YAN in any season. A possible explanation for the association between TSS and YAN could be a linkage with early ripening as there was a negative correlation between YAN and sampling date, suggesting that less YAN is available with extended ripening, possibly due to loss of arginine and increased levels of proline in the berries which would not be available for consumption by yeasts. A more detailed study of berry N and amino acid profiles of the berry samples could provide further insight into this issue.

There was a very strong negative relationship between pH and TA in all seasons (r = -.63 to -.71), an indication that up to 50% of the variation in pH could be accounted for by the variability in TA across the varieties despite the differences in climate, site and maturity levels (Table 6.4.7.1). These results indicate that varieties with higher levels of TA can be identified to minimise requirements for pH adjustment and reduce winemaking costs. There was however, unexpectedly, no relationship between pH and malic acid or tartaric acid (or YAN), except for positive relationships in 2009/10. These positive relationships are difficult to explain taking into account the negative association between pH and TA. It should be noted that the hot conditions and limited water supply at the Merbein site in that season may have been a contributing factor. Furthermore, TA was positively linked to malic acid levels in 3 seasons, except 2009/10, accounting for 10%, 34% and 44% of the variation in TA respectively in those seasons. TA was positively correlated with tartaric acid in only one season, 2013/14 and with YAN in two seasons (2012/13 and 2013/14). Relationships between malic acid and tartaric acid levels across the varieties varied with season. In the cool, wet 2011 season with delayed ripening there was a strong negative association between the acids compared to the positive relationship in 2012/13 and to a lesser degree ($p < 0.01$) in 2013/14. In contrast, there were strong relationships between malic acid and YAN in all seasons and between malic acid and LAI in two seasons, with a weaker but significant association in 2013/14 ($p<0.01$) suggesting that malic acid levels may be linked to canopy vigour, shade and N uptake. There were also very strong relationships between tartaric acid and YAN, indicating links with N uptake and amino acid profiles, particularly arginine across the varieties. As discussed above, a more detailed study of the berry N and amino acid profiles of the berry samples could provide further insight into this issue.

Table 6.4.7.1. Matrix of correlation coefficients (r) describing relationships between sampling date, berry weight (bewt.), total soluble solids (TSS), pH, titratable acidity (TA), malic acid (mal.), tartaric acid (tar.) and yeast assimilable nitrogen (YAN) and leaf area index (LAI) each season (2009/10, 2010/11, 2012/13, 2013/14). Highly significant correlations are highlighted in bold ($p<0.001$).

2010	**date**	**bewt.**	**TSS**	**pH**	**TA**	**mal.**	**tar.**	**YAN**
bewt	**.39**	-						
TSS	.11	**-.30**	-					
pH	**.20**	**.27**	**.28**	-				
TA	**-.29**	**-.32**	.05	**-.66**	-			
malate	-.05	.04	.11	**.24**	.13	-		
tartate	-.09	**-.26**	**.45**	**.18**	.05	.09	-	
YAN	**-.21**	-.01	**.39**	**.27**	.09	**.38**	**.44**	-
LAI	**-**	**.27**	-.06	.07	.07	**.43**	.07	.08

2011	**date**	**bewt.**	**TSS**	**pH**	**TA**	**mal.**	**tar.**	**YAN**
bewt	**.33**	-						
TSS	.08	**-.39**	-					
pH	**.36**	**.26**	.17	-				
TA	**-.38**	-.10	.02	**-.63**	-			
malate	.01	-.05	.00	-.03	**.33**	-		
tartate	-.15	**-.37**	**.36**	-13	.14	**-.27**	-	
YAN	-.13	-.09	**.22**	-.08	.03	**.29**	**.37**	
LAI	-	**.19**	-.04	.04	.12	**.27**	.06	**.**11

2013	**date**	**bewt.**	**TSS**	**pH**	**TA**	**mal.**	**tar.**	**YAN**
bewt	**.28**	-						
TSS	**-.18**	-.10	-					
pH	**.19**	**.27**	**.26**	-				
TA	**-.18**	**-.22**	.01	**-.71**	-			
malate	-.13	.03	.07	.00	**.58**	-		
tartate	**-.18**	**-.19**	**.48**	.04	.16	**.21**	-	
YAN	**-.25**	-.07	**.29**	.02	**.29**	**.39**	**.29**	-

2014	**date**	**bewt.**	**TSS**	**pH**	**TA**	**mal.**	**tar.**	**YAN**
bewt	**.38**	-						
TSS	**-.22**	-.06	-					
pH	**.43**	**.32**	.12	-				
TA	**-.46**	**-.23**	.04	**-.71**	-			
malate	**-.35**	-.03	.08	-.05	**.66**	-		
tartate	**-.33**	**-.21**	**.18**	-.12	**.29**	.15	-	
YAN	**-.32**	-.09	**.19**	-.13	**.48**	**.56**	**.45**	
LAI	-	.06	-.01	.07	.13	.15	.03	**.19**

6.4.8 Berry anthocyanins and phenolics

Total berry anthocyanins and phenolics were determined for red/black varieties and clones across four seasons for varieties in the CSIRO germplasm collection located at the CSIRO Merbein site in 2009/10 and 2010/11 and at the CSIRO Irymple site in 2012/13 and 213/14 (Figures 6.4.8.1 and 6.4.8.2). In each season there were highly significant correlations between anthocyanins and phenolics (r = 0.76 - 0.78). For anthocyanins, highly significant correlations between seasons (r = 0.76 - 0.94) indicate a very strong effect of genotype, despite the different seasonal conditions, the use of different sites and the different levels of maturity. In each season, correlations between anthocyanins and sample date or TSS were low or not significant (i.e. r < 0.16) indicating that sample date and maturity did not affect the results. However, there were significant negative correlations between colour and berry weight (r = -0.26 to - 0.33) indicating that varieties with large berries tended to have low colour. In all seasons, the distribution of anthocyanins displayed a skewed pattern, ranging from 0.2 - 6.0 mg/g with most varieties and clones having total anthocyanins concentrations in the 0.2 - 0.4 range. Only a small proportion of varieties had total anthocyanins above 1.0 mg/g. For comparison, the mean total anthocyanins of reference varieties Pinot Noir, Cabernet Sauvignon and Shiraz were 0.45, 0.56 and 0.95 mg/g, respectively. Varieties with total anthocyanins below 0.1 mg/g were considered to be not suitable for red wine production. Varieties with total anthocyanins that exceeded 1.5 mg/g, included Saint Macaire, De Chaunac, Dornfelder, Dunkelfelder, Jacquez, Lambrusco, Tyrian, Egiodola, Couderc Noir, Tannat, Lagrein, Teroldego, Petit Verdot, Bonarda, Scarlet, Salvador, Souzao, Rubired and Royalty. Varieties with low levels of total anthocyanins, between 0.1 and 0.3 mg/g, included Opuzensia Rana, Grenache, Rondinella, Sumoll, Mavro Naussis, Kadarka, Antigona, Sangiovese, Prokupac, Herbemont, Corvino and Uva di Troia.

For total phenolics, highly significant correlations between seasons (r = 0.56 - 0.85) indicate a very strong effect of genotype, despite the different seasonal conditions, the use of different sites and the different levels of maturity. In three out of the four seasons (2010/11, 20112/13 and 2013/14) there were highly significant negative correlations between phenolics and sample date (r = -0.20 to -0.27), indicating that late ripening varieties had lower levels of total phenolics. Correlations between total phenolics and TSS were generally not significant or small (i.e. r < 0.2). In all seasons, phenolics were negatively correlated with berry weight (r= -0.26 to -0. 54), an indication that varieties with large berries would have low total phenolics. In all seasons, the distribution of phenolics displayed a skewed pattern, ranging from 0.5 - 3.5 mg/g with peaks around 1.0 - 1.5 au/g. Varieties with high levels of total phenolics (> 2.0 au/g) included Petit Bouschet, Tyrian, Gamay de Bouze, Saint Macaire, Teroldego, Pinot Noir, Saint Macaire, Dunkelfelder, Marzemino, Egiodola, Rubired, Souzao and Royalty.

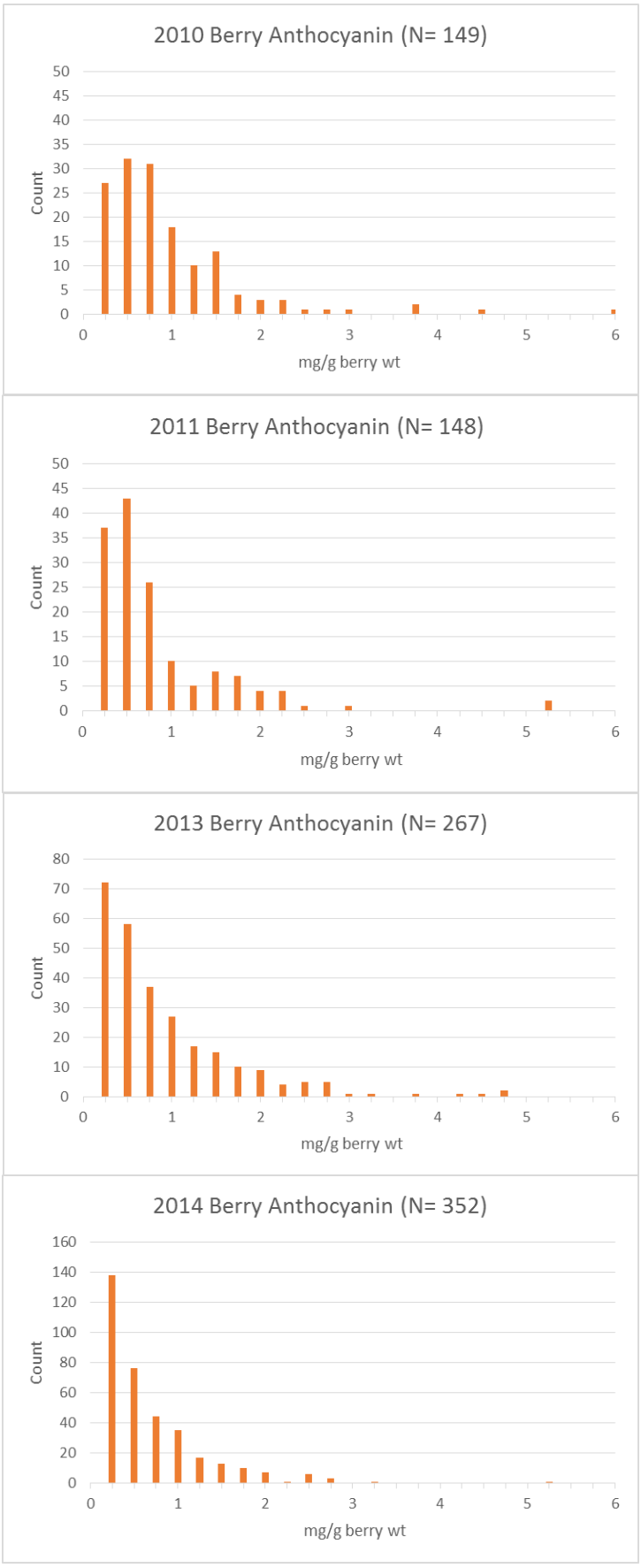


Figure 6.4.8.1. Distribution of total anthocyanins (mg/g) for berry samples collected over four seasons (2009/10, 2010/11, 2012/13 and 2013/14) from red varieties and selected clones in the CSIRO germplasm collection. Count = n^{o} of varieties.

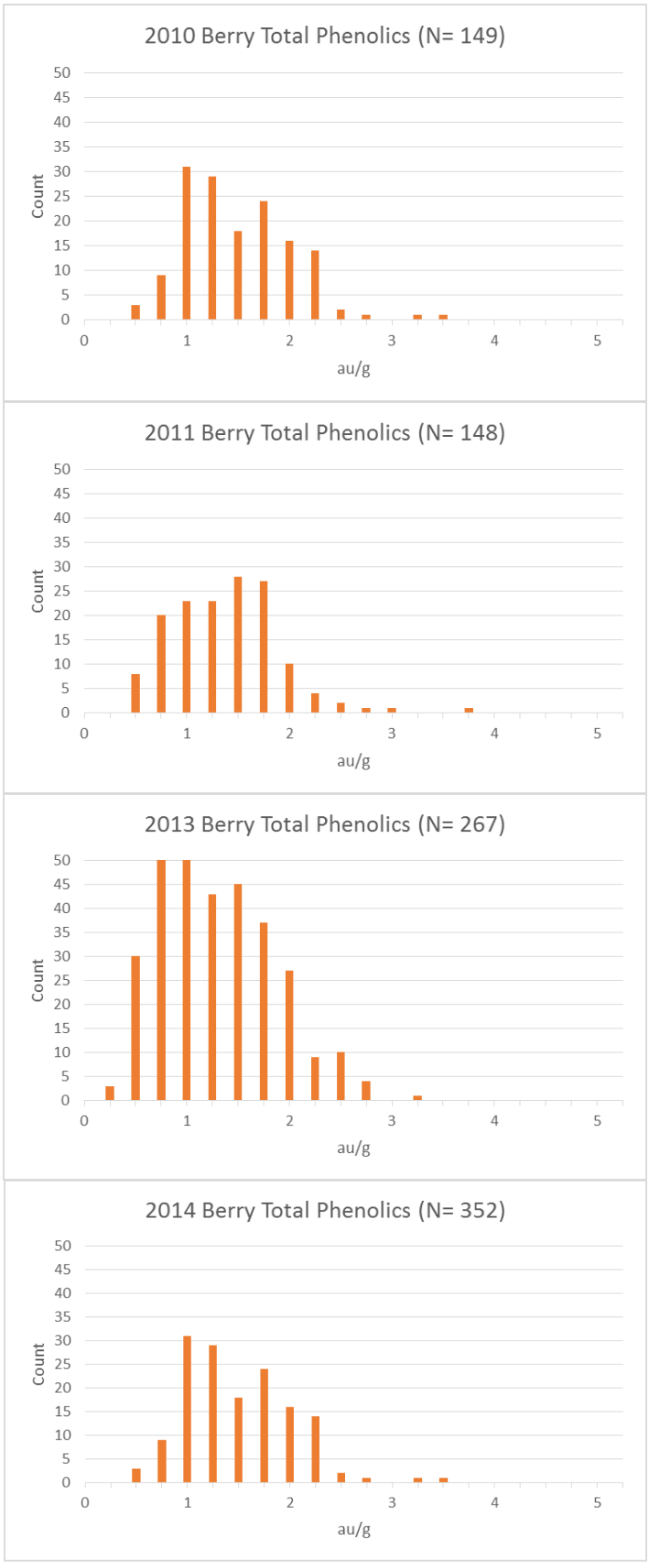


Figure 6.4.8.2. Distribution of total phenolics (au/g) for berry samples collected over four seasons (2009/10, 2010/11, 2012/13 and 2013/14) from red varieties and selected clones in the CSIRO germplasm collection. Count = n^{o} of varieties.

6.4.9. Mineral composition

Berry mineral composition was determined for a subset of samples retained from the Merbein site in 2009/10 and for samples from the Irymple site in 2013/14. In total there were 265 samples common to both sites. This study was undertaken to provide underpinning data to explore relationships between berry mineral composition, particularly K and key measurements of berry composition determined above. Mineral elements which recorded detectable and varying concentrations in the berry included K, Na, Ca, Mg, Zn, B, P and S. Surprisingly, in both seasons there were extremely large differences (10-fold or more) in berry composition across the varieties (Figures 6.4.9.1-8). Results of this magnitude were unexpected as the varieties in each season were managed on the one site with identical management. Except for Na, the ranges were similar in both seasons (sites). It is likely that the higher concentrations of Na in 2009/10 in some varieties could be associated with the limited application of irrigation water under hot, drought conditions as well as differences associated with the site (i.e. soil type, drainage and irrigation method). The highly significant correlations ($p<0.001$) between seasons for K (0.36), Ca (0.58), Mg (0.55), P (0.25), S (0.32) and B (0.19) indicate significant varietal control of berry mineral composition. These strong varietal effects warrant further investigation into the genetic basis for these responses which could be related to either differential uptake by the plant or partitioning into the berry during its development and ripening. Low correlations between seasons (sites) for Na and Zn indicate that these elements are more likely to be associated with site or climatic effects. It should be noted, that a much smaller number of samples were available for analysis of mineral compostion from the 2009/10 season compared to the 2013/14 season.

6.4.9.1. Potassium

The distribution of berry K followed a normal pattern and was similar for both the red and white varieties and consistent between seasons, ranging from very low concentrations, below 50 mg/L, to more than 360 mg/L, with peaks around 160 mg/L (Figure 6.4.9.1). White varieties with high berry K (200 mg/L) in both seasons included Baresana, Liliorila, Rabaner, Beogradska Rana, 10868 Seibel, Verdelho, Trajadura, Fernao Pires, Melon, Schonburger, Verduzzo, Lignan, Bianca, Bacchus, Fernao Pires, Agostenga, Castor, Delizia di Vaprio, Verdicchio, Ehrenfelser, Perle de Csaba, Leanoy, Lakhegyi Mezes, Mtsvane and Ezerfutu. Red varieties with high berry K included Marocain Noir, Corbeau, Grignolino, Cionoria, Negrette, Tempranillo, Jacquez, Pinot Gris, Pinotage, Marechal Foch, Cabernet Franc, Cabernet Sauvignon, Bequignol, Pinot Noir, Gascon, Bastardo, Pinot Precose, Marzemino and Cascade.

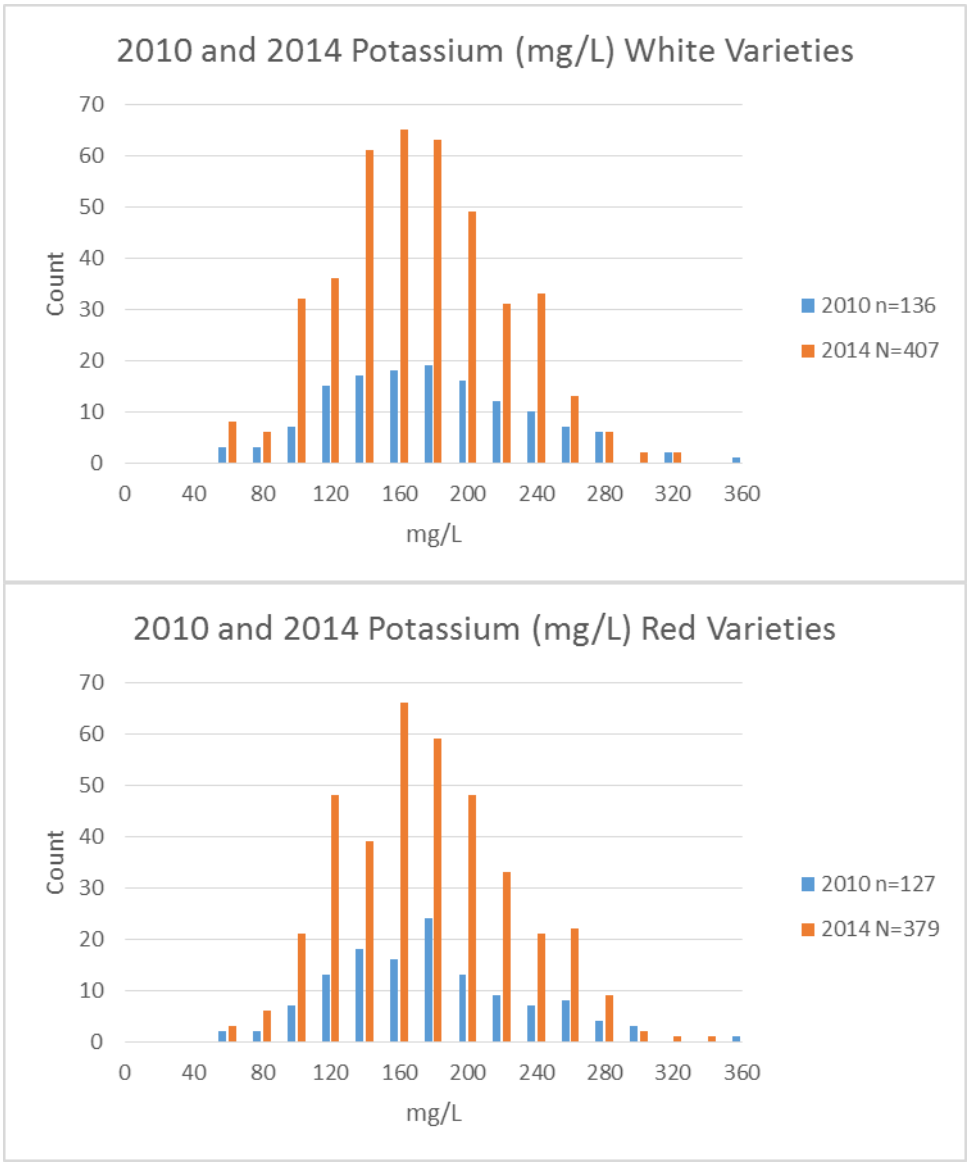


Figure 6.4.9.1. Distribution of berry K (mg/L) collected over two seasons (2009/10 and 2013/14) from white (top) and red (bottom) varieties and selected clones in the CSIRO germplasm collection. Extracts were from thawed frozen berries. Count = n^{o} of varieties.

6.4.9.2. Phosphorus

The distribution of berry P in the 2009/10 season followed a normal pattern and was similar for both the red and white varieties, ranging from 8 to 38 mg/L with peaks around 20 mg/L (Figure 6.4.9.2). In contrast, in season 2013/14 which included a greater number of varieties, the distribution over a similar range was skewed toward a higher proportion of the varieties having lower values than in 2009/10 with a peak concentration of 14 mg/L for the white varieties and 14-18 mg/L for the red varieties. This result is most likely due to differences associated with site and differences in soil available P.

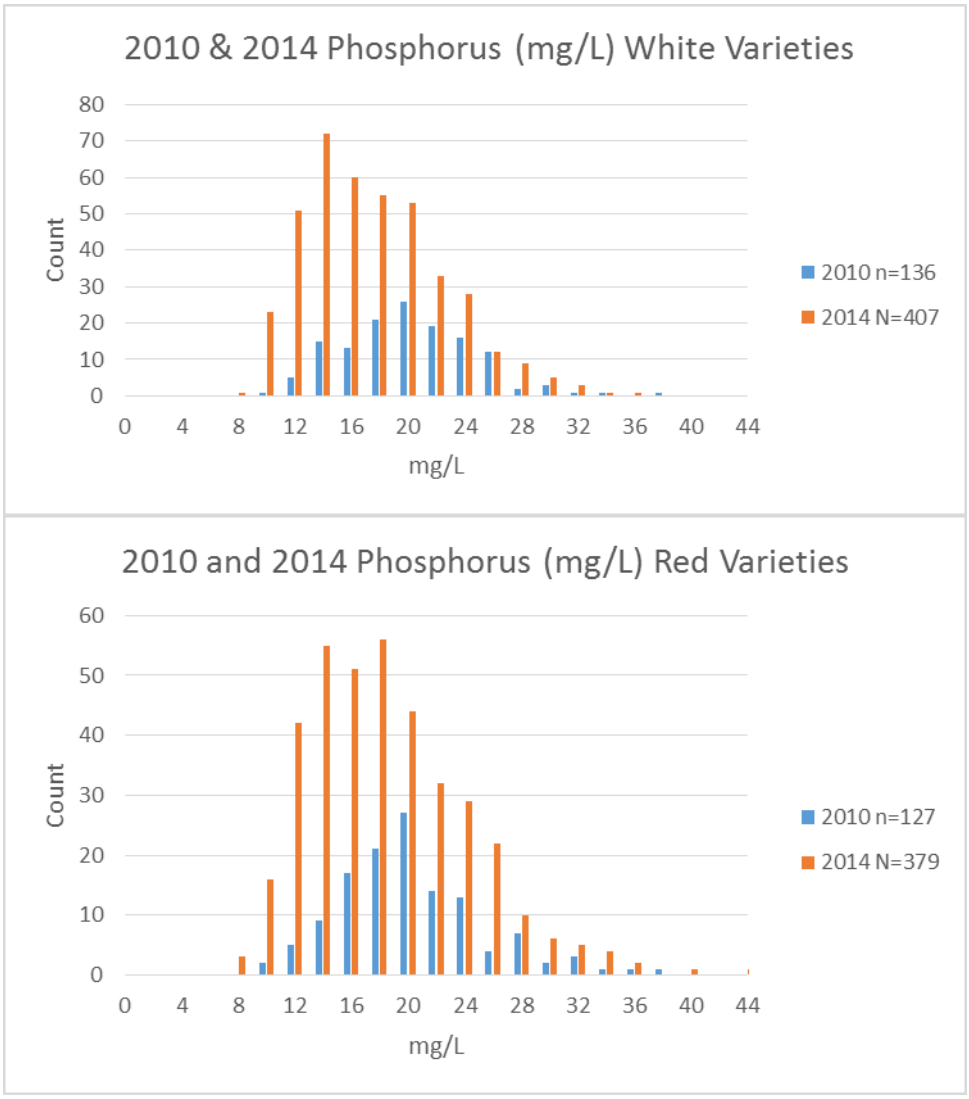


Figure 6.4.9.2. Distribution of berry P (mg/L) collected over two seasons (2009/10 and 2013/14) from white (top) and red (bottom) varieties and selected clones in the CSIRO germplasm collection. Extracts were from thawed frozen berries. Count = n^{o} of varieties.

