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Improving the quality of Cabernet Sauvignon grown in warm and hot regions



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1 Abstract

Cabernet Sauvignon vines were subjected to thinning 30% of the crop at veraison and irrigation cut back after veraison over three years. Thinning reduced yield and accelerated ripening. Irrigation cut back gave little or no reduction in yield, but increased berry anthocyanins (colour). Wines were made for two years and combined thinning and irrigation cut back gave wines with the highest tasting score in one year and the highest colour density in both years. The effect of the treatments on anthocyanins and tannins in grapes and wine was also determined by HPLC analysis in one year.

2 Executive summary

This project investigated management strategies, which could improve the fruit and wine quality of Cabernet Sauvignon grown in warm and hot regions. It was preceded by a scoping study and an industry workshop. The project addressed some of the opportunities and issues emerging from the study and workshop. These included: the perception that quality wine came from early intake fruit; an association between higher fruit colour and rapid ripening (shorter hang time); concern that harvest decisions based on fruit colour and sugar were not capturing information that may have a bearing on wine style (for instance presence of jammy flavours and herbaceous flavours, and absence of astringency) and; concern about post vinification colour stability; and an interest in the effect of viticultural practices on fruit and wine tannin.

A large field trial was established in 2003 on drip irrigated own rooted Cabernet Sauvignon vines at McGuigan Simeon's Coldridge vineyard near Loxton in the South Australian Riverland and assessed for three years. Treatments were designed to affect the rate of ripening by either reducing carbohydrate availability during ripening through the imposition of water stress after veraison, or by increasing carbohydrate availability during ripening through reducing the crop load at veraison. These treatments were applied in a trial of factorial design. A control treatment representing standard management practice for the vineyard was added to this design. The trial was assessed for three years (harvested in years 2004-2006).

Soil moisture monitoring showed that reducing irrigation after veraison quickly led to the development of a soil water deficit. This deficit increased vine water stress as indicated by reductions in both leaf water potential and rate of photosynthesis. Visual changes to the canopy were recorded for each treatment and are included to give indications that growers can use to determine stress levels.

The report contains records of the effects that crop thinning and reduced irrigation had on the time course of the development of grape maturity and colour between veraison and harvest and the effects on yield and components of yield recorded at harvest. Removing 30% of the fruit at veraison reduced yield, and in two of the three years ripened fruit more quickly than the control treatment. Application of 43% of the irrigation applied in the vineyard standard management practice between veraison and harvest gave little or no reduction in yield, but increased berry anthocyanins (red colour) in all years. There was no significant difference in berry weight at harvest between any of the treatments in two of the three years.

Fruit from each treatment was harvested at similar maturity and made into small lot wines for two of the years to assess wine quality. Combined thinning and irrigation cut back gave wines with the highest tasting score in one year, the highest colour density in both years and the highest total anthocyanins in one year.

Berry sensory assessment in the first two seasons of the trial found that at harvest in 2004, thinning decreased berry and pulp maturity and decreased the skin maturity in the absence of

irrigation cut back. Irrigation cut back advanced seed colour maturity. In 2005, irrigation cut back increased berry and pulp maturity, and thinning increased skin maturity. In 2004, irrigation cut back increased pulp and skin fruity aromas; thinning reduced skin tannic intensity; thinning increased pulp herbaceous aromas and in the absence of irrigation cut back, it increased skin herbaceous aromas and reduced skin astringency and dryness. In 2005, thinning increased the skin fruity aromas.

In 2004, berry homogenates and wines were analysed by HPLC. In homogenates, 13 anthocyanins and tannins were quantified and treatments affected the concentration of five of these. In wine, we quantified three anthocyanins, pigmented polymers and tannins. Either irrigation cutback or thinning decreased the concentrations of malvidin-3-glucoside and malvidin-coumaryl-glucoside. Thinning decreased the concentration of malvidin-acetyl-glucoside. Irrigation cutback increased the concentration of pigmented polymers and tannins, and, in the absence of irrigation cut back, thinning decreased pigmented polymer and tannin concentrations.

Prior to