6.4.9.3. Sulphur

The distribution of berry S followed a normal pattern and was similar for both the red and white varieties and consistent between seasons, ranging from low concentrations of 3 mg/L to more than 17 mg/L, with peaks around 7 mg/L (Figure 6.4.9.3).

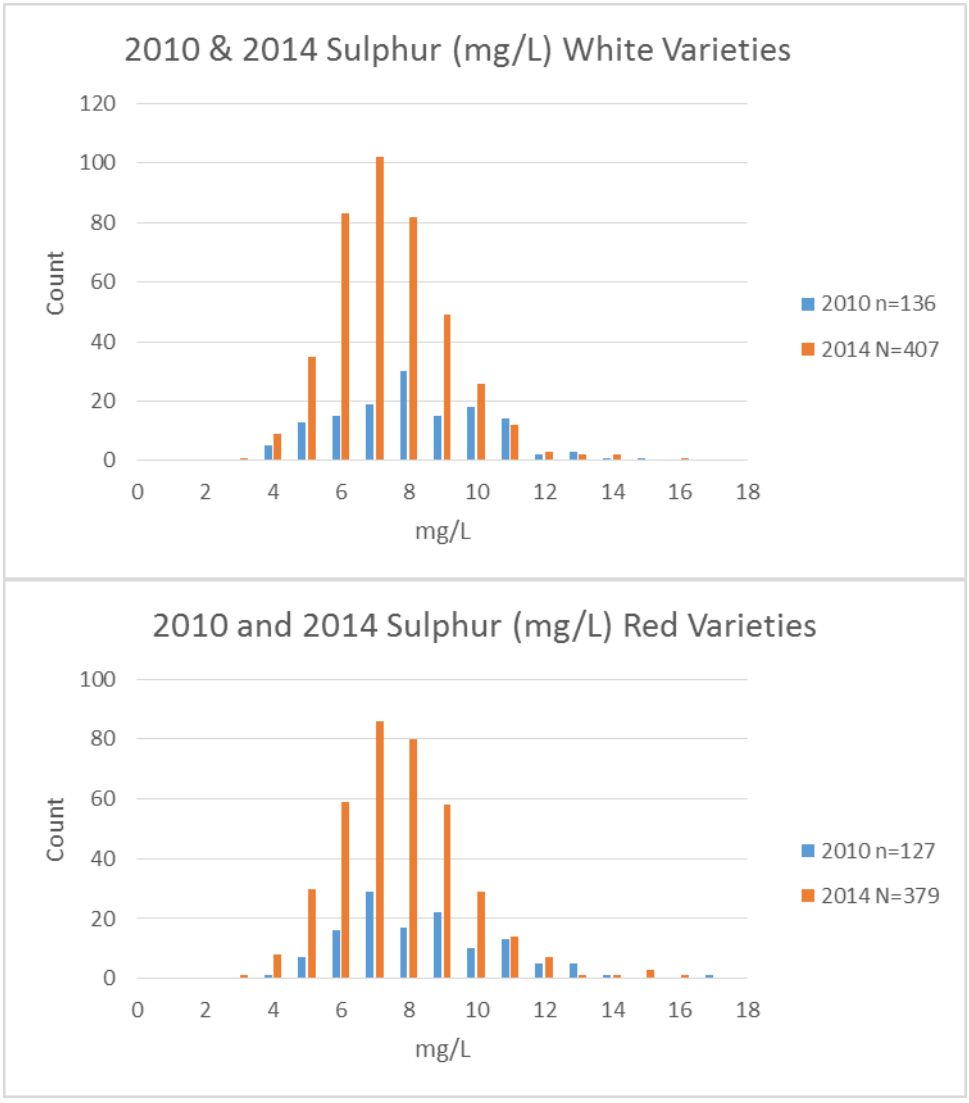


Figure 6.4.9.3. Distribution of berry S (mg/L) collected over two seasons (2009/10 and 2013/14) from white (top) and red (bottom) varieties and selected clones in the CSIRO germplasm collection. Extracts were from thawed frozen berries. Count = n^{o} of varieties.

6.4.9.4. Magnesium

The distribution of berry Mg followed a normal pattern and was similar for both the red and white varieties and consistent between seasons, ranging from low concentrations of 5 mg/L to more than 19 mg/L, with peaks around 9 mg/L (Figure 6.4.9.4). Most varieties had Mg concentrations in the range from 7-11 mg/L.

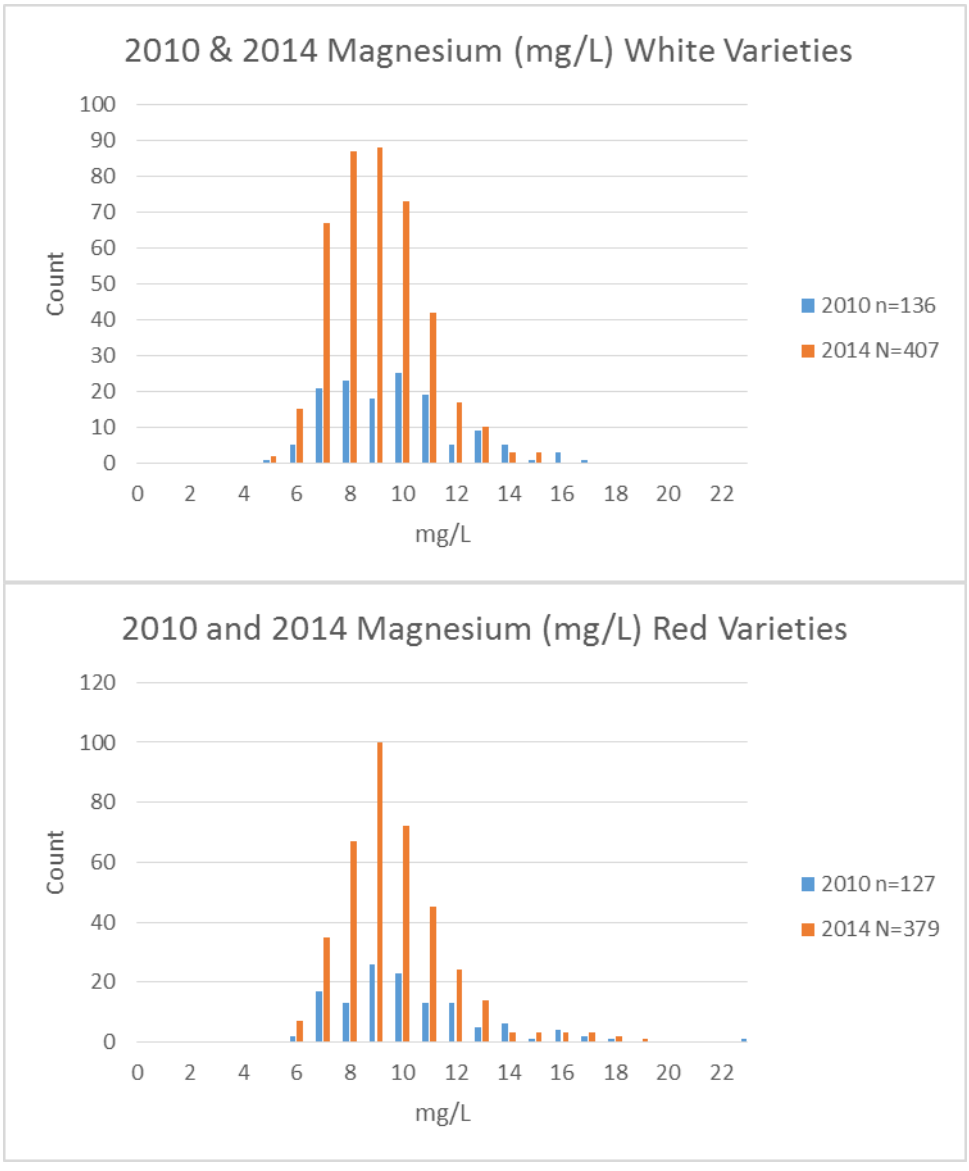


Figure 6.4.9.4. Distribution of berry Mg (mg/L) collected over two seasons (2009/10 and 2013/14) from white (top) and red (bottom) varieties and selected clones in the CSIRO germplasm collection. Extracts were from thawed frozen berries. Count = n^{o} of varieties.

6.4.9.5. Calcium

The distributions of berry Ca were similar for both the red and white varieties but varied to some degree between seasons (Figure 6.4.9.5). In the 2009/10 season berry Ca concentrations were skewed toward lower values, with a range from 5 - 22 mg/L with a peak at 8 mg/L (white varieties) and 10 mg/L (red varieties). The distributions followed more normal patterns in 2013/14 with a range from 6 - 26 mg/L and peak of 10 mg/L.

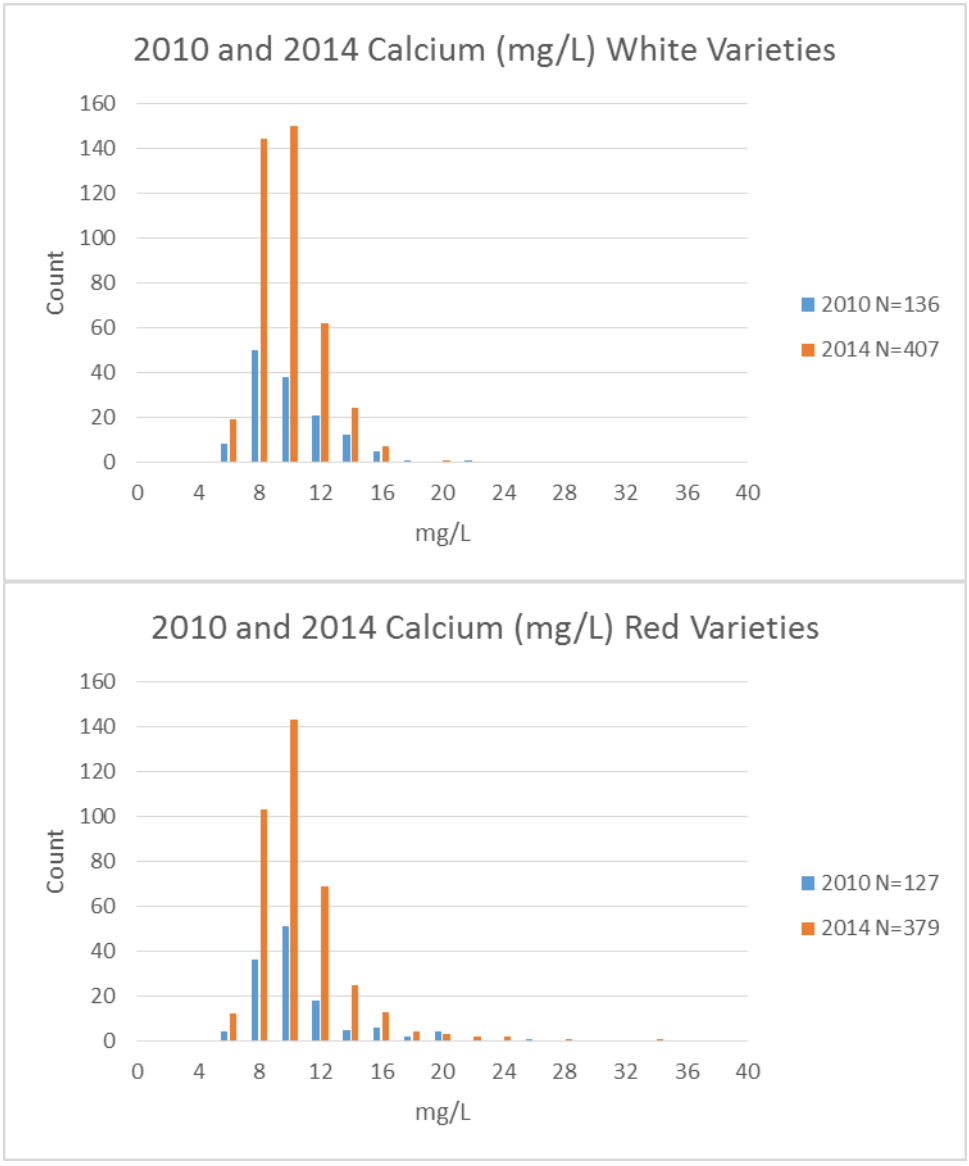


Figure 6.4.9.5. Distribution of berry Ca (mg/L) collected over two seasons (2009/10 and 2013/14) from white (top) and red (bottom) varieties and selected clones in the CSIRO germplasm collection. Extracts were from thawed frozen berries. Count = n^{o} of varieties.

6.4.9.6. Boron

The distribution of berry B followed a skewed pattern with most varieties having low values and a few varieties having relatively high concentrations (Figure 6.4.9.6). B concentrations of both the white and red varieties ranged from 0.5 to 3.0 mg/L with peaks of 1.25 mg/L and 0.75 mg/L for the white varieties and 1.0 mg/L and 1.25 mg/L for the red varieties, in the respective 2009/10 and 2013/14 seasons.

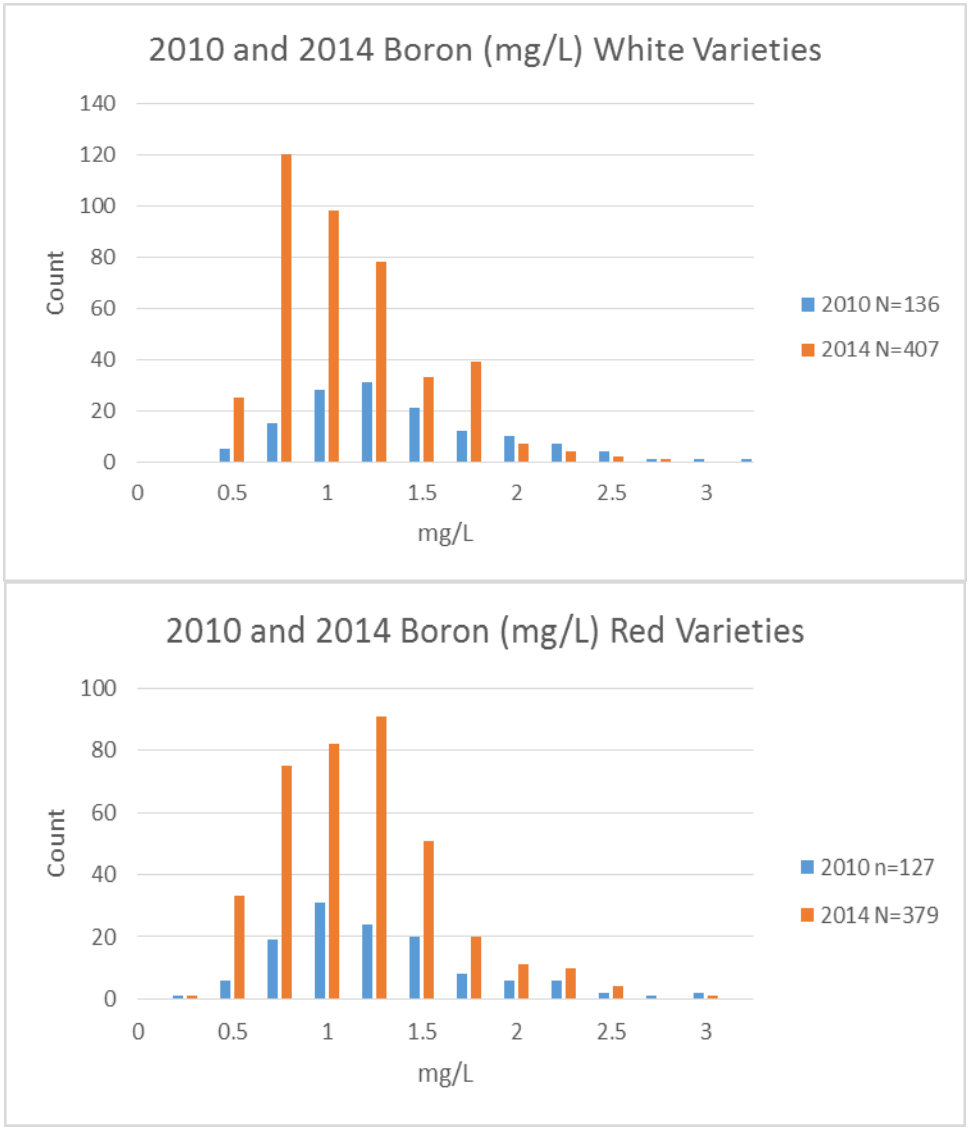


Figure 6.4.9.6. Distribution of berry B (mg/L) collected over two seasons (2009/10 and 2013/14) from white (top) and red (bottom) varieties and selected clones in the CSIRO germplasm collection. Extracts were from thawed frozen berries. Count = n^{o} of varieties.

6.4.9.7. Zinc

The distribution of berry Zn followed a skewed pattern with most varieties having low values and a few varieties having relatively high concentrations (Figure 6.4.9.7). In 2009/10 Zn concentrations of both the white and red varieties ranged from 0.1 to 0.55 mg/L with peaks of 0.15 mg/L. In 2013/14, the range for both the white and red varieties was wider from 0.05 to 0.9 mg/L with a peak at 0.1 mg/L for the white varieties and 0.2 mg/L for the red varieties. The differences between seasons is most likely associated with inclusion of a wider range of varieties in the study but could also be associated with site effects.

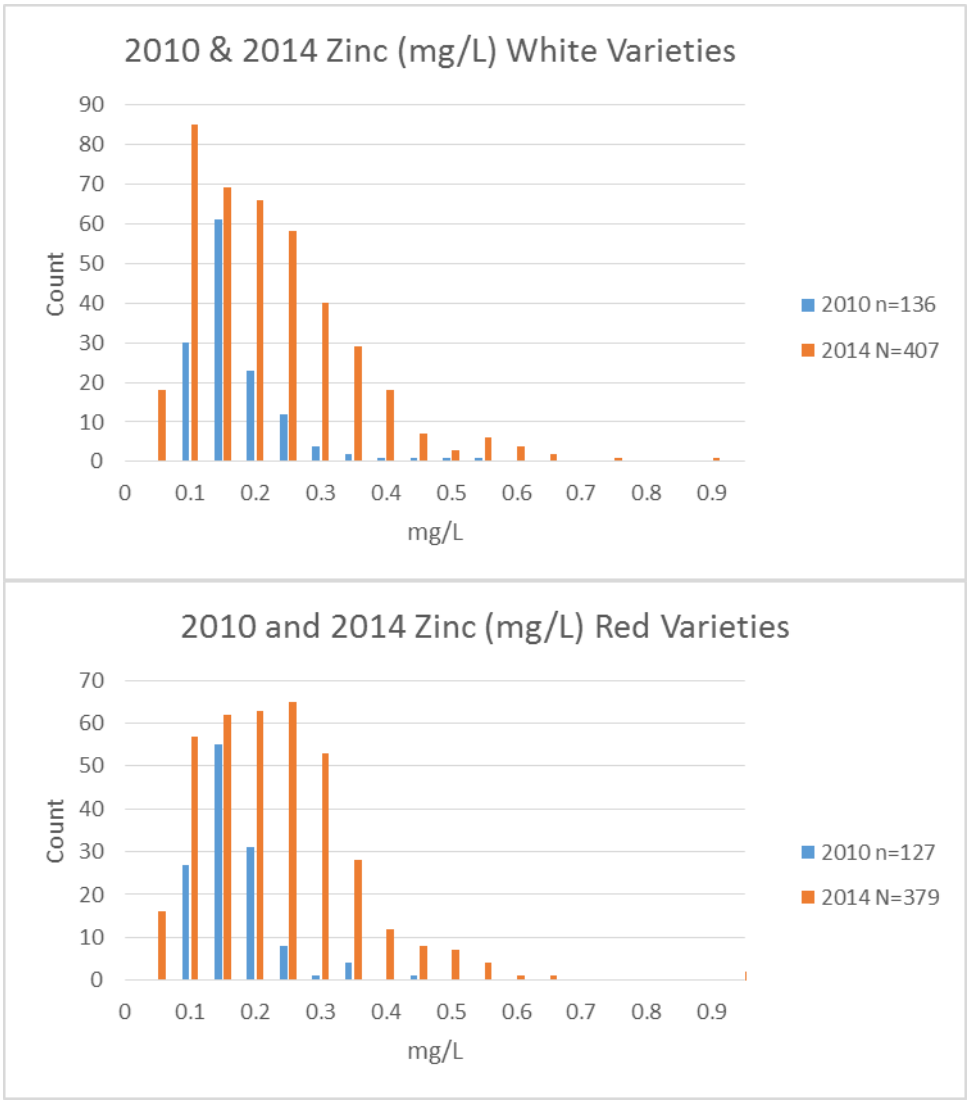


Figure 6.4.9.7. Distribution of berry Zn (mg/L) collected over two seasons (2009/10 and 2013/14) from white (top) and red (bottom) varieties and slected clones in the CSIRO germplasm collection. Extracts were from thawed frozen berries. Count = n^{o} of varieties.

6.4.9.1 Sodium

Most varieties had very low levels of Na in both seasons. The distribution of berry Na followed a strongly skewed pattern with most varieties having low values and a few varieties having relatively high concentrations (Figure 6.4.9.8). In 2009/10, Na concentrations for berries from the CSIRO Merbein site, ranged from 0.25 to 57 mg/L with most varieties having concentrations of less than 5 mg/L. In season 2013/14 there were no varieties which had high concentrations of Na with most having values equal to or less than 0.25 mg/L. The differences between seasons are most likely due to site effects associated with soil type, irrigation method and management and cumulative effects of deficit irrigation applied during the extended drought. Despite the relatively high concentrations of Na found in berries of a few varieties in 2009/10, none exceeded the maximum level of 60 mg/L required by some wineries to meet export standards for wine in some markets (Kerry Degaris, personal communication). Varieties with berries having higher concentrations of Na (e.g. >30 mg/L) at the CSIRO Merbein site in 2009/10 included the white varieties Grocanica and Muscat Ottonel and the red varieties Primitivo di Gioia, Antigona, Bakator and Limberger.

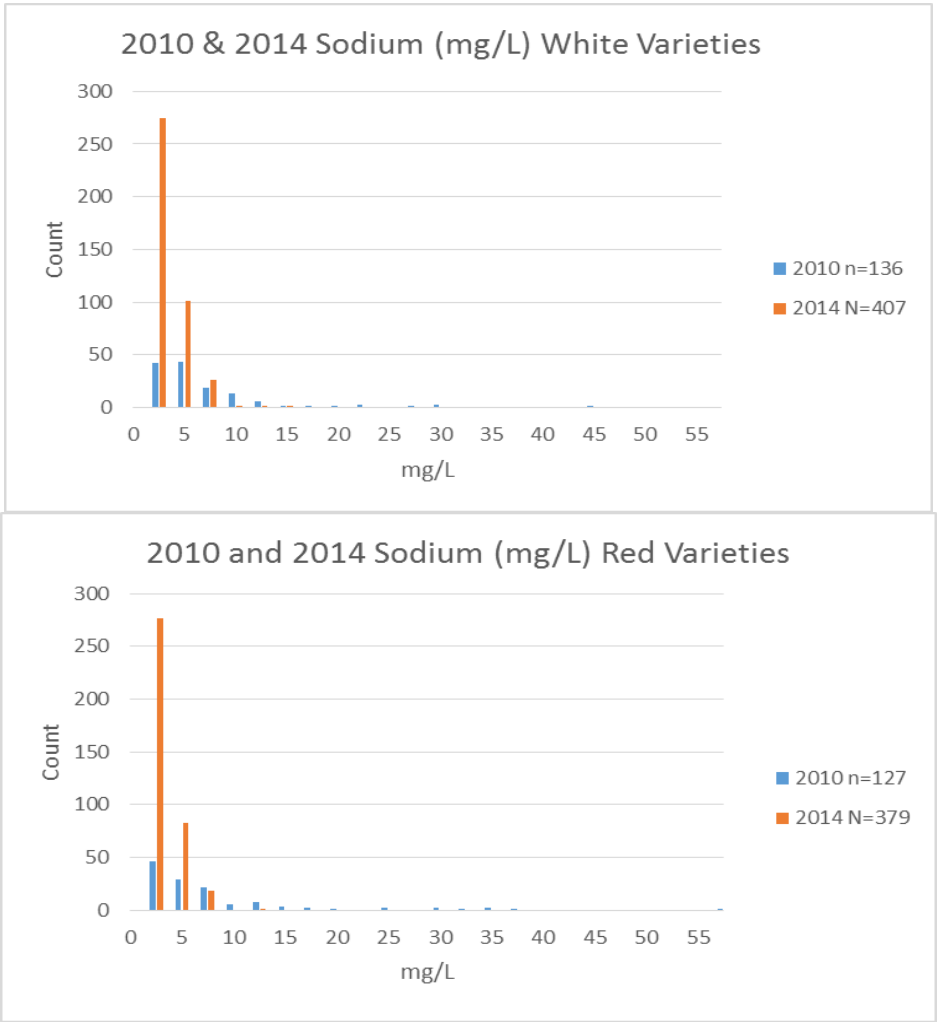


Figure 6.4.9.8. Distribution of berry Na (mg/L) collected over two seasons (2009/10 and 2013/14 from white (top) and red (bottom) varieties and selected clones in the CSIRO germplasm collection. Extracts were from thawed frozen berries. Count = n^{o} of varieties.

6.4.10. Relationships between mineral element concentrations

Correlation coefficients describing relationships between berry mineral element concentrations are provided for 2009/10 and 2013/14 in Tables 6.4.10.1 and 6.4.10.2, respectively. Across the varieties there were highly significant correlations between berry K and each of P, S and B in both seasons and between K and Mg in 2013/14. Similarly, berry P was highly correlated with S, Mg, Ca and B in both seasons; berry S was highly correlated with each of Mg and B in 2009/10 and each of Mg and Ca in 2013/14; and, berry Mg was highly correlated with Ca in both seasons. Such strong associations across the varieties indicate that transport of each of these elements into the berry, whether passive or active, is controlled by related processes. Given that large differences (ten-fold or more) were recorded across the varieties for each of the key mineral elements and that there is a strong effect of genotype, further research is required to elucidate the processes and understand the genetic control of mineral transport into the berry.

Table 6.4.10.1. Matrix of correlation coefficients (r) describing relationships between the concentration of berry mineral elements across varieties in the germplasm collection located at the CSIRO Merbein site in season 2009/10. Highly significant correlations are highlighted in bold ($p<0.001$, $N = 265$).

2010	**K**	**P**	**S**	**Mg**	**Ca**	**B**	**Zn**	**Na**
K	-							
P	**.53**	-						
S	**.60**	**.63**	-					
Mg	.16	**.49**	**.36**	-				
Ca	.07	**.35**	.17	**.71**	-			
B	**.37**	**.36**	**.52**	**.37**	.13	-		
Zn	.06	-.01	.03	.08	.08	.11	-	
Na	-.08	.15	.14	**.20**	-.01	**.29**	-.03	-

Table 6.4.10.2. Matrix of correlation coefficients (r) describing relationships between the concentration of berry mineral elements across varieties in the germplasm collection located at the CSIRO Irymple site in season 2013/14. Highly significant correlations are highlighted in bold ($p<0.001$, $N = 801$).

2014	**K**	**P**	**S**	**Mg**	**Ca**	**B**	**Zn**	**Na**
K	-							
P	**.44**	-						
S	**.49**	**.53**	-					
Mg	**.25**	**.42**	**.47**	-				
Ca	.01	**.19**	**.25**	**.66**	-			
B	**.31**	**.30**	.14	**.19**	.03	-		
Zn	-.04	.04	.00	.00	.01	.13	-	
Na	-.05	.02	-.11	.11	-.11	**.23**	.13	-

6.4.11. Relationship between berry minerals and fruit composition

Correlation coefficients describing relationships between berry mineral element concentrations and fruit composition are provided for 2009/10 and 2013/14 in Tables 6.4.11.1 and 6.4.11.2, respectively. In the 2009/10 season, with a subset of the varieties in the germplasm collection, there was no effect of sampling date on mineral element concentration (Table 6.4.11.1). In contrast, when all available varieties and clones were included in 2013/14 study, the highly significant correlations with sampling date indicate that late ripening varieties would be expected to have lower concentrations of Mg and Ca and higher concentrations of B, Zn and Na (Table 6.4.11.2). Furthermore, in 2009/10, when vines were managed with a significant deficit irrigation, there were no linkages between berry weight and mineral concentration except the negative relationship with Mg (Table 6.4.11.1). In contrast, the highly significant relationships with berry weight in 2013/14 across the larger number of varieties indicate that larger berries could be expected to have lower concentrations of Mg, Ca and Zn and higher concentrations of B and Na (Table 6.4.11.2).

Highly significant correlations presented in Tables 6.4.11.1 and 6.4.11.2 describe close, positive relationships between mineral ion concentration and fruit composition across the varieties. In both seasons, there were highly significant correlations between K, the dominant cation in berries (Figure 6.4.9.1), and TSS, pH, malic acid, tartaric acid and YAN. The very strong association between K and malic acid is particularly noteworthy as is the lack of a correlation between K and TA. Similar relationships were also determined between the anions, P and S, and each of TSS, pH, malic acid, tartaric acid and YAN in both seasons. Highly significant correlations between the divalent cations, Mg and Ca, indicate significant relationships (of each) with each of TSS, TA and tartaric acid. Berry Mg but not Ca was also correlated with YAN. While there were no significant relationships in 2009/10 between either Mg or Ca and each of pH or malic acid, there was a significant negative relationship between Ca and pH across the more diverse range of varieties located at the CSIRO Irymple site in 2013/14. There were also significant correlations between B and malic acid in both seasons and between B and each of tartaric acid and YAN in 2009/10. There were no significant correlations between Zn or Na and fruit composition in 2009/10. In 2013/14 there was a positive association between Zn and pH and negative associations between Zn and each of malic acid and YAN. In that season Na was also linked negatively to each of TA, malic acid and YAN.

While relationships with K and fruit composition have been described previously in single variety rootstock studies conducted in a similar environment to this study, e.g. TSS (Walker et al. 2000), pH and malic acid (Clingeleffer 1996, Clingeleffer et al. 2000, Ruhl et al. 1988), to the best knowledge of the authors, this is the first study to describe relationships between mineral ion concentrations in berries and aspects of fruit composition across a broad spectrum of varieties. Further analysis of the data sets will be undertaken, using covariate analyses and multi-linear regression techniques to refine the relationships and remove auto-correlative associations. This should provide useful insights into the role of mineral ions in the total solute pool in berries, not only of K, and pH buffering, ion balance and links with organic acids and YAN. Clearly, further research is required to enhance the understanding of the processes and genetic control of these relationships across the varieties. The study

also raises the possibility that fruit composition of varieties may be manipulated through nutritional management to alter berry ion contents.

Table 6.4.11.1. Matrix of correlation coefficients (r) describing relationships between the concentration of berry mineral elements and fruit composition across varieties in the germplasm collection located at the CSIRO Merbein site in season 2009/10. Highly significant correlations are highlighted in bold ($p<0.001$, $N = 265$).

2010	**date**	**bewt.**	**TSS**	**pH**	**TA**	**mal.**	**tar.**	**YAN**
K	-.16	-.15	**.35**	**.46**	-.08	**.62**	**.31**	**.41**
P	-.11	-.03	**.43**	**.31**	-.01	**.24**	**.43**	**.54**
S	-.07	-.14	**.35**	**.26**	-.03	**.26**	**.45**	**.60**
Mg	.05	**-.18**	**.29**	-.01	**.29**	.06	**.46**	**.25**
Ca	.09	-.14	.11	-.12	**.33**	.06	**.27**	.14
B	-.08	-.03	**.18**	.10	.03	**.21**	**.29**	**.20**
Zn	.10	.03	.03	.04	-.05	.07	.02	-.08
Na	-.04	.06	.05	.16	-.13	-.03	.07	.00

Table 6.4.11.2. Matrix of correlation coefficients (r) describing relationships between the concentration of berry mineral elements across varieties in the germplasm collection located at the CSIRO Irymple site in season 2013/14. Highly significant correlations are highlighted in bold ($p<0.001$, $N = 801$).

2014	**date**	**bewt.**	**TSS**	**pH**	**TA**	**mal.**	**tar.**	**YAN**
K	-.04	.12	**.33**	**.44**	.04	**.48**	**.28**	**.26**
P	.13	.09	**.21**	**.22**	.04	.12	**.17**	**.21**
S	-.11	-.12	**.31**	.12	**.16**	**.29**	**.31**	**.49**
Mg	**-.16**	**-.23**	**.35**	-.06	**.22**	.11	**.37**	**.18**
Ca	**-.18**	**-.23**	**.20**	**-.23**	**.23**	.00	**.24**	.06
B	**.20**	**.19**	.13	.10	.15	**.21**	.06	.10
Zn	**.49**	**-.19**	.06	**.24**	-.22	**-.19**	-.12	**-.16**
Na	**.23**	**.19**	.07	.13	**-.19**	**-.19**	-.06	**-.19**

6.4.12. **Conclusions from berry analyses**

Key determinants of berry composition were assessed across 566 varieties and clones in the CSIRO germplasm collection over four seasons. The study has revealed wide variability in composition with strong genetic control of pH, titratable acidity, organic acids (malic acid only, not tartrate), yeast assimilable nitrogen, and in red varieties, total anthocyanins and phenolics. This provides strong evidence for the selection of wine grape varieties with enhanced fruit composition. Indeed, varieties have been identified which consistently had low or high values for each of the variables which have been listed in the report. More importantly, compositional

data is available for all varieties in the data base. Unfortunately, the study has also shown that opportunities to select varieties with low pH, to minimise acid addition for pH adjustment, is very limited for grapes grown in the hot, irrigated regions and in relation to future climate change scenarios.

The compositional study has also provided interesting insights into the impact of maturation time (sample date), berry weight and total soluble solids on key aspects of fruit composition. Late ripening varieties could be expected to have higher pH with lower levels of TSS, TA and YAN than early ripening varieties. Varieties with larger berries could be expected to have higher pH and lower levels of TSS, TA, tartaric acid and YAN. In the study, regular sampling of berries was undertaken in an attempt to collect samples and harvest fruit at similar maturities. This proved to be quite difficult as ripening stopped at low maturities in some varieties and increased very rapidly in others, largely due to wilting during hot conditions. Consequently, TSS was also shown to have a strong genetic component with linkages to berry composition. Varieties with higher TSS would be expected to have higher tartrate and YAN levels, and in some seasons, higher pH.

Regression analyses provided evidence of close associations between compositional variables across the varieties. In particular, there was a very strong negative relationship between pH and TA, the latter being positively linked to malic acid, tartaric acid and YAN in some seasons. Across the varieties, there was a positive association with malic acid and both YAN and LAI, indicating linkages to canopy vigour and shade, vine N status and transport of N into the berry. A more detailed study of the berry N and amino acid profiles of the berry samples could provide further insight into this issue.

The study has also provided strong evidence linking berry composition across the varieties with mineral ion concentration. In particular it has described strong relationships indicating links between berry K and TSS, pH, tartaric acid and YAN; berry S and TSS, malic acid, tartaric acid and YAN and berry Mg and TSS and tartaric acid. More detailed statistical analyses of the data will provide useful insights into the role of mineral ions in berries and their association with fruit composition, their role in pH buffering, ion balance and links with organic acids and YAN. Further research is required to enhance the understanding of the processes and genetic control of these relationships across the varieties.

6.5 WINE EVALUATION

6.5.1 Varietal wines

Over the course of the project, small-scale wine lots were produced from a diverse range of varieties in the CSIRO germplasm collection that had been imported from different countries and regions with varying climatic conditions. Because of the limited resources available, every attempt was made to avoid alternative varieties already under consideration by industry groups, e.g. The Riverland Alternative Wine Group and the Riverland Vine Improvement Committee. Criteria for selection of varieties for winemaking varied each season. In general, the aim was to harvest white varieties between 20-22 ^{o}Brix and red varieties between 22-24 ^{o}Brix to enable assessment of the wines at moderately low alcohol levels. Criteria for selection for winemaking in the 2009/10 season were largely based on historical information and the phenology and vine growth data collected during the 2009/10 season. In the late ripening cool wet 2010/11 season selection was largely based on the fruit reaching adequate maturity levels and fruit condition (i.e. freedom from berry splitting, bunch rots and mould). In the 2011/12 and 2012/13 seasons selection was limited to varieties in full bearing in the relocated collection planted at the CSIRO Irymple site. In the 2013/14 season, selection for winemaking was largely based on interrogation of the fruit composition data base, particularly titratable acidity and pH with the aim to assess wines with enhanced fruit composition when grown in a hot climate. In each season, basic information on each variety used for winemaking is presented together with some basic must composition and a sensory score generated from a compilation of assessments undertaken with research, wine company and industry personnel. For the red varieties the colour density from spectral analysis of the wines is also included.

Season 2010

Background information for varieties used for small-scale winemaking in the 2009/10 season is presented in Tables 6.5.1.1 and 6.5.1.3 for white and red varieties, respectively. This information highlights the diversity of the wine variety origins. Must and wine assessment data are provided in Tables 6.5.1.2 and 6.5.1.4 for red and white varieties, respectively.

Harvest dates for the white varieties in the hot 2009/10 season ranged from 10 January (Early Muscat) to 10 March (Montils) (Table 6.5.1.2). The TSS values were generally close to the desired levels of 20 – 22 ^{o}Brix, except for Loureiro which had a low must value of 17.0 ^{o}Brix, and Petit Meslier and Pignoletto which had high values of 23.8 and 25.1 ^{o}Brix, respectively. In general, the pH values were higher than optimal, ensuring that acid additions of tartaric acid were required for pH adjustment during winemaking. Early Muscat, Montils and Green Veltliner produced very interesting white wines. Wines of Early Muscat, a seeded table grape from the USA which has produced interesting wines in earlier studies had attractive floral muscat flavour and aroma and a crisp acid palate. The French variety, Montils produced wines with aromatic citrus aromas, apricot and tropical flavours and a crisp acid palate. The Austrian variety, Green Veltliner produced perfumed wine with a spicy, tropical aroma and soft but flavoursome palate. Other white varieties producing wines of interest with a range of flavours and aromas were Petit Meslier, Arnsburger,

Rkatziteli, Viosinho, Baroque and Loureiro. The least preferred wine was produced from the overripe Pignoletto which displayed bitter, oxidised, phenolic characters.

Table 6.5.1.1. Background information for white varieties selected for small-scale wine from varieties grown at the CSIRO Merbein site in season 2009/10.

Variety	**Country of Origin / Information**
Early Muscat	USA / Wines show notes of citrus blossom, green tea and perfume.
Petit Meslier	France / Ancient variety in the Champagne region / sparkling wines are fruity, with green leaf characteristics and powerful aromas.
Arnsburger	Germany / Derived from Riesling / disease resistant / developed for sparkling wines / dry unfortified wines may be tart.
Green Veltliner	Austria / Grown in Austria and Eastern Europe and more recently world-wide / wines are typically dry, full bodied, peppery and spicy
Rkatziteli	Russia / Widely grown in Eastern Europe, China and USA / fruit has high acid and sugar levels and is used as a base for a wide range of wine styles.
Viosinho	Portugal / Grown in the Douro Valley & Dao regions / usually blended with Rabigato and Gouveio for white port and unfortified wines / adds structure and body and a floral flavour laced with stone fruits such as peaches and apricots.
Pignoletto	Italy / Grown in Bologne, and the North and Central regions / wines are lively and crisp / best still and sparkling are aromatic with the flavours of limes and green apples / high tannin levels add texture to wine.
Baroque	France / Required variety for white wines with the Tursan appellation / wines have high alcohol and fine aromas reminiscent of pears. Resistant to powdery mildew.
Loureiro	Portugal / Grown in the Vino verde region / wines are fine, aromatic, laurel scented and often low in alcohol.
Montils	France / Minor variety in the Cognac Region / produces wines with a low pH which may be useful in the hotter parts of Australia.

Table 6.5.1.2. Harvest date, must composition (total soluble solids, pH and titratable acidity) and sensory assessment score for 10 white wine varieties used for small-scale winemaking in season 2009/10.

Variety	Harvest date	TSS (^{o}Brix)	pH	Acid (g/L)	Score
Early Muscat	10/1	21.0	3.71	6.02	★ ★ ★ ★ ★
Petit Meslier	9/2	23.8	3.61	5.31	★ ★ ★ ★
Arnsburger	9/2	19.6	3.79	4.65	★ ★ ★ ★
Green Veltliner	22/2	22.1	3.76	6.31	★ ★ ★ ★ ★
Rkatziteli	22/2	22.5	3.58	5.03	★ ★ ★ ★
Viosinho	22/2	22.8	3.71	4.72	★ ★ ★ ★
Pignoletto	23/2	25.1	4.05	3.75	★ ★ ★
Baroque	23/2	22.5	3.71	5.30	★ ★ ★ ★
Loureiro	9/3	17.0	3.53	6.38	★ ★ ★ ★
Montils	10/3	20.0	3.71	5.16	★ ★ ★ ★ ★

In the 2009/10 season, harvest dates for the red varieties ranged from 14 February (Dunkelfelder) to 11 March (Refosco Nostrano and Croatina) (Table 6.5.1.4). The TSS values were in the acceptable range (22 – 24 ^{o}Brix) with the exception of Dunkelfelder which had 18.2 ^{o}Brix in the must (Table 6.5.1.4). Dunkelfelder and Valdigue had optimal must pH values around 3.6 indicating a minimal requirement for acid addition for pH adjustment compared to the other varieties. Must TA levels ranged from 5.3 g/L for Valdigue to a quite low value of 3.7 g/L for Mondeuse. Colour density of the wines ranged from very light styles with low values for Semembat (3.7 a.u.) and Valdigue (4.5 a.u.) to an exceptionally intense colour with Royalty (47.4 a.u.). Tereldego also produced a wine with high colour. Most of the other red varieties had colour densities expected for Cabernet Sauvignon and Shiraz from the region, i.e. around 8 (a.u.), The most interesting red varietal wine was produced from the Italian variety, Refosco Nostrano which had red berry and earthy aromas and a balanced palate with good fruit flavours and tannins. Other red wines of interest with a range of aromas, flavours and colour were produced from Dunkelfelder, Tinta Cao, Teroldego, Mondeuse, Valdigue and Croatina. The red fleshed German variety, Dunkelfelder, produced wines with excellent colour despite the low level of TSS and hence could be very useful for production of wines with lower alcohol. It would also be a useful variety for production in cool climates because of the early ripening. A number of industry personnel also expressed interest in wine from the hybrid species variety, Royalty, because of its intense colour and potential for blending. Semebat and Chancellor produced the least preferred wines. Wine produced from Semebat had a light red colour, an odd herbal aroma with a ‘steely’ palate. Chancellor, a species hybrid, produced tannic, unbalanced wines which lacked fruit flavours.

Table 6.5.1.3. Background information for red varieties selected for small-scale wine from varieties grown at the CSIRO Merbein site in season 2009/10.

Variety	**Country of Origin / Information**
Dunkelfelder	Germany / Grown in the Baden and Pfalz regions / coloured flesh and juice make it very useful for blending.
Chancellor	France / Species hybrid-Seibel 7053 / no longer used in France / in the USA wines are fruit driven and suitable for aging and blending with Vinifera varieties / susceptible to both powdery and downy mildew.
Tinta Cao	Portugal / Grown in the Douro Valley and Dao regions / top quality grape used for port.
Semebat	France / Small plantings in the southwest of France / INRA hybrid / wines are full bodied, herbaceous, fruity, and rich in colour.
Teroldego	Italy / Grown in the Trentino region / wines are deep coloured, fruity and very lively.
Royalty	USA / Species hybrid / almost exclusively grown in the San Joaquin Valley, California / red flesh and useful as a teinturier.
Mondeuse	France / Old variety from the Savoie region / best wines are juicy, peppery, powerfully flavoured and coloured / also blended with Pinot and Gamay.
Valdiguie	France / limited plantings in France /grown in California as Napa Gamay / very productive dark berried grape, resistant to powdery mildew / wines low in alcohol / some fruity flavours but little varietal distinction.
Refosco Nostrano	Italy / Grown in the Friuli region / member of Refosco group of red varieties / the best wines are full bodied, deeply flavoured with plums and a hint of almond / acids elevated.
Croatina	Italy/ grown in the Northern Piedmont and Lombardy regions / variety ripens late / wines are fruity / best drunk young.

Table 6.5.1.4. Harvest date, must composition (total soluble solids, pH and titratable acidity), wine colour density and sensory assessment score for 10 red wine varieties used for small-scale winemaking in season 2009/10.

Variety	**Harvest Date**	**TSS (^{o}Brix)**	**pH**	**Acid (g/L)**	**Colour density (a.u.)**	**Score**
Dunkelfelder	4/2	18.2	3.60	4.55	8.7	★ ★ ★ ★
Chancellor	9/2	23.0	3.87	4.44	8.6	★
Tinta Cao	22/2	22.5	4.05	5.25	4.5	★ ★ ★ ★
Semebat	22/2	22.8	3.78	5.07	3.7	★ ★ ★
Teroldego	9/3	22.3	4.04	4.20	13.5	★ ★ ★ ★
Royalty	9/3	24.7	4.02	4.19	47.4	★ ★ ★
Mondeuse	10/3	21.0	3.87	3.69	7.9	★ ★ ★ ★
Valdiguie	10/3	21.2	3.56	5.30	4.9	★ ★ ★ ★
Refosco Nostrano	11/3	24.7	4.00	4.62	8.6	★ ★ ★ ★ ★
Croatina	11/3	24.3	3.92	4.14	8.8	★ ★ ★ ★

Season 2011

A feature of the 2010/11 harvest was the delayed harvest, attributed to the cool season with record breaking rainfall events (Tables 6.1.1 and 6.1.3, Figure 6.1.1) which caused excessive shoot growth, loss of leaf due to fungal infection and significant fruit damage due to berry splitting, mildews and bunch rots. In general the harvest was about six weeks later than in the preceding, hot, dry 2009/10 season. As a consequence, no varieties were harvested for winemaking until early March. Indeed, it was not possible to access the vineyard until that time following the very large rainfall event which occurred on 4 February (Figure 6.1.1). Furthermore, it was necessary to harvest fruit at lower maturities to ensure fruit soundness for small-scale winemaking. Background information for varieties used for small-scale winemaking in the 2010/11 season is presented in Tables 6.5.1.5 and 6.5.1.7 for red and white varieties, respectively.

Harvest dates for the white varieties ranged from 1 March (Muscat Ottonel) to 20 April (Catarrato and Slankamenka) (Table 6.5.1.6). Despite the difficult season adequate levels of maturity were reached for most varieties, i.e. 20-22 ^{o}Brix. Two varieties that were harvested in early March, Bianca (24.7 ^{o}Brix) and Verduzzo (23.5 ^{o}Brix), had maturity levels that were higher than desired. Two late harvested varieties Smederevka and Catarrato were harvested at low levels of total soluble solids, i.e 16.7 and 16.3 ^{o}Brix respectively. Despite the generally low maturity levels most varieties had high pH levels requiring significant tartaric acid addition for pH adjustment. This was probably associated with the extended ripening period and in some cases, the low levels of titratable acidity (Table 6.5.1.6). In sensory assessments the most interesting wines were produced from Muscat Ottonel, Slankamenka, Cortese and Malvasia Moscato. Wine from Muscat Ottenel had a lifted floral, muscat aroma suited to ‘Moscato’ style production. Slankamenka produced well balanced wines with citrus and tropical fruit aromas. Cortese wines had spicy, peachy aromas with a good mouthfeel. Malvasia Moscato wines had aromatic floral muscat aromas and citrus palate. Other white interesting wines with a range of aromas, flavours and textures were produced from Liliorila, Raffiat de Moncade, Malvasia Rioja and Catarrato. Despite the low maturities, both Cattarato and Slankamenka wines received high scores in sensory assessments, an indication that they could be useful for the production of wines with lower levels of alcohol. Wines from Verduzzo and Len de L’El received the lowest scores.

Table 6.5.1.5. Background information for white varieties selected for small-scale wine from varieties grown at the CSIRO Merbein site in season 2010/11.

Variety	**Country of Origin / Information**
Muscat Ottonel	France / Grown in Alsace and Eastern Europe / wines are pale with subtle muscat character and aroma.
Picolit	Italy / Grown in Friuli region / used for sweet wines with delicate floral aromas and a light sweetness suggesting peaches and apricots.
Raffiat de Moncade	France / Grown in the South / berries are light skinned / wines light and crisp with aromas of green apples and pears / some floral notes.
Fernao Pires	Portugal / Widely planted in central and southern areas / wines are 'honeyed' and sometimes spicy.
Bianca	Hungary / Vinifera hybrid / wines tend to be neutral but can have floral aromas if picked late.
Liliorila	France / INRA Vinifera cross / Early maturing, wines are fruity and low in acid
Ansonica	Italy / Grown in Sicily and Tuscany / wines are crisp and dry and aromatic, showing nutty, citrusy characters with herbal notes.
Malvasia Rioja	Spain / Member of complex Malvasia group of varieties / white wines are deeply coloured, with strong character, high in alcohol and often have residual sugar.
Sideritis	Greece / Wines are spicy and crisp and can show flavour of grapefruit and citrus.
Cortese	Italy/ Grown in the Piedmonte Region / wines have a good level of acid but may be bland.
Verduzzo	Italy / Grown in the North East / dry wines can be astringent but sweet wines are golden, have a good density and honey aroma.
Malvasia Moscato	Italy / Dry wines can be clean and crisp and sweet wines show ripe pear flavours with a hint of honey and spice/ aromatic
Len de L'El	France / Grown in (South West), minor ingredient in the white wines of Gaillac / as a varietal wine it has high alcohol.
Malvasia di Candia	Italy / Different variety to the other Malvasia vines / often used in blending with Trebbiano, making crisp dry wines with notes of orange blossom.
Smederevka	Bulgaria / Wines are dry with relatively high alcohol and acidity. Also used in blends.
Catarrato	Italy / Sicily and California / the best wines are fine crisp and full of character.
Slankamenka	Slankamenka - Serbia / Also grown in Romania, Hungary and Ukraine / wines generally uninspiring.

Table 6.5.1.6. Harvest date, must composition (total soluble solids, pH and titratable acidity) and sensory assessment score for white wine varieties used for small-scale winemaking in season 2010/11.

Variety	Harvest date	TSS (^{o}Brix)	pH	Acid (g/L)	Score
Muscat Ottonel	1/3	19.1	3.90	4.09	★ ★ ★ ★ ★
Picolit	1/3	20.7	3.85	5.82	★ ★ ★ ★
Raffiat de Moncade	1/3	21.2	3.62	6.42	★ ★ ★ ★
Fernao Pires	2/3	19.6	3.62	5.33	★ ★ ★ ★
Bianca	7/3	24.7	3.89	4.42	★ ★ ★
Liliorila	7/3	22.4	3.56	5.32	★ ★ ★ ★
Cortese	16/3	22.0	3.70	5.64	★ ★ ★ ★
Ansonica	17/3	20.5	3.81	4.53	★ ★ ★ ★
Malvasia Rioja	17/3	21.2	4.13	4.28	★ ★ ★
Sideritis	17/3	18.8	3.69	5.78	★ ★ ★ ★
Verduzzo	17/3	23.5	4.04	3.77	★ ★
Malvasia Moscato	28/3	19.8	3.59	5.41	★ ★ ★ ★ ★
Len de L'El	31/3	20.3	3.96	4.74	★ ★
Malvasia di Candia	13/4	20.0	3.71	4.54	★ ★ ★ ★
Smederevka	13/4	16.7	3.79	4.38	★ ★ ★
Catarrato	20/4	16.3	3.72	5.58	★ ★ ★ ★ ★
Slankamenka	20/4	18.9	4.02	3.54	★ ★ ★ ★

Harvest dates for the red varieties ranged from 1 March (Egiodola and Medea) to 13 April (Calzin, Grand Noir de la Calmette, Herbemont and Uva di Troia) (Table 6.5.1.8). At harvest, the maturities of most varieties were below the desired level (22-24 ^{o}Brix). Despite the generally low maturity levels most varieties had high pH levels requiring significant tartaric acid addition for pH adjustment. This was probably associated with the extended ripening period and the generally low levels of titratable acidity. Despite the difficult seasonal conditions, Egiodola, Refosco Pedunclo Rosso and Grand Noir de la Calmette produced wines with good colour. In contrast, wines of Medea, Limberger, Troyen, Tinta Cao, Herbemont and Uva di Troia had low colour. The most interesting wines were produced from Egiodola, Refosco Pedunclo Rosso, Grand Noir de la Calmette and Medea. Egiodola produced rich, vibrant 'Bordeaux' style wine with violet and plum aromas and an excellent palate with soft tannins. Refosco Pedunclo Rosso wines had a bright purple colour, red fruit aroma and black currant flavours with good tannin structure. Grand Noir de la Calmette produced wines with a balanced structure and spicy cinnamon and pepper aromas

and flavours. Wine produced from Medea were suited to a lighter ‘Beaujolais’ style with a lighter colour, raspberry confectionary aromas and a spicy, savoury palate.

Table 6.5.1.7. Background information for red varieties selected for small-scale wine from varieties grown at the CSIRO Merbein site in season 2010/11.

Variety	**Country of Origin / Information**
Egiodola	France / INRA hybrid / used for both red and rosé wines /full bodied / herbaceous / notes of plum and blackberry.
Medea	Hungary (synonym Medina) / Species hybrid with resistance to downy and powdery mildew.
Leon Millot	France / Species hybrid / grown in USA and Canada / wines are light to medium bodied / deep colour / range of berry aromas.
Limberger	Austria / Grown in Austria. Hungary and Germany / wine light red style / low in acid / blended with Trollinger for improved colour / wines can show spicy black fruit flavours and density.
Troyen	France / Ancient fruitful variety / well adapted to humid marly soils / Synonymous with Luverdon (Schneider et al. 2001).
Tinta Cao	Portugal / see Table 6.5.1.3
Refosco Pedunclo Rosso	Italy / Recognised as the finest member of the Refosco group of red varieties in the Fruili region / see Refosco Nostrano Table 6.5.1.3 for additional comments.
Calzin	USA / UCD Vinifera hybrid / wines high in tannins, antioxidants and anthocyanin / requires aging to perform at its best.
Grand Noir de la Calmette	France / French Vinifera hybrid / high yielding / red flesh / the Italian Appellation Toscana IGT is 100% Grand Noir de la Clamette / the light styled wine has an intense ruby colour, is fruity, with hints of strawberries, spices and pepper, and has a velvety texture.
Herbemont	USA / Inter species hybrid / resistant to fungal diseases/ grown in Brazil.
Uva di Troia	Italy / Grown in Puglia in Southern areas / wines are good quality / full bodied / good structure and tannins / flavours include raspberry, cherry, dark forest fruits and plums through to licorice and spice.

Table 6.5.1.8. Harvest date, must composition (total soluble solids, pH, titratable acidity), wine colour density and sensory assessment score for red wine varieties used for small-scale winemaking in season 2010/11.

Variety	Harvest Date	TSS (^{o}Brix)	pH	Acid (g/L)	Colour density (a.u.)	Score
Egiodola	1/3	22.6	4.04	3.97	11.6	★ ★ ★
Medea	1/3	24.0	3.97	4.04	3.1	★ ★ ★ ★
Leon Millot	3/3	23.5	3.97	5.20	6.8	★ ★ ★
Limberger	3/3	20.7	3.47	5.64	4.6	★ ★ ★ ★
Troyen	7/3	20.8	3.59	4.91	3.2	★ ★ ★
Tinta Cao	16/3	19.9	4.04	5.11	4.4	★ ★ ★
Refosco Pedunclo Rosso	16/3	22.6	3.86	4.72	8.2	★ ★ ★
Calzin	13/4	19.1	3.78	4.67	5.7	★ ★ ★ ★
Grand Noir de la Calmette	13/4	18.4	4.09	4.77	7.6	★ ★ ★ ★
Herbemont	13/4	20.3	3.79	5.67	1.7	★ ★ ★
Uva di Troia	13/4	16.1	3.97	4.46	2.1	★ ★

Season 2012

A limited number of wines were produced in the 20011/12 season from young vines established at the CSIRO Irymple site. It should be noted that winemaking was not planned for the 2011/12 season in the original proposal. Background information for varieties used for small-scale winemaking in the 2011/12 season is presented in Tables 6.5.1.9 and 6.5.1.11 for white and red varieties, respectively.

Harvest dates for the white varieties ranged from 25 January (Early Muscat) to 19 March (Putzscheere) (Table 6.5.1.10.). Maturity levels of Monbadon (17.0 ^{o}Brix) and Early Muscat (23.6 ^{o}Brix) were lower and higher respectively, than the desired level of 20-22 ^{o}Brix. Except for Albana, most varieties had high pH levels requiring significant tartaric acid addition for pH adjustment. Morio Muskat produced the most interesting wine with a lovely floral muscat aroma and flavour. Wine from Early Muscat also had a nice floral muscat character with a crisp acid finish although the palate tended to be slightly bitter and phenolic. Albana produced a wine with savoury, pepper characters and an acid palate. Verdicchio wine had some perfume and vanilla fruit characters and a viscous flat palate. The Monbadon wine had some pepper and perfume characters but tended to lack fruit character and had a watery palate. The Putzscheere wine had some aromatic spicy character but tended to be bitter. The least preferred wine was produced from the unnamed German hybrid. It had some apple but unpleasant acrid and yeasty characters, possibly due to a winemaking fault.

Table 6.5.1.9. Background information for white varieties selected for small-scale wine from varieties grown at the CSIRO Irymple site in season 2011/12.

Variety	Country of origin/information
Early Muscat	USA / see Table 6.5.1.1
Morio Muskat	Germany / Vinifera hybrid grown in Germany / alternative muscat type / very strong flavour / used to add flavour to blends / acidity high to medium.
Albana	Italy / Grown in Emilia-Romagna Region in the North East / thick skinned / dry wines are crisp, neutral with little character / sweet wines are of better quality with a light nutty finish.
Verdicchio	Italy / Grown in Central Italy / Modern style wines have a lemony acidity and bitter almond after taste / high acidity and pH contribute to a rounded wine.
GF V3125	Germany / Unnamed Hybrid (Schiava Grossa x Reisling) / well balanced wine.
Monbadon	France / Wines have subdued flavours and low phenolics / wines maintain their delicacy / suitable for apera style wines
Putzscheere	Hungary / Grown in Hungary / Germany and California USA / high yielding / produces simple wine / synonyms Green Hungarian and Butschera.

Table 6.5.1.10. Harvest date, must composition (total soluble solids, pH and titratable acidity) and sensory assessment score for white wine varieties used for small-scale winemaking in season 2011/12.

Variety	Harvest date	TSS (^{o}Brix)	pH	Acid (g/L)	Score
Early Muscat	25/1	23.6	3.76	4.05	★ ★ ★ ★
Morio Muskat	6/2	22.3	3.78	3.77	★ ★ ★ ★ ★
Albana	9/2	20.9	3.50	7.67	★ ★ ★ ★
Verdicchio	6/3	23.2	3.45	4.00	★ ★ ★
GF V3125	6/3	21.7	4.22	3.83	★
Monbadon	19/3	17.0	3.87	6.42	★ ★ ★
Putzscheere	19/3	19.1	3.75	4.97	★ ★

Harvest dates for the red varieties ranged from 13 February (Black Gem) to 6 March (Garonnet) (Table 6.5.1.12.). Black Gem, a seedless currant variety developed by

CSIRO was included because it had displayed outstanding disease resistance in the wet 2010/11 season and had produced interesting wines in earlier studies. Except for Calzin (20.2 ^{o}Brix), maturity levels were in the desired range of 22-24 ^{o}Brix. Except for Calzin, most varieties had high pH levels requiring significant tartaric acid addition for pH adjustment. Titratable acidity levels of Black Gem and Garronet were also low. Colour density was highest in wines produced from Black Gem and lowest in Etraire de la dui and Garonnet, an indication that they would only be suited to lighter style wines. Black Gem wines were described as having intense colour with a rich and fruity spice character, soft tannins and a slightly odd rubbery palate, possibly associated with its' species hybrid background. Garonnet produced a lighter style wine with some fruit and savoury characters. Calzin and Etraire de la dui w were the least preferred. The Calzin wine had a smoky character, low tannins and a bitter palate. The Etraire de la dui wine had a strong herbal, vegetative and stalky character and a bitter palate.

Table 6.5.1.11. Background information for red varieties selected for small-scale wine from varieties grown at the CSIRO Irymple site in season 2011/12.

Variety	**Country of origin/information**
Black Gem	Australia / disease tolerant currant / wine has intense colour and is high in antioxidants
Calzin	USA / see Table 6.6.1.7
Etraire de la dui	France / Historic variety / grown pre phylloxera / South East Phone Valley and Savoie Region/ wines suitable for aging.
Garonnet	France / species hybrid / heat tolerant

Table 6.5.1.12. Harvest date, must composition (total soluble solids, pH, titratable acidity), wine colour density and sensory assessment score for red wine varieties used for small-scale winemaking in season 2011/12.

Variety	**Harvest date**	**TSS (^{o}Brix)**	**pH**	**Acid (g/L)**	**Colour density (a.u.)**	**Score**
Black Gem	13/2	22.4	3.87	3.01	11.3	★ ★ ★ ★
Calzin	6/3	20.2	3.61	8.06	4.5	★ ★
Etraire de la dui	6/3	22.5	3.75	6.92	4.2	★ ★
Garonnet	6/3	22.3	4.14	4.09	6.3	★ ★ ★

Season 2013

Background information for varieties used for small-scale winemaking in the 2012/13 season is presented in Tables 6.5.1.13 and 6.5.1.15 for white and red varieties, respectively. Harvest dates for the white varieties ranged from 31 January (Bianca and Demir Kopja) to 5 March (Monbadon) (Table 6.5.1.14). Maturity levels of a number of varieties were significantly higher than the desired level of 20-22 ^{o}Brix, particularly Rossignola (24.8 ^{o}Brix), Viosinho (28.1 ^{o}Brix), Malvasia Moscato (26.6 ^{o}Brix) and Rieslina (24.8 ^{o}Brix). Except for Hibernal and Rieslina, most varieties had high must pH levels requiring significant tartaric acid addition for pH adjustment. High pH of Bianca and Demir Kopja appeared to be linked to very low levels of titratable acidity. Interestingly, Rossignolia which had the highest must pH also had the highest titratable acidity. Wines of Malvasia Moscato were highly rated. These wines had a strong fruity floral musk aroma, a soft palate with high levels of flavour. Other wines of interest were Bianca, the German selection Hibernal, Rossignola and Monbadon. Bianca wines displayed pleasant apple and pear characters with an oily, long lasting palate. The Hibernal wine was very floral with herbaceous characters and had a good mouthfeel. Rossignola produced a very crisp, fruity acidic wine. Wine of the late ripening Monbadon had pleasant floral aroma with a crisp but undistinctive palate. The Demir Kopja wine had a scented aroma and a clean crisp, but slightly bitter palate. Rauschling wine had scented aroma and an oily palate with good fruity flavour. The unidentified variety, collected from an old vineyard in Coldstream R1V3 in the Yarra Valley, produced a well-structured interesting wine with a long lasting but bitter palate. Viosinho and Rieslina wines were the least preferred wines and displayed little character. The Viosinho wine displayed some musk character and the Rieslina wine, some fruity pineapple character.

Table 6.5.1.13. Background information for white varieties selected for small-scale wine from varieties grown at the CSIRO Irymple site in season 2012/13.

Variety	**Country of origin/information**
Bianca	Hungary/ see Table 6.5.1.5
Demir Kopja	Yugoslavia / early ripening seeded table grape / crisp berries / pleasant muscat flavour / medium disease resistance
Hibernal	Germany / Vinifera hybrid (GM 322-58) / resistance to downy mildew / wine is similar to Scheurebe / wine flavours are herbal, citrus grapefruit, lemon or honeysuckle.
Rossignola	Italy / Grown in the Veriona province / wines are tart / often blended with Rondinella
Viosinho	Portugal / See 6.5.1.1
Malvasia Moscato	Italy / see 6.5.1.5.
Rieslina	Argentina / Riesling hybrid / Ripens at similar time as Riesling / no distinctive character.
Rauschling	Switzerland / Also grown in Baden Southern Germany / high acidity /fine and crisp wines / also used in blending.
Coldstream R1V3	Australia* / unnamed vine selected from the Yarra Valley, Victoria / pre-phylloxera. * 'Heritage' variety.
Monbadon	France / see 6.5.1.9

Table 6.5.1.14. Harvest date, must composition (total soluble solids, pH and titratable acidity) and sensory assessment score for white wine varieties used for small-scale winemaking in season 2012/13.

Variety	**Harvest Date**	**TSS (^{o}Brix)**	**pH**	**Acid (g/L)**	**Score**
Bianca	31/1	23.8	3.99	3.90	★ ★ ★ ★
Demir Kopja	31/1	21.9	4.19	2.60	★ ★ ★
Hibernal	12/2	22.8	3.14	4.50	★ ★ ★ ★
Rossignola	14/2	24.8	4.43	7.34	★ ★ ★ ★
Viosinho	18/2	28.1	4.38	4.36	★ ★
Malvasia Moscato	22/2	26.6	3.72	4.57	★ ★ ★ ★ ★
Rieslina	22/2	24.8	3.38	5.04	★ ★
Rauschling	22/2	22.5	3.72	4.27	★ ★ ★
Coldstream R1V3	22/2	23.6	3.57	5.03	★ ★ ★
Monbadon	5/3	19.2	3.78	4.93	★ ★ ★ ★

Harvest dates for the red varieties ranged from 18 January (Dornfelder) to 5 March (Best's R3V54) (Table 6.5.1.16.). Except for Best's R3V54 (21.7 ^{o}Brix), maturity levels of the varieties were in the desired range of 22-24^{o}Brix. Must pH levels of Arinarnoa and Calzin were in the required range to not require tartaric acid addition for pH adjustment. In contrast, Dornfelder and Best's R3V54 had high pH levels, requiring pH adjustment, in particular the German variety, Dornfelder (4.51 pH). Dornfelder also had the lowest level of titratable acidity. Dornfelder had the highest colour density. Colour density of Arinarnoa, was similar to levels achieved with standard varieties such as Cabernet Sauvignon or Shiraz. The low colour densities of wines of Calzin and Best's R3V54 indicate that they are only suited to the production of lighter style wines. The most interesting wines were produced from Arinarnoa and Dornfelder. The Arinarnoa wine had deep purple hues, with nice spicy/pepper aroma and flavours and a lovely mouthfeel with soft tannins. The Dornfelder wine had good colour with deep purple hues, rich fruity characters and a soft palate. The Calzin wine was a lighter style with red-purple hues, with some herbaceous and berry fruit characters. Best's R3V54 produced a light coloured wine with spicy/vegetative characters.

Table 6.5.1.15. Background information for red varieties selected for small-scale wine from varieties grown at the CSIRO Irymple site in season 2012/13.

Variety	**Country of origin/information**
Dornfelder	Germany / Vinifera hybrid / wines are deeply coloured with good acidity / suitable for aging / texture is velvety / slightly floral.
Calzin	USA / see Table 6.6.1.7
Arinarnoa	France/ INRA Vinifera hybrid / wines are strong dark red.
Best's R3V54	Australia* / unnamed vine selected from Great Western, Victoria / pre-phylloxera. * 'Heritage' variety.

Table 6.5.1.16. Harvest date, must composition (total soluble solids, pH, titratable acidity), wine colour density and sensory assessment score for red wine varieties used for small-scale winemaking in season 2012/13.

Variety	**Harvest Date**	**TSS (^{o}Brix)**	**pH**	**Acid (g/L)**	**Colour density (a.u.)**	**Score**
Dornfelder	18/2	23.6	4.51	3.51	15.3	★ ★ ★ ★
Calzin	21/2	22.1	3.52	5.01	3.1	★ ★ ★
Arinarnoa	21/2	23.8	3.53	6.12	6.4	★ ★ ★ ★ ★
Best's R3V54	5/3	21.7	3.88	4.89	3.3	★ ★ ★

Season 2014

Background information for varieties used for small-scale winemaking in the 2013/14 season is presented in Tables 6.5.1.17 and 6.5.1.19 for white and red varieties, respectively. Harvest dates for the white varieties ranged from 21 January (GM 318-57, Trajadura) to 11 March (Best's L) (Table 6.5.1.18.). Maturity levels of Trajadura (24.3 ^{o}Brix), GM 643-16 (23.5 ^{o}Brix) and Raffiat de Moncade (24.9 ^{o}Brix) were significantly higher than the desired level of 20-22 ^{o}Brix. Except for Perdea, most varieties had high must pH levels requiring tartaric acid addition for pH adjustment despite a number having good levels of titratable acidity, i.e. > 6.0 g/L. The preferred white wines were produced from the unnamed German selection, GM 643-16, the Australian sourced White Muscat, Baroque and Merlot Blanc. The GM 643-16 wine had a pleasant floral, vanilla and muscat character. The White Muscat wine had rich fruity apple and peach floral characters with acidic overtones. The Baroque wine had a golden colour with dusty floral characters and a pleasant palate. The early ripening, unnamed German selection GM 318-57 produced a clean soft wine with floral geranium like characters. Perdea produced an acceptable, lighter style thin wine with some pear/apple floral characters. Raffiat de Moncade wine had a green colour with a dusty aroma and oily sweet palate. Wine from the unidentified Coldstream R1V3 variety had lovely apple floral characters but a coarse palate. The least preferred wines were produced from Trajadura, Arnsburger and Best's L, which had a stuck ferment, winemaking fault. Trajadura produced a slightly fruity wine with dusty apple characters with a savoury oily palate and unpleasant after taste. The Arnsburger wine had a pink hue and lacked character.

Table 6.5.1.17. Background information for white varieties selected for small-scale wine from varieties grown at the CSIRO Irymple site in season 2013/14.

Variety	**Country of origin/information**
GM 318-57	Germany / Unnamed Interspecific hybrid / resistant to powdery mildew but susceptible to downy mildew. Wines are aromatic with a hint of apple.
Trajadura	Portugal / Usually blended / adds character to Vinho Verde when picked early.
Perdea	France / INRA Vinifera hybrid / wines perfumed with good acids / best suited to drier styles of wine.
GM 643-16	Germany / Unnamed Interspecific hybrid / resistant to powdery mildew but susceptible to downy mildew.
White Muscat	Australia* / Unidentified muscat selection from Stanthorpe, Queensland / pre phylloxera. * ‘Heritage’ variety
Raffiat de Moncade	France / see 6.5.1.5
Coldstream R1V3	Australia*/ see 6.5.1.13. * ‘Heritage’ variety.
Arnsburger	Germany / Hybrid / low susceptibility to grey rot / fruity wines / similar to Riesling in flavours.
Baroque	France / see 6.5.1.1.
Merlot Blanc	France / Grown in Bordeaux / not a white mutant of Merlot
Best’s L	Australia* / Unidentified vine selected from Great Western, Victoria / pre phylloxera / late ripening / relatively high pH and acid / wines may lack character. * ‘Heritage’ variety.

Table 6.5.1.18. Harvest date, must composition (total soluble solids, pH and titratable acidity) and sensory assessment score for white wine varieties used for small-scale winemaking in season 2013/14.

Variety	**Harvest Date**	**TSS (^{o}Brix)**	**pH**	**Acid (g/L)**	**Score**
GM 318-57	21/1	21.7	3.59	6.11	★ ★ ★
Trajadura	21/1	24.3	3.75	6.09	★ ★
Perdea	28/1	20.3	3.41	7.84	★ ★ ★
GM 643-16	30/1	23.5	3.68	5.33	★ ★ ★ ★
White Muscat	6/2	22.6	3.84	6.02	★ ★ ★ ★
Raffiat de Moncade	11/2	24.9	3.90	4.34	★ ★ ★
Coldstream R1V3	26/2	21.2	3.84	3.60	★ ★ ★
Arnsburger	6/3	20.5	3.90	4.23	★ ★
Baroque	6/3	21.0	3.85	3.82	★ ★ ★ ★
Merlot Blanc	6/3	20.7	3.54	3.71	★ ★ ★ ★
Best's L	11/3	22.6	3.74	7.47	★

Harvest dates for the red varieties ranged from 4 February (Limberger) to 6 March (Souzao) (Table 6.5.1.20). Maturities were in the desired range of 22-24^{o}Brix however all had high pH levels, particularly Egiodola, requiring pH adjustment in winemaking. Egiodola also had a very low titratable acidity level. Egiodola and Salvador wines had the highest colour densities. Colour densities of Limberger and Souzao were similar to expected values for wines of the commercial varieties, Cabernet Sauvignon and Shiraz, grown in the region. All varieties produced very interesting wines. The most preferred wine, produced from Egiodola, was a very rich wine with high colour, deep purple hues and displayed fruity vanilla and herbal characters. Limberger wine had a deep purple colour, rich savoury characters and soft tannins. The species hybrid, Salvador produced a rich deep purple wine with distinct fruity plum characters. The Souzao wine had deep purple hue and fruity plum characters with soft tannins and a pleasant after taste.

Table 6.5.1.19. Background information for red varieties selected for small-scale wine from varieties grown at the CSIRO Irymple site in season 2013/14.

Variety	**Country of origin/information**
Limberger	Austria / see 6.5.1.7
Egiodola	France / see 6.5.1.7
Salvador	France / French inter species hybrid (Seibel 128) / red fleshed / used as a teinturier in blends.
Souzao	Portugal / Grown in Northern Portugal and California USA / wine has high colour and acidity / traditionally used for port

Table 6.5.1.20. Harvest date, must composition (total soluble solids, pH, titratable acidity), wine colour density and sensory assessment score for red wine varieties used for small-scale winemaking in season 2013/14.

Variety	**Harvest Date**	**TSS (^{o}Brix)**	**pH**	**Acid (g/L)**	**Colour density (a.u.)**	**Score**
Limberger	4/2	21.7	3.91	4.60	6.4	★ ★ ★ ★ ★
Egiodola	26/2	23.8	4.27	2.26	12.1	★ ★ ★ ★ ★ ★
Salvador	26/2	22.2	3.78	4.21	14.9	★ ★ ★ ★ ★
Souzao	6/3	23.5	3.77	3.32	8.1	★ ★ ★ ★ ★

Summary and conclusions from varietal wine evaluations

Over five seasons, small-scale wines were made from a total of 87 wine varieties (56 whites and 31 reds) held in the CSIRO germplasm collection sourced from a range of countries and regions. The results indicate that there are significant opportunities to extend the spectrum of varieties grown in Australia to enhance fruit composition, extend the season, and provide a greater range of colours, flavours, aromas and textures suited to varying wine styles, including those with lower alcohol. Despite varying seasonal conditions described in section 6.1, desired maturity levels were generally achieved (i.e. 20-22 ^{o}Brix for white wines and 22-24 ^{o}Brix for red wines). For the white varieties, 28 (50%) were harvested within the optimal maturity range, 9 had low TSS (below 19.5 ^{o}Brix) and 19 had high TSS levels (above 22.5 ^{o}Brix). For the red varieties, 20 (65%) were harvested at optimal maturity, 9 had low TSS (below 21.5 ^{o}Brix) and 2 had high TSS levels (above 24.5 ^{o}Brix). In regards to must composition, only two of the white varieties had must pH values below 3.4 while 42 varieties (75%) had pH values greater than 3.6. Similarly for the red varieties, there were none with must pH values below 3.4 and 25 (81%) with pH values above 3.6. These results show that selection of varieties with low pH to avoid tartaric acid addition for pH adjustment and reduce winemaking costs is problematic, despite the fact that 26 (46%) of the white varieties and 10 (32%) of the red varieties had titratable acidities above 5 g/L.

It is of interest to note that across the white varieties correlations between TSS and pH and TSS and titratable acidity were not significant (r = 0.20 and -0.14, respectively). However, there was a very weak, but significant correlation (r = -0.30) between pH and TA, an indication that must pH across the varieties was largely independent of TA, the relationship accounting for less than 10% of the variability. Across the red varieties, there were weak but significant correlations between TSS and pH (r = 0.33) and TSS and TA (r = -0.30), an indication that about 10% of the variation in pH and TA could be accounted for by differences in maturity. Across the red varieties there was also a significant correlation between pH and TA (r = -0.55), an indication that must pH was influenced by TA, the relationship accounting for 30% of the variability. In both the red and white varieties the weak relationships between must pH and TA were unexpected, an indication that both factors are independently under the strong control of genotype. There was also a weak relationship between TSS and wine colour (r = 0.35) an indication that only about 25% of the variability in wine colour could be accounted for by differences in maturity with strong control of wine colour by the genotype.

The information on harvest date (i.e. potential to extend the season), must composition, wine colour (red varieties) and outcomes of the sensory assessment has been used to identify varieties of interest with the most potential for industry adoption. Ideally, small-scale winemaking evaluation across a number of seasons and in different environments would provide extra information on the potential performance and wine quality of these varieties. Six white varieties with high potential, moderately low must pH levels (i.e. < 3.8), and which ranked highly in the sensory assessments, have been selected. These include:

- the US table grape variety, Early Muscat, selected for its early ripening and aromatic, floral flavour and aroma characteristics

- the Austrian variety, Green Veltliner, selected for its spicy, tropical aroma and soft but flavoursome palate
- the French variety, Montils selected for its aromatic citrus aromas, apricot and tropical flavours and a crisp acid palate
- the Italian variety, Malvasia Moscato selected for its late ripening and aromatic floral muscat aromas and citrus palate characters
- the Italian variety, Catarrato selected for its very late ripening and suitability for low alcohol wine production
- the German variety, Morio Muskat, selected for lovely floral muscat aroma and flavour.

A number of other promising white varieties were also identified with significant potential based on their moderately low pH and wine assessments. The details of these selections can be found above. They include Petit Meslier, Arnsburger, Rkatziteli, Viosinho, Baroque, Loureiro, Raffiat de Moncade, Fernao Pires, Liliorila, Cortese, Sideritis, Malvasia di Candia, Monbadon, Merlot Blanc, Hibernal and the unnamed German selection, GM 643-16.

In the studies, eight high priority red varieties have been selected with high potential based on the assessment of the wine including colour and to a lesser degree than for the white varieties, fruit composition. These varieties include:

- the Italian variety, Refosco Nostrano selected for its red berry and earthy aromas, balanced palate with good fruit flavours and tannins
- the German red fleshed variety, Dunkelfelder, selected for its high colour, early ripening and suitability for lower alcohol wine production
- the Italian variety, Teroldego selected for its excellent colour and wine characteristics
- the German red fleshed variety, Dornfelder, selected for its excellent colour and wine characteristics in the difficult 2010/11 season
- the French variety, Egiodola, selected for its richness, high colour with deep purple hues and fruity vanilla and herbal characters

A number of other promising red varieties were also identified with significant potential. The details of these selections can be found above. They include Croatina, Mondeuse and Grand Noir de la Calmette. Four further varieties of interest have been idenitified for the production of lighter style wines, i.e. Valdigue, Medea, Limberger and Calzin.

6.5.2 Advanced selections

In 2009/10 and 2010/11, small-scale wine lots were produced from 10 CSIRO 'advanced' selections (five white and five red varieties) planted at the CSIRO Merbein site. In season 2011/12 wines were made from six of these selections established in a vineyard in Victoria. For each of these 'advanced' selections, fruit was harvested at a low and normal maturity level where sufficient fruit was available, to provide data to determine optimum maturity levels and assess potential for the production of lower alcohol wines. In 2014/15 small-scale wines were also produced from four selections grafted on two rootstocks, 1103 Paulsen and Ramsey, established in a vineyard in the Riverland of South Australia. Only the harvest must data is available at the time of report preparation.

Season 2010

In the 2009/10 season, the first harvest date for the five white 'Advanced Selections' ranged from 1 February to 10 March with a mean TSS of 22.0 $\pm$ 0.6 ^{o}Brix while the second harvest date ranged from 16 February to 30 March, with a mean TSS of 25.3 $\pm$ 1.3 ^{o}Brix (Table 6.5.2.1). Apart from AdW4 most the selections tended to have high pH values, particularly at the second harvest requiring tartaric acid addition for pH adjustment during winemaking. The later ripening selections, AdW4 and AdW5 had good levels of titratable acidity. All the 'Advanced Selections' produced acceptable and interesting wines with a preference for those produced at lower maturities around 22.5 ^{o}Brix, particularly AdW1, AdW4 and AdW5. Wines from the second harvest with higher TSS values (i.e. AdW3, AdW4 and AdW5) were sweet, indicating levels of residual sugar due to incomplete fermentation. Wines produced from AdW1 had lovely spicy/grass fruit characters with low phenolics and a crisp palate. Wines of AdW2 and AdW3 tended to have some fruit character and crisp palates but had no distinguishing features. AdW4 produced a very rich wine with nice fruity apple character with good length on the palate. AdW5 produced floral/spicy wines with a crisp texture when picked early.

Harvest dates of the first harvest of the red 'Advanced Selections' ranged from 29 January to 26 February with a mean TSS of 22.2 $\pm$ 0.8 ^{o}Brix (Table 6.5.2.2). A second harvest was only possible for two of the five selections, mean TSS of 24.5 ^{o}Brix. All the red 'Advanced Selections' tended to have high pH values and low levels of titratable acidity at harvest, requiring significant tartaric acid addition for pH adjustment during winemaking. All wines had excellent levels of colour, with colour densities ranging from 11.6-21.3 a.u. and were rated highly in sensory assessments (Table 6.5.22). For the two selections for which wines were produced at two maturity levels, there was no preference for wines from the more ripe fruit, despite the wines having higher colour densities (i.e. mean 19.0 cf 11.9 a.u.). AdR1 produced a rich wine that was the most preferred. It had high colour, lovely spicy fruit characters with soft tannins. AdR2 wine also produced rich wine with plum, mulberry and fruit jube characters with full flavour and soft tannins. AdR3 wine displayed vegetative, chocolate and vanilla fruit characters with a vegetative, tannic palate. AdR4 produced rich wines with spicy, savoury fruit characters which were well balanced with a persistent palate. AdR5 wines were described as having a meaty character

with stewed peach, plum and mulberry fruit flavours and aroma and a slightly unpleasant phenolic palate.

Table 6.5.2.1. Harvest date, must composition (total soluble solids, pH and titratable acidity) and sensory assessment score of wines from white advanced selections used for small-scale winemaking in season 2009/10.

Selection	Harvest Date	TSS (°Brix)	pH	Acid (g/L)	Score
AdW1	1/2	22.4	4.03	4.12	★★★★★
	16/2	23.5	4.15	4.02	★★★★
AdW2	1/2	19.8	3.70	4.82	★★★
	16/2	23.0	3.97	3.67	★★★★
AdW3	2/2	22.6	3.63	5.04	★★★
	16/2	30.0	4.05	4.11	★★★
AdW4	16/2	22.3	3.40	6.37	★★★★★
	24/2	24.0	3.52	5.10	★★
AdW5	10/2	22.9	3.66	6.43	★★★★★
	30/3	26.0	3.83	5.16	★★★

Table 6.5.2.2. Harvest date, must composition (total soluble solids, pH and titratable acidity) and sensory assessment score of wines from red advanced selections used for small-scale winemaking in season 2009/10.

Selection	Harvest Date	TSS (°Brix)	pH	Acid (g/L)	Colour density (a.u.)	Score
AdR1	29/1	23.7	3.72	4.28	16.8	★★★★★★
AdR2	29/1	21.9	3.87	4.26	20.5	★★★★★
AdR3	26/2	21.0	4.27	2.99	18.3	★★★★
AdR4	1/2	24.2	3.87	4.80	12.2	★★★★★
	16/2	26.0	4.24	3.51	16.7	★★★★★
AdR5	3/2	20.3	3.54	4.03	11.6	★★★
	9/3	23.0	4.53	2.81	21.3	★★★

Season 2011

Despite the impact of the severe climatic conditions on vine growth, crop development, fruit maturation and disease development in the 2010/11 season, wines were produced from all of the 'Advanced' Selections' at two maturity levels where sufficient fruit was available. The first harvest date of the white selections ranged from 3 February - 28 March, with a mean TSS of 20.1 $\pm$ 0.6 ^{o}Brix. The second harvest date ranged from 1 - 31 March, with a mean TSS of 21.0 $\pm$ 0.4 ^{o}Brix (Table 6.5.2.3). AdW3, AdW4 and AdW5 had acceptable must pH and titratable acidity levels for winemaking at both maturity levels. In contrast, AdW1and AdW2 had high pH and low levels of titratable acidity requiring significant addition of tartaric acid for pH adjustment for all wines. For the first harvest, AdW3 was harvested prior to the record breaking rain event which occurred on 4 February (i.e. 200 mm, Figure 6.1.2). Of the two wines of AdW3, the early harvest was preferred. It had fresh aromatic fruit characters and a clean crisp palate. Wine of AdW3 from the latter harvest had pleasant floral and spice characters and a slightly phenolic palate. Both AdW1 wines had perfumed aromas with floral and spice characters with excellent palate flavour. In this case, wine from the later harvest was preferred, largely because of its palate flavour and structure. The first harvest of AdW4 was preferred. Wines of AdW4 had pleasant spicy fruit characters and were well balanced, textured palates. The second harvest wine of the late ripening AdW5 selection was preferred. The first harvest wine of AdW5 had a green colour with citrus and rose petal fruit characters and a phenolic, harsh palate, whereas the second harvest wine was more golden and had more spice fruit characters. The AdW2 wines were the least preferred compared to the other selections. The first harvest of AdW2 had some rose petal vanilla character with an acid finish, whereas wine from the later harvest had some apple character and an acid palate but lacked distinctness.

Table 6.5.2.3. Harvest date, must composition (total soluble solids, pH and titratable acidity) and sensory assessment score of wines from white advanced selections used for small-scale winemaking in season 2010/11.

Selection	Harvest Date	TSS (^{o}Brix)	pH	Acid (g/L)	Score
AdW3	3/2	20.8	3.53	8.09	★★★★★
	1/3	21.2	3.69	6.21	★★★★
AdW1	7/3	21.1	4.04	4.41	★★★★
	23/3	21.2	4.23	3.22	★★★★★
AdW2	16/3	18.0	3.94	4.12	★★★
	31/3	20.0	4.06	3.34	★★
AdW4	16/3	20.4	3.31	6.70	★★★★★
	28/3	21.6	3.58	7.15	★★★★
AdW5	28/3	20.3	3.55	7.42	★★★
	31/3	22.1	3.41	7.35	★★★★

Dates of the first harvest of the red 'Advanced Selections' ranged from 4 February to 17 March, with a mean TSS of 20.7 ± 0.8 ^{o}Brix (Table 6.5.2.4). A second harvest was only possible for two of the five selections, with a mean TSS of 22.1 ^{o}Brix. AdR2, AdR1 and AdR3 all had low, acceptable pH levels. AdR2 also had a very high acid level. AdR4 and AdR5 had high pH and low levels of titratable acidity requiring addition of tartaric acid for pH adjustment during winemaking. Despite the low maturity levels, all wines produced from the red selections had good levels of colour with colour densities ranging from 7.0 - 13.8 AU. Wine produced from AdR3 was the most preferred. It had deep purple hues, slight vegetative and stewed plum fruit characters with a drying finish. Wine from the first harvest of AdR4 produced a lighter style wine with purple hues, nice spicy fruit characters with a soft palate. It was preferred over wine from the later harvest which had peach and stewed plum fruit characters and a thin palate. AdR5 wines had spice, stewed plum and mulberry fruit characters and toasty bitter palates. Despite the excellent colour, the low scoring AdR2 wine displayed major winemaking faults with medicinal characters.

Table 6.5.2.4. Harvest date, must composition (total soluble solids, pH and titratable acidity) and sensory assessment score of wines from red advanced selections used for small-scale winemaking in season 2010/11.

Selection	Harvest Date	TSS (^{o}Brix)	pH	Acid (g/L)	Colour density (a.u.)	Score
AdR2	4/2	21.1	3.56	9.05	15.2	★
AdR1	10/3	17.7	3.45	4.11	12.9	★★★
AdR3	16/3	20.6	3.61	5.81	13.8	★★★★★
AdR4	7/3	22.8	3.72	4.72	7.0	★★★★
	23/3	22.5	4.00	3.30	9.0	★★★
AdR5	17/3	21.2	3.93	3.44	8.7	★★★
	28/3	21.7	3.98	3.99	11.8	★★★

Season 2012

In the 2012 season, small-scale wines were produced from the first significant crop of six of the ten 'Advanced Selections' planted as grafted vines on 140 Ruggeri in a vineyard in Victoria. As in the previous seasons fruit was harvested at two maturity levels. The first harvest date for all of the three white selections was 31 January, with a mean TSS of 20.9 ± 0.7 ^{o}Brix (Table 6.5.2.5). The second harvest date was 14 February, with a mean TSS of 23.6 ± 1.4 ^{o}Brix. The must of AdW4 from both harvests had very low pH levels with high levels of titratable acidity. In contrast, AdW1 and to a lesser degree AdW2 had high pH levels and lower levels of titratable

acidity, an indication of a requirement for addition of tartaric acid for pH adjustment in winemaking. Fruit from all selections produced wines which were rated highly with no obvious preference for early or late harvest. AdW1 produced rich wines with floral and geranium fruit characters. Wines of AdW2 had pleasant perfumed fruit aromas but tended to lack character on the palate, although wine from the second harvest displayed a richer, lush texture. AdW4 wines displayed perfumed and stewed quince fruit characters. The early harvest wine had an acidic, harsh finish compared to the second harvest wine which was more lush.

Table 6.5.2.5. Harvest date, must composition (total soluble solids, pH and titratable acidity) and sensory assessment score of wines from white advanced selections used for small-scale winemaking in season 2011/12.

Selection	Harvest Date	TSS (^{o}Brix)	pH	Acid (g/L)	Score
AdW1	31/1	22.3	3.81	4.8	★ ★ ★ ★ ★
	14/2	25.8	3.82	4.7	★ ★ ★ ★ ★
AdW2	31/1	19.8	3.69	4.9	★ ★ ★ ★
	14/2	22.6	3.67	4.4	★ ★ ★ ★ ★
AdW4	31/1	20.5	3.05	9.5	★ ★ ★ ★
	14/2	22.4	3.01	7.6	★ ★ ★ ★

The first harvest date for the three red 'Advanced Selections' was 25 January, with a mean TSS of 20.2 $\pm$ 1.1 ^{o}Brix (Table 6.5.2.6). The second harvest date ranged from 31 January to 14 February, with a mean TSS of 22.7 $\pm$ 1.2 ^{o}Brix. The must of all selections, particularly from the first harvest, had low to acceptable pH levels and excellent levels of titratable acidity, an indication that pH adjustment was not required, except for the second harvest of AdR4 and AdR2. Fruit from all selections produced wines which were rated highly with no preference for early or late harvest. Wines produced from AdR4 had high levels of colour, pleasant perfumed and herbal fruit characters and a rich texture. AdR2 produced wines with high levels of colour, perfumed aromas with very soft tannins and a rich, lush texture, particularly with the high maturity second harvest. AdR3 wines had high levels of colour and displayed perfumed and vanilla fruit characters. The early harvest, low maturity wine, had a crisp acid finish compared to the later harvest wine which had a very pleasant after taste.

Table 6.5.2.6. Harvest date, must composition (total soluble solids, pH and titratable acidity), colour density and sensory assessment score of wines from red advanced selections used for small-scale winemaking in season 2011/12.

Selection	Harvest Date	TSS (^{o}Brix)	pH	Acid (g/L)	Colour density (a.u.)	Score
AdR4	25/1	22.3	3.38	8.36	21.5	★ ★ ★ ★
	31/1	25.1	3.62	7.95	26.4	★ ★ ★ ★ ★
AdR2	25/1	19.5	3.26	7.17	33.2	★ ★ ★ ★ ★
	14/2	22.1	3.58	6.17	30.1	★ ★ ★ ★
AdR3	31/1	18.8	3.32	9.67	27.7	★ ★ ★ ★
	14/2	21.0	3.21	7.95	23.9	★ ★ ★ ★ ★

Season 2015

In the 2014/15 season an opportunity was taken to make wines from the first significant crops of four of the 'Advanced Selections' established on two rootstocks, 1103 Paulsen and Ramsey in the Riverland of South Australia. All selections were harvested on the same date, 13 February except the white selection, AdW5 which was harvested on 9 March (Table 6.5.2.7). Compared to 1103 Paulsen, Ramsey rootstock produced a delay in maturation (i.e. 21.0 ^{o}Brix compared with a mean of 22.8 ^{o}Brix), except with AdR1. The TSS levels were, in general, in the desired range for white and red wine production except for AdW5 and AdR5 on Ramsey rootstock. The must of both white selections from both 1103 Paulsen and Ramsey rootstocks had acceptable pH levels, particularly AdW3, and excellent levels of titratable acidity. In contrast, the must of both red selections had higher pH levels and lower titratable acid levels than the white selections, and required tartaric acid addition for pH adjustment during winemaking.

Table 6.5.2.7. Harvest date, must composition (total soluble solids, pH and titratable acidity) and sensory assessment score of wines from advanced selections grafted on two rootstocks (1103 Paulsen and Ramsey) and used for small-scale winemaking in season 2014/15.

Selection	Colour	Rootstock	Harvest	TSS (^{o}Brix)	pH	TA (g/L)
AdW3	White	1103P	13/2	21.0	3.36	6.9
	White	Ramsey	13/2	20.3	3.36	6.9
AdW5	White	1103P	9/3	22.8	3.62	7.0
	White	Ramsey	9/3	18.5	3.54	7.0
AdR1	Red	1103P	13/2	23.7	3.75	5.3
	Red	Ramsey	13/2	24.0	3.82	5.3
AdR5	Red	1103P	13/2	23.8	3.83	7.4
	Red	Ramsey	13/2	21.0	3.82	5.3

Summary and conclusions from wine evaluation of 'Advanced Selections'

Wines were produced from the 10 Advanced Selections grown at the CSIRO Merbein site in seasons 2009/10 and 2010/11 and for six of the selections from another site in Victoria. Where possible, fruit was harvested at two maturity levels to provide information on suitability for lower alcohol wine production. Over the three seasons, harvest maturities of the white selections ranged from 18 ^{o}Brix to 30 ^{o}Brix, although only two had maturities greater than 25 ^{o}Brix (AdW1 in 2011/12 and AdW3 in 2009/10) (Tables 6.5.21, 6.5.23, 6.5.25). Across the dataset encompassing the white selections and seasons (n = 26), the correlations between TSS and pH or TSS and TA were not significant (i.e. r = 0.2), an indication that the differences in both pH and TA were associated with genotype rather than differences in maturity. There was, however, a very significant negative correlation between pH and TA (r = - 0. 87), an indication that differences in TA accounted for 76% of the variability in pH.

Wines of selection AdW1 consistently received high assessment scores across the three seasons, although there was no obvious preference for wines made at different maturities. The must of AdW1 consistently had high pH (3.81 - 4.23) and low TA (3.2 - 4.8 g/L). Assessment scores for wines of AdW2 were more variable, receiving low scores in the difficult 2010/11 season. There was a preference for wines from the higher maturities (22.6- 23.0 ^{o}Brix) compared to 19.8 ^{o}Brix in 2009/10 and 2011/12. Must of AdW2 tended to have high pH (3.7 - 4.06) from the Merbein site but a lower pH from the other Victorian site (3.67- 3.69). TA levels of AdW2 were relatively low (i.e. 3.67 - 4.9 g/l). Wines of AdW4 generally received high assessment scores, except at the higher maturity in 2010. Generally the lower maturity wines were preferred. Must of AdW4 always had low pH (3.01 – 3.52) and high levels of TA (5.1 - 9.5 g/L) with minimal requirement of acid addition for pH adjustment. Wines of

AdW3 were highly ranked in the difficult 2010/11season but did not receive high assessment scores in 2009/10. The must of AdW3 tended to have moderately low pH, except when harvested late and overripe (30 ^{o}Brix) in 2009/10. It also tended to have good TA levels (i.e. 4.1 - 8.1 g/L). AdW5 wines were preferred with maturity levels around 22.1 - 22.9 ^{o}Brix rather than when harvested at a high maturity (26 ^{o}Brix in 2009/10) or a low maturity (20.3 ^{o}Brix in 2010/11). Must of AdW5 had low pH (3.41- 3.83, except when overripe) with relatively high levels of TA (5.2 - 7.4 g/L).

Over the three seasons, harvest maturities of the red selections ranged from 18.8 ^{o}Brix to 26.0 ^{o}Brix (Tables 6.5.22, 6.5.24, 6.5.26). Across the data set encompassing the red selections and seasons (n = 26) there was a significant correlation between, TSS and pH (r = 0.5), an indication that the variability in pH was associated with both maturity and genotype. However the relationship between TSS and TA was not significant (r = - 0.22), an indication that variability in TA was driven by genotype. Furthermore there was no relationship between maturity and wine colour density (r = - 0.1), an indication that wine colour was driven by genotype. There was, however, a highly significant negative correlation between pH and TA (r = - 0.8), indicating that TA accounted for 64% of the variability in pH. Colour density was also correlated positively with TA (r = 0.6) but not with pH (r = - 0.4).

Wines of AdR2 were rated highly, except in 20010/11, despite being harvested at relatively low maturities (19.5 - 22.1 ^{o}Brix). Despite these low levels of maturity, wine colour densities were always very high, 15.2 - 33.2 a.u. (i.e. 2 - 4 fold higher than expected from standard varieties such as Cabernet Sauvignon or Shiraz). Except in 2009/10, pH of AdR2 tended to be relatively low (3.58 - 3.87) with high levels of TA (4.3 - 9.1 g/L), an indication of a minimal requirement for pH adjustment. Wines of AdR3 were rated highly in all seasons despite being harvested at relatively low maturities (18.8 - 21.0 ^{o}Brix). Despite these low levels of maturity, wine colour densities were always very high, 13.8 - 23.9 a.u. (i.e. 2 - 3 fold higher than expected from standard varieties). Except in 2009/10, pH of AdR3 tended to be relatively low (3.21 - 4.27), with high levels of TA (3.0 - 9.7 g/L), an indication of a minimal requirement for pH adjustment. In general, AdR4 was harvested at higher maturities than the previous red selections (22.8 - 26.0 ^{o}Brix). Wines of AdR4 were rated highly except for the later harvest in 2010/11 and had high colour densities in 2009/10 and 2011/12. Must pH of AdR4 tended to be high from the CSIRO Merbein site in 2009/10 and 2010/11 (3.72 - 4.24) but lower from the other Victorian site in 2011/12 (3.38 - 3.62). TA levels were low from the Merbein site but high from the other Victorian site in 2011/12 (8.0 - 8.4 g/L). AdR5 was harvested at moderately low maturities (20.3 - 23.0 ^{o}Brix) and produced wines with high colour, except at the first harvest in 2010/11. The wines, however, did not receive high assessment scores. The must of AdR5 tended to have high pH (3.54 - 4.53) and low levels of acidity (2.8 - 4.0 g/L). AdR1 was harvested at a low maturity in 2010/11 (17.7 ^{o}Brix) and relatively high maturity (23.7 ^{o}Brix) in 2009/10. In both seasons, the wines had high colour but were only given a high assessment score in given 2009/10. The must had a relatively high pH (i.e. 3.72) when harvested at the higher maturity and low levels of TA in both seasons (4.1 - 4.3 g/L).

In summary, the must analysis and small- scale winemaking studies with the ten advanced selections show potential to breed and provide industry with potential alternative varieties with varying flavour and aroma profiles and wine texture. A number of these selections have enhanced fruit composition with low requirements

for pH adjustment and in the case of red wine types, produce wines with significantly more colour than expected from standard varieties grown under similar conditions. In general, wines made from fruit harvested at low maturity received favourable assessments.

6.5.3 ‘Best 100 selections’

Small-scale wines were also produced from a number of the ‘Best 100 Selections’ established in multiplied plantings at the CSIRO Irymple site in seasons 2012/13, 2013/14 and 2014/15. These selections had first been evaluated at the CSIRO Merbein site (2005/06 - 2008/09) and identified with potential, prior to commencement of this project and relocated to the Irymple site.

Season 2013

In the 2012/13 season, harvest date for seven white selections from the ‘Best 100 Selections’ ranged from 31 January to 20 February (Table 6.5.3.1). Apart from BW1 all the selections were harvested at maturities which were higher than the desired range of 20-22 ^{o}Brix, particularly BW4 (i.e. 32.4 ^{o}Brix). Nonetheless, the must of most selections with the exception of BW4, had acceptable to slightly elevated pH levels, requiring minimal addition of tartaric acid for pH adjustment. All the white selections produced acceptable and interesting wines. Despite the low maturity, the most preferred wine was from BW1. It had a golden colour with lovely floral spicy characters and a dense textured, luscious mouthfeel. BW2 produced a heavy wine with big flavour and with spicy, pepper fruit characters and a rich mouthfeel. BW4 wine had a golden colour associated with fermentation issues due to the very high TSS but displayed highly flavoured, floral, spicy fruit characters with a good acid finish. Wine of BW5 was not distinctive but had had some floral and musk character with an acid palate. Wine of BW6 also displayed little character but had a soft, oily acid texture. BW7 wine had a pleasant herbal character with an oily acid texture. The least preferred wine, BW3 displayed winemaking faults associated with a stuck fermentation, i.e. brown colouration and a level of sweetness.

Table 6.5.3.1. Harvest date, must composition (total soluble solids, pH and titratable acidity) and sensory assessment score of seven white wines from the ‘Best 100 Selections’ used for small-scale winemaking in season 2012/13.

Selection	Harvest date	TSS (^{o}Brix)	pH	TA (g/L)	score
BW1	31/1	20.5	2.88	5.9	★ ★ ★ ★ ★★
BW2	31/1	24.2	3.46	4.1	★ ★ ★ ★ ★
BW3	12/2	26.0	3.62	4.5	★ ★
BW4	18/2	32.4	4.06	5.7	★ ★ ★ ★ ★
BW5	18/2	25.6	3.70	5.9	★ ★ ★ ★
BW6	20/2	23.6	3.62	4.2	★ ★ ★ ★
BW7	20/2	23.2	3.57	5.5	★ ★ ★ ★

In the 2012/13 season, harvest date for eight red selections from the 'Best 100 Selections' ranged from 31 January to 20 February (Table 6.5.3.2). In general, the selections were harvested at maturities which were slightly higher than the desired range of 22-24 ^{o}Brix, the exceptions being BR3, BR4 and BR8. Nonetheless, the must of five selections had low or acceptable pH (< 3.6). Only BR7 and BR8 had excessively high pH values requiring high levels of tartaric acid addition for pH adjustment. BR7 had a particularly low level of titratable acidity. For most selections, wine colour density was similar to, or slightly higher than expected from standard varieties such as Cabernet Sauvignon and Shiraz (i.e. 7 - 8 a.u.). The lower colour density of BR6 and BR7 indicate that these selections are more suited to the production of lighter style wines. All the red selections produced acceptable and interesting wines. The most preferred wine from BR5, was full bodied with pleasant berry fruit characters and a rich, lush texture. Wine of BR1 displayed spicy, pepper vegetative characters with big flavour and lush texture. BR3 wine had a lovely balance of fruit and spice characters with soft tannins and a full finish on the palate. BR4 wine had a very purple colour and displayed intense plum and berry fruit characters. BR6 produced a lighter style wine with excellent berry characters and soft tannins. BR7 wine had purple hues, vegetative characters, soft tannins and some bitterness. BR8 had very purple hues, slightly vegetative fruit characters and a nice acidic palate with soft tannins. The least preferred wine, BR2 had good colour with unpleasant stewed mulberry fruit characters and was slightly bitter.

Table 6.5.3.2. Harvest date, must composition (total soluble solids, pH and titratable acidity), colour density and sensory assessment score of eight red wines from the 'Best 100 Selections' used for small-scale winemaking in season 2012/13.

Selection	Harvest Date	TSS (^{o}Brix)	pH	TA (g/L)	CD (a.u.)	score
BR1	31/1	25.1	3.46	4.0	8.8	★ ★ ★ ★ ★
BR2	31/1	26.0	3.20	4.9	7.9	★ ★ ★
BR3	5/2	22.7	3.05	5.1	9.3	★ ★ ★ ★ ★
BR4	5/2	23.1	2.94	5.0	7.9	★ ★ ★ ★ ★
BR5	12/2	25.5	3.71	5.9	10.3	★ ★ ★ ★ ★★
BR6	12/2	25.5	3.41	7.3	5.4	★ ★ ★ ★
BR7	18/2	24.5	4.20	3.4	5.3	★ ★ ★ ★
BR8	20/2	22.9	3.95	4.9	6.7	★ ★ ★ ★

Season 2014

Harvest dates of seven white selections from the 'Best 100 Selections' ranged from 30 January to 7 March in season 2013/14 (Table 6.5.3.3). Across the selections, maturity levels ranged from 21.2 - 25.2 ^{o}Brix, with most in the desired range of 20 - 22 ^{o}Brix. There was a significant range in must pH, 3.03 - 3.83 with most requiring tartaric acid addition for pH adjustment in winemaking. Levels of titratable acidity in the must ranged from a low value of 3.0 g/L to high values of 7.7 g/L. Interestingly, BW10 had both high pH and high acid levels in the must. All the white selections produced acceptable and interesting wines. The most preferred wine, produced from BW4 had a subtle fragrant perfume with pineapple and pear fruit characters with a soft palate. BW8 wine had lovely spicy floral characters with a rich, soft palate. BW9 wine had floral, geranium and fresh peach characters with a soft acid palate. BW11 wine had savoury and peach characters with a soft palate. BW12 wine had spicy, geranium fruit characters but was slightly oxidized with a course finish on the palate. The least preferred wine, produced from BW10, had apple and dried peach fruit characters with an oxidised, slightly bitter palate.

Table 6.5.3.3. Harvest date, must composition (total soluble solids, pH and titratable acidity) and sensory assessment score of seven white wines from the 'Best 100 Selections' used for small-scale winemaking in season 2013/14.

Selection	Harvest date	TSS (^{o}Brix)	pH	TA (g/L)	score
BW8	30/1	24.0	3.60	6.2	★ ★ ★ ★ ★
BW9	3/2	21.2	3.45	5.8	★ ★ ★ ★ ★
BW10	3/2	21.4	3.74	9.0	★★★
BW4	6/2	25.2	3.83	5.4	★ ★ ★ ★ ★★
BW11	6/2	22.6	3.63	5.5	★ ★ ★ ★
BW12	7/3	21.4	3.03	7.4	★ ★ ★ ★
BW13	7/3	22.8	3.53	4.4	★ ★ ★ ★

Harvest dates of nine red selections from the 'Best 100 Selections' ranged from 4 February to 20 March in season 2013/14 (Table 6.5.3.4). In general, the maturity of the selections was in the desired range (i.e. 22 - 24 ^{o}Brix). Across the selections there was a significant range in must pH, 3.45 - 4.18, with most, except BR15, requiring tartaric acid addition for pH adjustment in winemaking. Levels of titratable acidity in the must ranged from a low value of 3.4 g/L to 6.4 g/L. Wines of most selections tended to have low colour densities, except BR12 which had a very high colour density. All the selections, with the exception of BR17, produced wines which were rated highly in the assessments. Wines of BR12 and BR13 were the most preferred. BR12 wine had deep purple colour with rich plum and mulberry fruit characters with a well-structured palate. BR13 produced a rich wine with strong spicy

fruit characters, a vegetative palate and a luscious finish. BR9 produced a lighter style red wine with rich savoury fruit characters and a slightly stalky palate. BR10 wine had very rich plum, raisin and mulberry fruit characters with soft tannins. BR11 displayed some rich vanilla fruit character with a soft but thin palate. BR14 wine had some savoury and fruit characters with a slightly thin palate. BR15 wine had spicy and plum fruit characters, soft tannins with a slightly thin, acidic palate. BR16 wine displayed herbal fruit characters with a lingering after taste. The least preferred wine, produced from BR17, was a lighter style with some spicy fruit character, a thin palate and an acrid after taste.

Table 6.5.3.4. Harvest date, must composition (total soluble solids, pH and titratable acidity), colour density and sensory assessment score of nine red wines from the 'Best 100 Selections' used for small-scale winemaking in season 2013/14.

Selection	Harvest date	TSS (^{o}Brix)	pH	TA (g/L)	CD	score
BR9	4/2	21.5	3.68	4.4	5.3	★ ★ ★ ★ ★
BR10	11/2	22.9	3.99	4.7	5.2	★ ★ ★ ★ ★
BR11	26/2	22.9	4.03	3.4	6.1	★ ★ ★ ★ ★
BR12	26/2	22.2	3.76	4.1	16.2	★ ★ ★ ★ ★★
BR13	3/3	22.6	3.76	5.4	6.3	★ ★ ★ ★ ★★
BR14	7/3	21.9	3.74	4.8	6.3	★ ★ ★ ★
BR15	7/3	20.5	3.45	6.4	6.4	★ ★ ★ ★
BR16	11/3	21.7	3.75	3.8	4.7	★ ★ ★ ★
BR17	20/3	21.9	4.18	3.9	4.6	★ ★

Season 2015

Harvest dates of eight white selections from the 'Best 100 Selections' ranged from 28 January to 25 February in season 2014/15 (Table 6.5.3.5). In general the maturity of the selections was slightly higher than desired levels (i.e. 20 - 22 ^{o}Brix). Nonetheless, pH levels of the must, in the range 3.26 - 3.69, indicate zero or minimal requirements for acid addition for pH adjustment in winemaking (i.e. < 3.6 pH). Wines were not available for assessment at the time of report preparation.

Table 6.5.3.5. Harvest date, must composition (total soluble solids, pH and titratable acidity of eight white wines from the 'Best 100 Selections' used for small-scale winemaking in season 2014/15.

Selection	Harvest Date	TSS (^{o}Brix)	pH	TA (g/L)
BW14	28/1	23.4	3.39	7.67
BW3	28/1	22.1	3.26	7.04
BW15	11/2	22.1	3.69	5.87
BW9	11/2	23.0	3.41	5.29
BW4	18/2	23.1	3.64	6.01
BW9	18/2	22.4	3.48	5.59
BW11	25/2	22.5	3.57	4.75
BW7	25/2	22.0	3.64	5.15

Harvest dates of 18 red selections from the 'Best 100 Selections' ranged from 4 February to 4 March in season 2014/15 (Table 6.5.3.6). In general, the maturity of the selections was in the desired range (i.e. 22 - 24 ^{o}Brix). Across the selections there was a significant range in must pH, 3.49 - 4.17 with most requiring tartaric acid addition for pH adjustment in winemaking. Levels of titratable acidity in the must ranged from a low value of 3.0 g/L to high values of 7.7 g/L.

Table 6.5.3.6. Harvest date, must composition (total soluble solids, pH and titratable acidity) of 18 red wines from the 'Best 100 Selections' used for small-scale winemaking in season 2014/15.

Selection	Harvest date	TSS (^{o}Brix)	pH	TA (g/L)
BR18	4/2	23.5	3.49	4.2
BR1	4/2	23.8	3.60	4.7
BR10	12/2	24.6	3.88	6.5
BR8	12/2	23.4	3.72	6.0
BR2	12/2	26.7	4.09	3.6
BR19	16/2	22.5	3.54	7.7
BR17	19/2	22.6	3.70	4.7
BR20	19/2	21.6	3.71	4.4
BR6	19/2	23.7	3.57	5.4
BR13	19/2	24.2	3.67	5.8
BR11	26/2	23.1	3.96	4.4
BR20	26/2	24.1	4.23	3.4
BR21	26/2	22.5	4.17	3.0
BR15	26/2	21.8	3.89	4.8
BR9	26/2	22.1	3.91	3.0
BR22	26/2	23.0	4.05	3.7
BR23	4/3	21.2	3.63	4.8
BR12	4/3	22.5	3.81	4.1

Summary and conclusions from wine evaluation of 'Best 100 Selections'

In the last three seasons of the project 2012/13, 2013/14 and 2014/15 small scale wines have been produced from 57 of the '100 Best selections' (i.e. 22 whites and 35 reds). A further 30 have been culled because of poor vineyard performance (i.e. growth characteristics, fruit set, yield etc.). Winemaking for the 2014/15 season was not completed within the project time frame. Overall, the results indicate that many of the selections demonstrate potential warranting larger scale testing as the wines display a diverse range of flavour, aroma and texture characteristics and have received high assessment scores. Furthermore, many of the selections have excellent must composition and potentially may be suited to the production of lower alcohol wines. A number may also be useful to extend the harvest period.

Over the three seasons, harvests dates for the 22 white selections ranged from 28 January to 7 March with maturities ranging from 20.5 ^{o}Brix to a very high value of 32.4 ^{o}Brix, although with few exceptions, most were below 24 ^{o}Brix (Tables 6.5.28, 6.5.30, 6.5.32). The pH levels ranged from 2.88 to 4.06 with most below 3.7. Titratable acidity ranged from 4.1 to 9.0 g/L with most above 5 g/L. Across the selections there was a strong correlation between TSS and pH (r = 0.7), an indication that maturity accounted for almost 50% of the variation in pH. Consequently, to fully assess the impact of genotype on must pH it will be necessary to sample closer to optimal maturity levels around 20 - 22 ^{o}Brix. Interestingly however, the relationships between TSS and TA and between pH and TA were not significant (r = -0.2) suggesting a strong genotypic effect on TA, independent of pH.

Over the three seasons, harvests dates for the 35 red selections ranged from 31 January to 20 March with maturities ranging from 21.2 ^{o}Brix to 26.7 ^{o}Brix, with most in the desired range of 22 - 24 ^{o}Brix. (Tables 6.5.29, 6.5.31, 6.5.33). The pH levels ranged from 2.94 to 4.23 with most below 3.7. Titratable acidity ranged from 3.4 to 7.7 g/L with most below 5 g/L. Across the selections the correlations between TSS and pH (r = -0.04) or TSS and TA (r = 0.1) were not significant, an indication of strong control of these factors by genotype. There was however a significant relationship between pH and TA (r = -0.5) which accounted for 25% of the variability in pH. For the 17 wines where it was possible to determine spectral properties, there were no significant relationships between colour density (range 3.0 - 16.2 a.u.) and TSS, pH or TA (r = 0.14, - 0.28, 0.01 respectively) indicating strong independent control of wine colour by genotype.

6.5.4 Analysis of wine aroma and flavour compounds

The potential to link wine aroma profiles with wine preferences was explored on a limited scale in this study using small-scale wines from the 2012 season. The study was limited due to the fact that the flavour and aroma profiles of the wines were not assessed in a formal process by a trained sensory panel. Furthermore, it was not extended to wines from other seasons as the capability to undertake the work was not available (i.e. access to GCMS and trained staff). Nonetheless, the results clearly show that each variety had a distinct flavour and aroma compound footprint enabling them to be clearly identified based on GCMS measurement of volatile compounds. In total, 74 key volatile, aroma and flavour, compounds were measured by GCMS for wines of 11 varieties. The varietal wines included the white varieties, Early Muscat, Morio Muscat, Albana, Monbadon and Putzcheere and an unnamed selection from Germany (GFV3125) and the red varieties Black Gem, Calzin, Etaire de la Dui and Garonnet (see Section 6.5.1 including Tables 6.5.1.9 -12 above).

The total number of volatile compounds assessed by GCMS included 23 monoterpenes (four unnamed), 35 esters, nine alcohols and seven other compounds). A considerable number of these compounds were detected at significant concentrations in most of the wines, and hence not useful for varietal wine discrimination. The attributes, of the twelve compounds of most interest to this study, have been described previously for wine (www.flavornet.org). These compounds included five monoterpenes, i.e. geranyl acetate (rose attributes), beta citronellool (floral), vitispirane (chrysanthemum), TDN (kerosene) and methyl salicylate (peppermint) (Figure 6.5.4.1); the alcohols, benzyl alcohol (sweet) and 1-hexanol (green) (Figure 6.5.4.2); the esters, ethyl benzoate (camomile), methyl decanoate (wine) and isoamyl propionate (apricot/pineapple) (Figure 6.5.4.3) and 2-undecanone (fresh orange) and octanoic acid (sweet cheese) (Figure 6.5.4.4).

All the white wines had undetectable levels or very low levels of benzyl alcohol, ethyl benzoate, isoamyl propionate and high levels of octanoic acid (Figures 6.5.4.1-4). Based on the volatile profiles, the two most preferred white wines, described as having floral muscat characters, Morio Muscat and Early Muscat, were easily distinguishable from the other white varieties by their high levels of geranyl acetate (rose attributes) which were not detected in the other white varieties, with Morio Muscat having the highest level. Both Morio Muscat and Early Muscat had high levels of 2-undecanone (orange/fresh attributes). Wines of Morio Muscat and Early Muscat could be separated using a broader spectrum of compounds, not included in the Figures. Compared to Early Muscat wines, Morio Muscat wines had higher levels of cis geraniol and lower levels of hortienol, linalool, linalool oxide, hexanoic acid and (Z)-3-hexen-1-ol. The wine of GFV3125, described as having apple, acidic and yeasty characters was distinguishable from the remaining white varieties by its high levels of vitispirane (chrysantherum) and TDN (kerosene). Wines of Verdicchio, described as having perfumed and vanilla characters and Albana described as having savoury and pepper characters had high levels of 2- nonanone (not shown) and compared to wines of all the other white varieties, low levels of β-damascenone. However, wines of Verdicchio had much higher levels of methyl salicylate (peppermint). Wines of Monbadon, described as having weak pepper and perfume characters and Putzcheere, described as having spicy aromatic characters, had high levels of methyl decanoate (wine attributes). However, Monbadon had much higher levels of methyl salicylate (peppermint) than Putzcheere.

The red wines had undetectable levels or very low levels of geranyl acetate, methyl decanoate, isoamyl propionate, 2-undecanone and high levels of TDN (Figures 6.5.4.1-4). Black Gem wine, described as having rich fruity spice characters with an odd 'hybrid' character was easily distinguishable from the other red wines as it had the highest levels of beta citronellol (floral) and benzyl alcohol (sweet). Wines of Calzin, described as having a smokey, bitter character, had the highest levels of vitispirane (chrysanthemum), ethyl benzoate (camomile) and TDN (kerosene). Wines of Etaire de la Dui, described as having herbal, vegetative and stalky characters, had the highest levels of 1-hexanol (green) and isoamyl propionate (apricot/pineapple). Wine of Garonnet, described as having savoury fruit characters, was easily distinguished from the other red wines as it was the only red wine having a significant concentration of methyl salicylate (peppermint). It also had a high level of isoamyl propionate (apricot/pinapple).

In summary, each varietal wine displayed a unique chemical flavour and aroma profile. It would be useful to undertake further research to assess the potential of the technology for varietal wine identification across a wider range of varieties, taking into account differences between seasons, regions and crop load. To more accurately link wine sensory information to the aroma and flavour compounds, trained sensory panels using descriptive techniques would be required. Further research to link the aroma and flavour compounds with precursors in berries would also be very useful in variety evaluation studies.

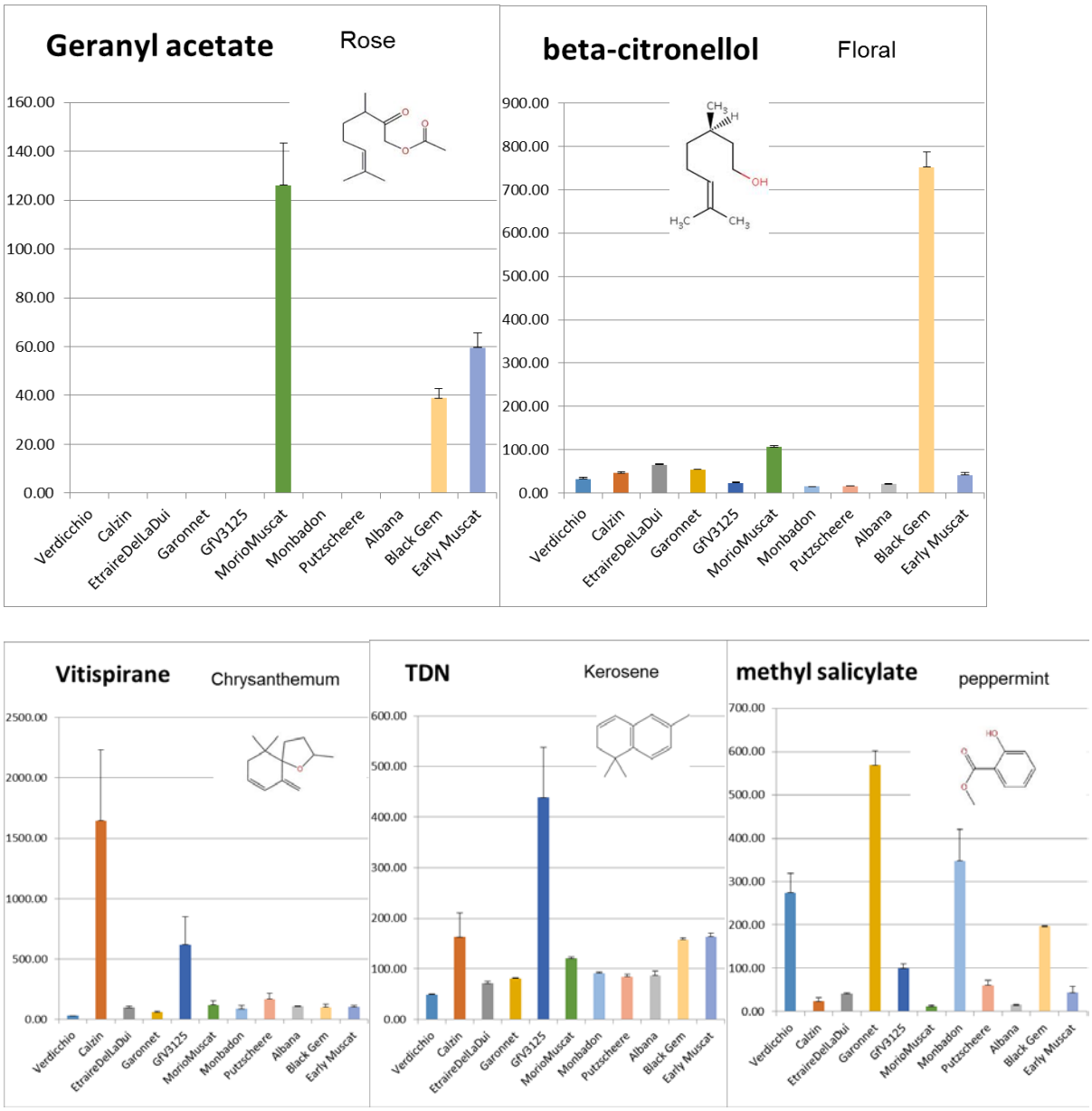


Figure 6.5.4.1. Concentration of selected monoterpenes (Geranyl acetate, beta-citronellol Vitispirane, TDN, methylsalicylate) detected by GCMS in 11 wines from the 2012 season. Y-axis is peak height relative to internal control.

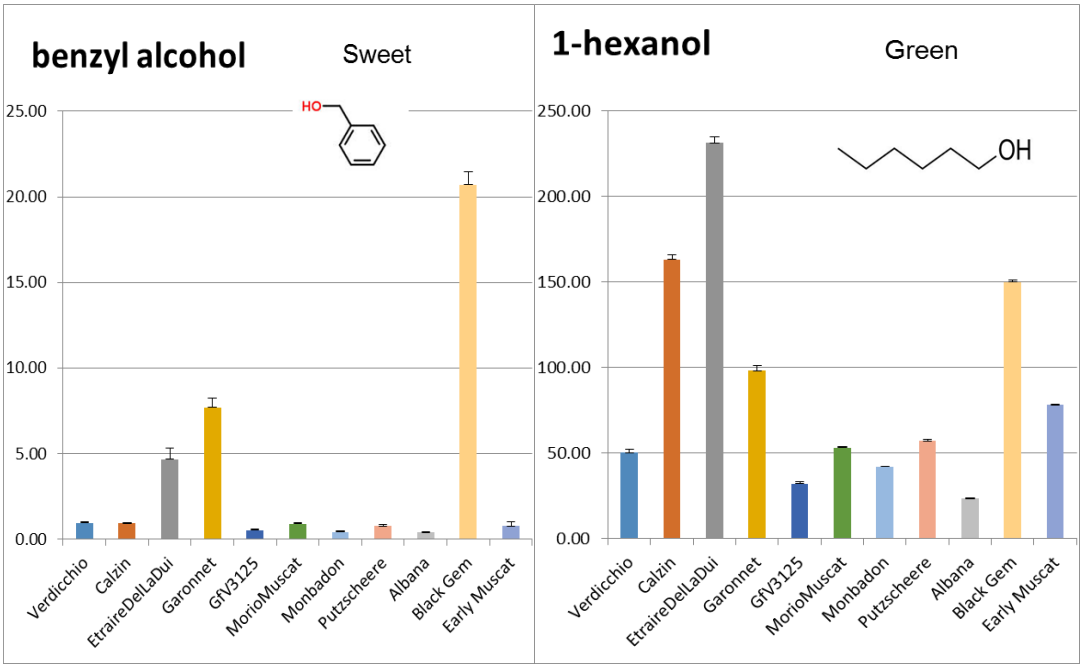


Figure 6.5.4.2. Concentration of selected alcohols, benzyl alcohol and 1-hexanol, detected by GCMS in 11 wines from the 2012 season. Y-axis is peak height relative to internal control.

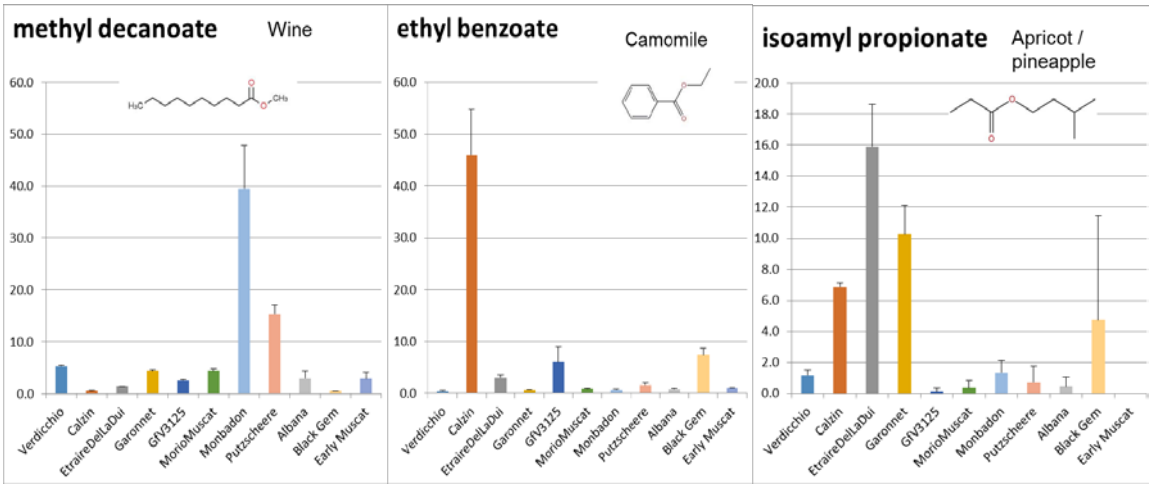


Figure 6.5.4.3. Concentration of selected esters, methyl decanoate, ethyl benzoate and isoamyl propionate, detected by GCMS in 11 wines from the 2012 season. Y-axis is peak height relative to internal control.

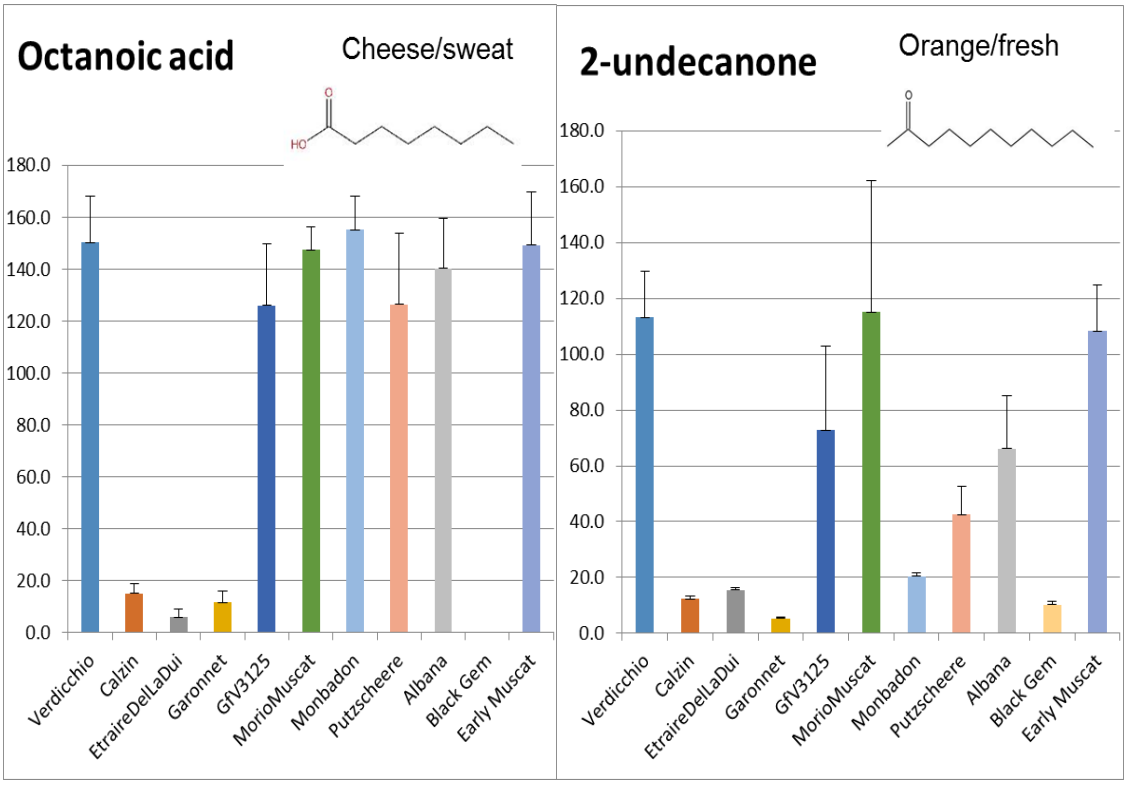


Figure 6.5.4.4 Concentration of octanoic acid and 2-undecanone, detected by GCMS in 11 wines from the 2012 season. Y-axis is peak height relative to internal control.

6.5.5 Analysis of spectral properties of red wines

Thirty four red varietal wines were produced in the small-scale winemaking studies conducted over five seasons. Spectral analyses of these wines, undertaken within three months of bottling, are presented in Table 6.5.5.1. The results of total berry anthocyanins and total berry phenolics determined by spectrometry reported in section 6.4. are also included to enable exploration of relationships between berry colour and the spectral properties of the wine. In addition, berry anthocyanin profiles of these varieties were also determined by HPLC to provide data to explore linkages between berry anthocyanins and wine colour. This information is not reported as initial analyses indicated problems with varieties that have a species hybrid background or red flesh due to the presence of other forms of anthocyanins, e.g. diglucosides. A more detailed analysis of the chromatograms is required to explore this issue.

Across the red varieties used in the small-scale winemaking study, there was a 25 fold range in total berry anthocyanins (0.26 - 6.38 mg/g) (Table 6.5.5.1). The range in total phenolics was smaller, i.e. 6 fold (0.63 - 3.53 mg/g). In regard to the wine spectral properties there was a 15 fold range in wine colour density (3.08 - 47.37 a.u), a 2.4 fold range in hue (0.46-1.1), a 136 fold range in total anthocyanins (52 - 7069 mg/L), a 39 fold range in ionized anthocyanins (10.5 - 411.5 mg/L) and a 32 fold range in total phenolics (10.1 - 324.6 mg/L). Approximately half of the wines had colour densities equal to or greater than the benchmark, 2010 Shiraz. Wine colour of the hybrid variety, Royalty was extremely high indicating a high potential for use in blending. Other varieties with significantly higher colour than Shiraz included Teroldego, Egiodola, Black Gem and 128 Seibel. Varieties with low colour more suited to lighter style wines, included Tinta Cao, Semembat, Valdigue, Medea, Limberger, Troyen, Herbemont, Uva di Troia Calzin, Etraire de la dui and Best's R3V54. Wines of a number of varieties had high hue values, indicating brown pigmentation rather than deep purple hues. These included Medea, Leon Millot, Troyen, Herbemont, Uva di Troia, Etraire de la dui and Best's R3V54.

Regression analyses were used to explore the relationships between the berry anthocyanins and phenolics and the wine spectral properties (Table 6.5.5.2). Highly significant correlations ($p<.001$) indicate that total berry anthocyanins was an excellent predictor of wine colour density ($r = 0.92$), total anthocyanins ($r = 0.83$), ionized anthocyanins ($r = 0.90$) and total wine phenolics ($r = 0.89$), accounting for 85%, 69%, 81% and 79% of the variation across the varietal wines in those wine parameters, respectively. It should be noted that these very strong relationships were achieved despite the winemaking being spread across seasons with different climatic conditions with fruit harvested at different maturities from two different sites. While there was a significant correlation between berry anthocyanins and berry phenolics ($r = 0.78$), relationships between berry phenolics and wine parameters were not as strong, accounting for only 34%, 35% and 37% of the variation in wine colour density, ionized anthocyanins and total phenolics across the varieties. Within the wine parameters, highly significant correlations show that colour density is tightly linked to ionized anthocyanins ($r = 0.99$), total anthocyanins ($r = 0.94$) and total phenolics ($r = 0.96$).

Table 6.5.5.1. Total berry anthocyanins (TA_{be}) and phenolics (TP_{be}), and wine spectral properties, i.e. color density (CD), hue, total anthocyanins (TA_w), ionized anthocyanins (IA_w) and total phenolics (TP_w) of 34 wines produced over five seasons (2010/11- 2013/14). Results for 2009/10 Shiraz wine, produced from a nearby vineyard, are included for comparative purposes.

	Berry		**Wine**				
	TA	**TP**	**CD**	**hue**	**TA**	**IA**	**TP**
	mg/g	au/g	Au	Au	mg/L	mg/L	au/L
Shiraz (2010)	0.67	1.26	7.68	0.52	461	71.4	41.4
Dunkelfelder	2.54	2.44	8.68	0.47	455	58.0	65.0
Chancellor	0.87	1.05	8.55	0.56	1245	70.5	56.8
Tinta Cao	1.42	2.11	4.45	0.55	459	22.4	45.6
Semebat	0.91	1.96	3.67	0.57	394	24.8	52.2
Teroldego	2.05	2.15	13.52	0.47	914	103.5	83.9
Royalty	6.38	3.53	47.37	0.46	7069	411.5	324.6
Mondeuse	1.37	1.99	7.85	0.50	631	62.6	72.6
Valdiguie	1.11	1.74	4.87	0.52	417	37.5	45.0
Refosco Nostrano	1.01	1.57	8.57	0.51	716	65.4	65.6
Croatina	1.42	1.90	8.84	0.50	681	64.3	79.7
Egiodola	2.38	2.28	11.61	0.61	309	76.0	58.1
Medea	0.59	1.22	3.08	0.82	120	16.2	26.9
Leon Millot	0.70	1.13	6.75	1.10	501	30.1	43.2
Limberger	0.99	1.36	4.62	0.65	139	32.4	21.9
Troyen	0.77	1.92	3.15	0.79	117	18.9	27.3
Tinta Cao	1.35	1.82	4.38	0.57	199	31.6	22.3
Refosco Pedunclo-*	-	-	8.20	0.57	303	57.7	31.6
Calzin	0.77	1.45	5.68	0.59	74	33.4	30.7
Grand Noir ----*	1.59	1.71	7.64	0.53	245	63.5	39.1
Herbemont	0.26	0.63	1.66	0.89	52	10.5	10.1
Uva di Troia	0.33	0.92	2.11	0.72	687	14.3	22.2
Black Gem 2011	1.17	0.98	8.55	0.60	1115	66.8	65.1
Black Gem 2012	-	-	11.3	0.55	1184	103.1	78.7
Calzin	1.51	2.85	4.47	0.49	219	42.6	34.2
Etraire ---------*	0.65	1.21	4.17	0.73	253	24.0	27.6
Garonnet	1.04	0.73	6.33	0.67	846	49.8	41.5
Dornfelder	1.66	1.34	15.3	-	-	-	-
Calzin	0.74	1.42	3.13	0.64	109	20.4	28.3
Arinarnoa	1.13	1.29	6.39	0.60	201	38.4	28.0
Best's R3V54	1.01	1.23	3.29	0.83	114	12.2	18.8
Limberger	1.21	1.66	6.14	0.67	304	41.1	33.3
Egiodola	1.91	2.29	12.1	0.53	566	95.5	61.0
128 Seibel	2.35	1.68	14.9	0.71	692	93.9	61.6
Souzao	2.43	2.55	8.1	0.76	236	33.2	32.5

* Full names: Refosco Pedunclo Rosso, Grand Noir de la Calmette and Etraire de la dui.

Table 6.5.5.2. Correlation matrix describing relationships between berry anthocyanins and phenolics and wine total and ionised anthocyanins, total phenolics, wine colour density and colour hue (n=34). Highly significant values (P<0.001) are highlighted in bold.

	Berry Antho.	Berry Phenolics	Wine colour density	Wine colour Hue	Wine total Antho.	Wine ionised antho.
Berry phenolics	**.78**	-				
Wine colour density	**.92**	**.58**	-			
Wine colour Hue	-.39	-.51	-.34	-		
Wine total anthocyanins	**.83**	.48	**.94**	-.28	-	
Wine ionised anthocyanins	**.90**	**.59**	**.99**	-.39	**.96**	-
Wine total phenolics	**.89**	**.61**	**.96**	-.39	**.96**	**.97**

7. Outcome/Conclusion

A limited number of winegrape varieties are grown commercially in Australia. This may restrict the capability of the wine industry to meet challenges associated with predicted climate change scenarios. These challenges include the consistent supply of quality product in a variable and changing environment; the effects of temperature on fruit composition and wine attributes; a compression of the seasonal cycle, leading to an inability to process fruit at optimum maturity and, adapting to limited water supply and drought. The potential to exploit genetic variability to meet these challenges through adoption of alternative varieties has been explored. A systematic approach has been used to phenotype 566 wine varieties, a number of clones of specific varieties and CSIRO breeding lines in the CSIRO germplasm collection, located in a hot irrigated region, for traits considered to be important for climate change adaptability. The study included close monitoring of vine phenology (i.e. budburst, flowering, veraison and harvest date); measurement of key growth characteristics (shoot fruitfulness, leaf area index, berry weight and estimates of yield); measurement of berry composition (total soluble solids, pH, titratable acidity, malic and tartaric acids, yeast assimilable nitrogen, mineral ion concentrations, and in red varieties, total anthocyanins and phenolics). The study was supported by the production and evaluation of small-scale wines of selected varieties and advanced CSIRO breeding lines. The information has been stored in a readily searchable form in FileMaker Pro13 database.

The project has demonstrated that there are significant opportunities to further broaden the genetic base and range of varieties available to the Australian wine industry. The study has shown potential to identify varieties with:

- short seasonality to improve water use efficiency
- smaller canopies to minimise transpiration, improve water use efficiency and improve production efficiencies if used in high density plantings
- long seasonality to ripen in cooler conditions
- optimal pH and titratable acidity levels which may also be harvested at lower maturities to produce lower alcohol wines
- improved composition and wine quality attributes which may provide opportunities to produce wines for marketing at higher price points.

Adoption of enhanced varieties will enable the industry to maintain its production base in existing regions, despite the impacts of climate change and minimise the significant economic, social and environmental costs of re-positioning and developing wine grape production and processing in new regions (ie. irrigation, vineyards, wineries, bottling and packaging and transport infrastructure). Furthermore, production from varieties suited to lower alcohol wine production will facilitate the industry capacity to address the issue of high alcohol in many Australian wines. In the longer term this should provide a basis for attitudinal change within the Australian community toward consumption of wines with excellent flavour and aroma and lower alcohol. Furthermore early ripening varieties with short seasonality may also be useful to diversify the production base in cooler regions.

Over the course of the project, six white varieties with high potential, moderately low must pH levels (i.e. < 3.8) and which ranked highly in the sensory assessments have been selected. These include, Early Muscat, selected for its early ripening and aromatic, floral flavour and aroma characteristics; Green Veltliner, selected for its spicy, tropical aroma and soft but flavoursome palate; Montils, selected for its aromatic citrus aromas, apricot and tropical flavours and a crisp acid palate; Malvasia Moscato, selected for its late ripening and aromatic floral muscat aromas and citrus palate characters; Catarrato selected for its very late ripening and suitability for low alcohol wine production; and Morio Muskat, selected for lovely floral muscat aroma and flavour. A number of other promising white varieties were also identified with significant potential based on their moderately low pH and wine assessments. They include Petit Meslier, Arnsburger, Rkatziteli, Viosinho, Baroque, Loureiro, Raffiat de Moncade, Fernao Pires, Liliorila, Cortese, Sideritis, Malvasia di Candia, Monbadon, Merlot Blanc, Hibernal and the unnamed German selection, GM 643-16.

In the studies, eight high priority red varieties have been selected with high potential based on the assessment of the wine and colour and to a lesser degree than for the white varieties, fruit composition. These varieties include, Refosco Nostrano, selected for its red berry and earthy aromas, balanced palate with good fruit flavours and tannins; Dunkelfelder, selected for its high colour, early ripening and suitability for lower alcohol wine production; Teroldego selected for its excellent colour and wine characteristics; Dornfelder, selected for its excellent colour and wine characteristics in the difficult 2010/11 season; and Egiodola, selected for its richness, high colour with deep purple hues and fruity vanilla and herbal characters. Other promising red varieties with potential include Croatina, Mondeuse and Grand Noir de la Calmette. Four further varieties of interest have been identified for the production of lighter style wines, i.e. Valdigue, Medea, Limberger and Calzin.

The study has described significant variation in key traits across the varieties which were driven by the genotype (variety), despite varying climatic conditions, assessment of vines of varying age at two locations with different soil types and management practices. The variation in traits across the varieties included a differences of six weeks in budburst, a two-fold difference in seasonality (i.e. budburst to harvest) with harvest spread over more than a four month period, five-fold differences in fruitfulness and LAI, 15-fold differences in berry weight, 10-fold differences in berry mineral ion concentrations with large differences in key measurements of fruit composition (pH, titratable acidity, organic acid composition, yeast assimilable nitrogen and, in red varieties, total anthocyanins and phenolics).

The study has shown that opportunities to select named, imported varieties with low pH, to minimise acid addition for pH adjustment, are extremely limited for grapes grown in the hot, irrigated regions and to address future climate change scenarios. In contrast, many of the CSIRO breeding lines had excellent fruit composition with optimal pH and acid levels. Those selections showing good wine quality attributes warrant further assessment for potential release to industry.

Interrogation of the data has shown that varieties with the most optimal fruit composition for winemaking were those that ripened early in the season and had small berries. Late ripening varieties and those with large berries could be expected to have high pH with low levels of total soluble solids, titratable acidity and yeast

assimilable nitrogen. The study also showed that the ability of a variety to achieve acceptable levels of maturity had a strong genetic component. Ripening of some varieties appeared to cease at low maturities whereas in other varieties it increased rapidly, possibly due to wilting in hot conditions. Varieties with high TSS, would be expected to have higher tartrate and YAN levels and in some seasons, higher pH.

The study has provided strong evidence linking berry composition across the varieties with berry mineral ion concentration, particularly K, S and Mg. Further research is required to enhance the understanding of the processes and genetic control of these relationships across the varieties involving uptake of minerals by the vine, their transport into the berry and the role they play in pH buffering and ion balance. Furthermore, the study has also shown that fruit composition across varieties is impacted by vine growth characteristics, particularly canopy size (LAI) and berry weight. The positive association with malic acid and both YAN and canopy size (LAI), indicate linkages to canopy vigour and shade, vine N status and transport of N into the berry. A more detailed study of the berry N and amino acid profiles of the berry samples could provide further insight into this issue. Overall, these results raise the possibility, warranting further research, that fruit composition of individual varieties may be manipulated through control of vine vigour by irrigation, pruning or canopy management and nutrition management.

Outcomes from the small-scale winemaking have been used to identify a range of interesting varieties and advanced CSIRO breeding lines which have potential for adoption by industry to broaden the genetic base available to the Australian industry. For red varieties, the strong relationship between berry anthocyanins and wine spectral properties is of particular interest as it shows that varieties with high levels of berry anthocyanins, a trait that was very stable across seasons, can be selected to produce wines with stable colour across seasons for use as alternative varieties or for blending. Furthermore, the scoping study involving the assessment of wine aroma and flavour profiles using GCMS has shown that each varietal wine tested displayed a unique chemical flavour and aroma profile. It would be useful to undertake further research to assess the potential of the technology for varietal wine identification across a wider range of varieties, taking into account differences between seasons, regions and crop load. Further research to link wine sensory information to the aroma and flavour compounds using trained sensory panels would add significant value to such studies. Furthermore, research to link the aroma and flavour compounds with precursors in berries would also be very useful in variety evaluation.

8. Recommendations

The project, has phenotyped a diverse range of varieties for key traits related to wine production and quality, particularly related to climate change adaptability. It has identified significant opportunities for further scientific research and industry development which are listed below. It is recommended that:

1. The database containing all the phenotyping data of key traits be refined in a readily searchable format for use by researchers and industry (as recommended by the reference group in January 2015). The refined database could be linked to CSIRO's historical photographic records used for ampelographic purposes and photographic field records collected in 2014. The database could form the basis for development of a **Winegrape Selector Tool**.

2. To maximise the benefit from the phenotyping study, which has shown that the significant variation in a number of key traits across more than 500 wine varieties is driven by genotype, there is an opportunity to employ a genotype-by-sequence approach for identifying SNPs for genome wide association studies to map the loci for selected traits. This knowledge would provide underpinning information to improve breeding efficiency and deliver elite germplasm to industry. Compared to the effort in collecting the phenotypic data this study would be relatively inexpensive.

3. Further research be undertaken to enhance understanding of relationships between vine growth characteristics, vine nutrient status, berry mineral content and fruit composition, particularly pH, organic acid composition. This should address issues involving plant nutrient status, transport of ions into the berry, roles in ion balance and pH buffering and links with organic acids.

4. Nutrition research be targeted at manipulation of berry composition to enhance fruit composition rather than whole vine status using petiole analysis. The results of this study have described 10-fold variation in berry ion concentrations linked to fruit composition. Such a study could be extended to identify the potential to manipulate fruit composition by control of vine vigour by irrigation, pruning or canopy management in addition to nutrition management.

5. Further research be conducted to relate anthocyanin profiles already determined in berries across a diverse range of red varieties including species hybrids and red fleshed types using HPLC techniques with anthocyanin profiles in the wine. CSIRO has retained sample wines for most of the red varieties included in the study. The study has shown that there is a very close correlation with anthocyanins in the berries and final wine spectral properties. This study should be relatively low cost as the berry chromatograms are already available.

6. Further research be undertaken to extend the GCMS analysis of key wine aroma and flavour compounds to a broader set of alternative varieties linked to more controlled sensory studies. The fact that each variety had a distinct set of flavour and aroma compounds indicated that it could be a useful tool in the study and verification of alternate wine varieties. Such research should be

extended to the measurement of precursors in fruit and enhance the understanding of links between fruit composition and wine quality attributes.

7. Discussions continue with industry with regard to formation of an Australian National Grapevine Variety Collection that may enable varieties of significant interest to the Australian wine industry, identified in this study, to be made available to industry through development of a formal process involving mothervine establishment with high health material and variety verification involving DNA typing of international reference material where available. (The Project Reference Committee strongly endorsed this approach in January 2015).

8. Further research be undertaken to verify the uniqueness of unidentified varieties sourced by CSIRO from old Australian vineyards which were planted prior to the outbreak of phylloxera in Europe. It is possible that some of this material may not only have potential for industry adoption but may also be of significant heritage value. DNA studies could be undertaken to verify uniqueness or relationships of this material to other named varieties.

9. Adoption of enhanced germplasm facilitated through ongoing interactions with AGWA, regional wine groups and wine companies to evaluate small-scale wines produced from varieties in the CSIRO germplasm collection, advanced breeding lines and the ‘Best 100 selections’, while wine stocks exist.

10. Evaluation of the 10 ‘advanced selections’ be maintained with commercial wine companies to identify those most suited to commercial development. Path to market mechanisms identified and implemented with varieties protected by PBR.

11. Commercial evaluation sites be established for the most promising selections identified from the ‘Best 100 selections’, to assess vineyard performance, wine characteristics and style and market preferences and acceptance.

Appendix 1: Communication

Presentations have been given to a wide range of national and international symposia, wine industry and grower audiences over the course of the project. These included:

- The national ASVO/AAVWS seminar in Mildura in November 2010 (see reference below)
- The 18th International Symposium GiESCO, Porto, Portugal, 7-11 July, 2013 (see reference below)
- The Australian Wine Industry Technical Conference, 'Alternative wine variety workshop' in Adelaide, July 2010
- Poster presentation at the Australian Wine Industry Technical Conference in Adelaide, July 2010
- The GWRDC/DAFF climate change workshop in Adelaide in October 2010
- The Crush seminar in Adelaide, September 2011
- Poster presentation at the International Cool Climate Symposium in Hobart in January 2012 (attached below)
- Numerous presentations, supported by wine tastings with grower and industry groups from the Riverland, including the Riverland Alternative Wine Group, the Barossa Valley, Adelaide Hills and Langhorne Creek Wine Groups in South Australia, and Wine Groups at Stanthorpe in Queensland, Mildura and Mornington Peninsula in Victoria
- The conduct of tastings with wine companies, including project collaborators.

The conduct of wine tastings with wine companies and industry groups has generated considerable interest in the potential of alternative wine varieties to assist the industry to meet future challenges associated with climate change, limited water supply and lower alcohol wine production.

Papers Published:

- Clingeleffer, P.R. and Davis, H.P. 2011. Enhanced varieties and clones to meet the challenges of climate change and deliver low alcohol wines. In: Proceedings ASVO & AAVWS; Think Global: Plant Local. Mildura, 5th November 2010.
- Clingeleffer, P.R., Tarr, C.R. and Davis H.P. 2013. Measurement of phenology, growth characteristics and berry compostion to identify winegrape varieties adapted to future climate change scenarios. Journal of Enology and Viticulture-vol 28, Proceedings 18th International Symposium GiESCO, Porto, Portugal, 7-11 July,2013, 987-991
- Clingeleffer, P.R., Davis, H.P. and Tarr, C.R. 2011. Alternative varieties to meet the challenges of climate change. 8th International Cool Climate Symposium, Hobart, Tasmania, 31 January - 4 February, 2012. Poster presentation.

Selection of alternative varieties to meet the challenges of climate change

Peter R. Clingeleffer, Hilary P. Davis and Caroline R. Tarr. CSIRO Plant Industry

Introduction

Major challenges for the Australian wine industry are the consistent supply of quality product in a variable and changing environment; adapting to limited water supply and drought; improving the economic sustainability of growers; and a requirement to produce lower alcohol wines. The potential to exploit genetic variability of grapevine material through adoption of alternative varieties that broaden the genetic base of the Australian industry offers an alternative approach to assist industry to meet these challenges. Approximately 500 varieties grown at CSIRO Merbein have been evaluated.

Methods

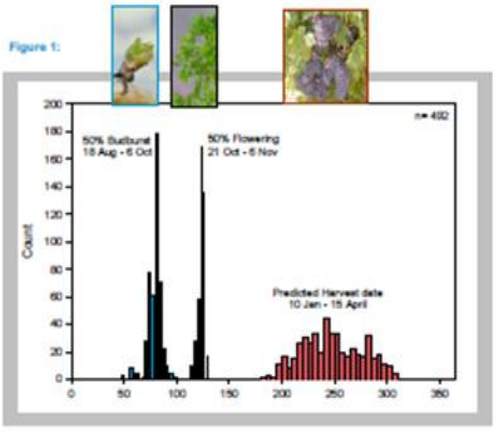
The vines were managed with a deficit irrigation of (5 ML/ha) and mechanically hedged. Measurements included determination of key phenological stages, growth characteristics (leaf area and fruitfulness), yield components and fruit composition. Small scale wine lots were produced from varieties best meeting key criteria. These criteria included:-

- Good fruit flavour and composition
- Extended season (early and late) to reduce impacts of compressed seasons
- Early ripening with short seasonality to reduce water requirements and for use in cooler regions
- High fruit to leaf ratios to improve water use efficiency (a surrogate for crop water use index, i.e. yield to water transpired)
- Early release of flavour during fermentation to facilitate production of low alcohol wines.

Results

The timing of phenological stages (budburst, flowering, harvest) across 492 varieties is shown in Figure 1 (2009 -10 season).

Figure 1:



- There was no correlation between predicted harvest date (22°Brix) and budburst date or flowering date.
- There are opportunities to identify varieties with *short* seasonality to improve water use efficiency and to identify varieties with *long* seasonality to ripen in cooler conditions.



Figure 2: Examples of the range of canopy size and crop-load

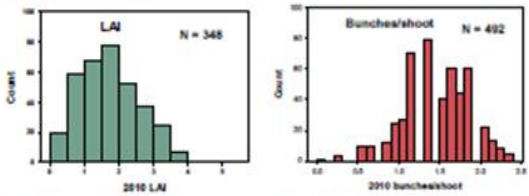


Figure 3 Leaf area index and fruitfulness of 492 varieties, season 2009 - 10

- The LAI results show a 5-fold difference indicating opportunities to identify varieties with reduced transpiration (expected 1L/day/m² canopy).
- There was a wide range in fruitfulness across the varieties. Varieties with low fruitfulness may have production problems with hedging or spur pruning and require cane or minimal pruning.

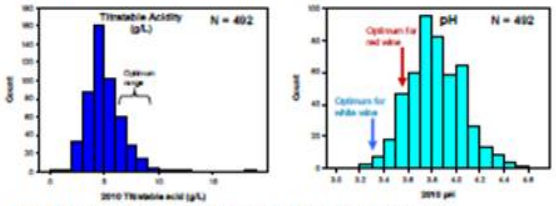


Figure 4: Titratable acidity and pH of 492 varieties at harvest during vintage 2010.

The fruit composition results shown in Figure 4 indicate opportunities to identify varieties in optimum pH and titratable acidity ranges. High levels of tartaric acid addition would be required for varieties with high pH, increasing wine making costs.

Early ripening varieties of interest from the winemaking studies, which may be suited to cooler climates include:-

- **the white varieties**, Early Muscat (USA), Petit Meslier (France), Amsburger (Germany), Gruner Veltliner (Austria), Rkatziteli (Russia), Viosinho (Portugal), Baroque (France), Muscat Ottonel (France), Picolit (Italy), Raffiat de Moncade (France) and Lilorila (France).
- **the red varieties**, Dunkelfelder (Germany), Tinta Cao (Portugal), Semebat (France), Teroldego (Italy), Mondeuse (France), Valdiguie (France), Refosco Nostrano (Italy), Croatina (Italy), Egiodola (France), Medea (Hungary), Leon Millot (France), Limberger (Austria), Troyen (France) and Refosco Pedunclo Rosso (Italy).

Conclusion

The studies have shown there is a wide range of alternative varieties to assist the industry to meet future challenges associated with climate change.

CSIRO

gwrdc

Reference

P. Clingeleffer & H. Davis, 2010, Enhanced varieties and clones to meet the challenges of climate change and deliver low alcohol wines. In: Think Global. Plant local – alternative varieties. ASVO Seminar Proceedings, 5th November 2010, Mildura, Australia. www.asvo.com.au/proceedings

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Appendix 2: Intellectual Property

The intellectual property generated in the project includes:

1. The information on 880 varieties and clones held in the project data base which could be refined to provide a readily searchable format for use by researchers and industry. This information will facilitate both the decision making processes and provide an excellent resource for future reference and use by industry. It also provides a valuable research resource for studies on genetic diversity, fruit composition and wine quality attributes. Of particular interest is the subset of unidentified varieties sourced by CSIRO from old Australian vineyards which were planted prior to the outbreak of phylloxera in Europe. It is possible that some of this material is unique and of significant heritage value. DNA studies could be undertaken to verify uniqueness of the material and their relatedness to existing varieties. Potentially the refined data base could be linked to both the photographic field records collected in this project and to CSIRO's historical photographic records, used for ampelographic purposes. The data base could form the basis for development of a **Winegrape Selector Tool**.

2. Promising selections identified from the CSIRO advanced breeding lines and 'Best 100 Selections' with potential for commercialization and release to industry through agreed commercialisation strategies that include Plant Breeders Rights and that protect the benefit for Australia.

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Appendix 4: Staff

Peter Clingeleffer	Project Supervisor
Hilary Davis	Research Officer
Caroline Tarr	Research Officer
Arryn Clarke	Farm manager
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Ben Riggs	Project Officer
Chris Mitcham	Project Officer
Karen Connolly	Project Officer
James Martin	Project Officer
Bronwyn Smithies	Project Officer
Adele Craig	Project Officer
Lekha Sreekantan	Project Officer
Jake Dunlevy	Project Officer
Gabriele Rivera Hernandez	Project Officer
Ruwan Robale-Lenorage	Project Officer
Anthony Pearce	Project Officer

Appendix 5: Outputs/activities

Year 1	Output	Due Date	Activities
A	Project reference group appointed	30/11/2009	Key industry personnel representing commercial winemakers, marketing representatives and grower groups invited to participate in Reference Group. First meeting held.
B	Data base established with key varietal, clonal and preliminary phenotyping data	30/04/2010	• Varietal and clonal information from all sources (ie. the literature, previous CSIRO winemaking history) documented in a format to assist selection processes • Preliminary phenotyping data of phenology, growth documented in database (see below) • Data base interrogated to identify most promising types based on sorting and ranking against key selection criteria
C	Twenty genotypes identified, harvested and wines produced by Provisor	30/04/2010	• Varietal and clonal information and preliminary phenotyping and compositional criteria, collected in season 1 applied to identify promising varieties and clones for winemaking.
D	Phenotyping of varieties, clones and selected advanced breeding lines implemented.	30/06/2010	• Key phenological information collected (ie. budburst, flowering date, veraison date, harvest date) • Growth characteristics determined (ie. fruitfulness, maximum canopy size, bunch architecture, berry and bunch weight and yield) • Basic fruit composition information collected (ie. total soluble sugars, titratable acidity, free run juice colour, total anthocyanins and phenolics). • Berry flavour characteristics determined
E	Evaluation of ‘Superior’ selections	30/06/2010	• Cutting material collected and provided to companies for propagation on a range of rootstocks to establish semi-commercial plantings. • Wines produced from ‘Superior’ selections at two different maturities, ie. with a low and normal level of maturity. • Basic wine compositional parameters assessed, including spectral properties where appropriate • Wines assessed by industry reference group

Year 2	Output	Due Date	Activities
A	Preliminary recommendation based on assessment of 2010 wines developed.	31/12/2010	• Wines from 20 genotypes produced in 2010 assessed by Reference Group and industry tasting panel(s) • Preliminary recommendations provided to Reference Group and, if deemed appropriate, to industry.
B	Twenty genotypes identified, harvested and wines produced by Provisor	30/04/2011	• Varietal and clonal information and preliminary phenotyping and compositional criteria, collected in season 1 applied to identify promising varieties and clones for winemaking.
C	Evaluation of 'Superior' selections	30/6/2011	• Cutting material collected and provided to companies to complete propagation on a range of rootstocks to establish semi-commercial plantings. • Wines produced from 'Superior' selections at two different maturities, ie. with a low and normal level of maturity. • Basic wine compositional parameters assessed, including spectral properties where appropriate • Wines assessed by industry reference group
D	Phenotyping of varieties, clones and selected advanced breeding lines completed.	30/06/2011	• Key phenological information collected (ie. budburst, flowering date, veraison date, harvest date) • Growth characteristics determined (ie. fruitfulness, maximum canopy size, bunch architecture, berry and bunch weight and yield) • Basic fruit composition information collected (ie. total soluble sugars, titratable acidity, free run juice colour, total anthocyanins and phenolics). • Berry sensory flavour characteristics determined • Targeted fruit samples retained for detailed analyses (ie. for organic acids, anthocyanin and tannin profiles etc)
E	Source mother blocks of promising genotypes lished	30/06/2011	• Cuttings collected and propagated to establish plantings as source motherblocks of promising genotypes. • Close consultation with the Reference Group and industry re mechanisms of material supply to industry

Year 3	Output	Due Date	Activities
A	Recommendations based on assessment of 2011 wines developed.	31/12/2011	• Wines from 20 genotypes produced in 2011 assessed by Reference Group and industry tasting panel(s) • Recommendations provided to Reference Group and, if deemed appropriate, to industry.
B	Wine and berry composition determined	30/06/2012	• Organic acids, anthocyanin and tannin profiles determined for targeted berry samples collected in previous seasons. • Organic acids, anthocyanin and tannin profiles determined for wines produced in previous seasons. • Di-glucoside levels in wines determined.
C	Evaluation of 'Superior' selections	30/06/2012	• Vineyard establishment, initial growth and rootstock compatibility assessed in semi-commercial plantings. • Wines produced from 'Superior' selections at two different maturities, ie. with a low and normal level of maturity. • Basic wine compositional parameters assessed, including spectral properties where appropriate • Wines assessed by industry reference group.
D	Source mother blocks of promising genotypes established	30/06/2012	• Cuttings collected and propagated to establish plantings as source mother blocks of promising genotypes. • Close consultation with the Reference Group and industry re mechanisms of material supply to industry
E	Classification of varieties completed for hot climate production, water use efficiency and lower alcohol wine production	30/06/2012	• All information collated, analysed and documented • Varieties, clones and advanced selections classified based on their potential for hot climate wine production, water use efficiency and use for low alcohol wine production • Document with detailed information for each genotype covering ranking and final selection against key criteria produced for publication
F	Final report with recommendations to industry completed	30/09/2012	• Final report completed and submitted to GWRDC • Recommendations re potential new varieties and clones provided to industry • Recommendations for further research identified

Outputs 2012-13 (variation requested and approved August 2013)

Year 4	**Output**	**Due date**	**Activities** (to be completed by December 2013)
A	Varieties and advanced lines phenotyped	31/12/2013	• Key phenological information collected (ie. budburst, flowering date, veraison date, harvest date) • Growth characteristics determined (ie. fruitfulness, maximum canopy size, bunch architecture, berry and bunch weight and yield) • Basic fruit composition information collected (ie. total soluble sugars, titratable acidity, total anthocyanins and phenolics).
B	Small-scale wine lots produced from targeted varieties and advanced breeding lines	31/12/2013	• Varietal information and phenotyping and compositional criteria collected to date in the project used to identify promising varieties and advanced selections for winemaking • Small-scale wine lots produced from 15 targeted varieties and 15 advanced breeding lines in season 2013.
C	Small-scale wine lots assessed by a broad range of industry personnel	31/12/2013	• Small scale wine lots assessed by wine companies, regional groups and Project Reference group.
D	Relationships between berry and wine colour attributes explored	31/12/2013	• Berry anthocyanin profiles measured by HPLC for red varieties used to produce wine in the season 2013 seasons • Links to wine colour attributes explored for red wines produced in the project • Predictive value of berry anthocynains determined in relation to wine spectral properties.
E	Relationships between berry organic acid profiles, pH and requirements for acid addition explored.	31/12/2013	• Berry organic acids determined by FTIR for berry samples collected over the 2013 harvest period • Relationships with must pH, berry organic acid composition and requirements for acid addition in winemaking determined for all small-scale wine lots produced in the project.
F	Wine aroma profiles linked to wine preferences.	31/12/2013	• Key aromatic and flavour compounds measured in wine samples produced in 2013 by GCMS • Information on aromatic compounds linked to wine preferences in industry assessments of 2013 wines and older wines
G	Mechanisms for release of new varieties developed	31/12/20103	• Industry consulted in regard to development of mechanisms for supply of material to industry of varieties identified in this project. • Mechanism for supply of material endorsed by Reference Group
H	Final report with recommendations to industry completed	31/12/2013	• Final report completed and submitted to GWRDC • Recommendations re potential new varieties provided to industry • Recommendations for commercial assessment of a suite of advanced lines provided • Recommendations for further research identified

Outputs 2013-14 (variation August 2013)

Year 5	Output	Due date	Activities
A	Small-scale wine lots produced from targeted varieties and advanced breeding lines in season 2014	30/06/2014	• Varietal information and phenotyping and compositional criteria collected to date in the project used to identify promising varieties and advanced selections for winemaking • Small-scale wine lots produced from 15 targeted varieties and 15 advanced breeding lines in season 2014. • 2014 wines assessed by Project Reference Group
B	Relationships between berry organic acid profiles, pH and requirements for acid addition explored.	31/05/2014	• Berry organic acids determined by FTIR for berry samples collected over the 2014 harvest period • Relationships with must pH, berry organic acid composition and requirements for acid addition in winemaking determined for all small-scale wine lots produced in the project.
C	Small-scale wine lots assessed by a broad range of industry personnel	30/11/2013	• Small scale wine lots assessed by wine companies, regional groups and Project Reference Group.
D	Relationships between berry and wine colour attributes explored	30/05/2014	• Berry anthocyanin profiles measured by HPLC for red varieties used to produce wine in the season 2013 season • Links to wine colour attributes explored for red wines produced in the project • Predictive value of berry anthocynains determined in relation to wine spectral properties.
E	Wine aroma profiles linked to wine preferences.	31/05/2014	• Key aromatic and flavour compounds measured in wine samples produced in 2013 by GCMS • Information on aromatic compounds linked to wine preferences in industry assessments of 2013 wines and older wines
F	Mechanisms for release of new varieties developed	30/06/2014	• Industry consulted in regard to development of mechanisms for supply of material to industry of varieties identified in this project. • Mechanism for supply of material endorsed by Reference Group
G	Varieties and advanced lines phenotyped	30/05/2014	• Key phenological information collected (ie. budburst, flowering date, veraison date, harvest date) • Growth characteristics determined (ie. fruitfulness, maximum canopy size, bunch architecture, berry and bunch weight and yield) • Basic fruit composition information collected (ie. total soluble sugars, titratable acidity, total anthocyanins and phenolics).
H	Final report with recommendations to industry completed	30/09/2014	• Final report completed and submitted to GWRDC • Recommendations re potential new varieties provided to industry • Recommendations for commercial assessment of a suite of advanced lines provided • Recommendations for further research identified

Note: A further variation to extend the end date of the project to 30 April 2015 was approved by AGWA in December 2014. This was largely to:

- assess the performance/potential of the best of the 100 advanced selections which were identified in season 2014
- assess the performance of four Superior selections established on a commercial property in the Riverland
- undertake ICP mineral element analysis of berry samples from the 2010 and 2014 seasons to explore relationships with K and other key compositional measurements.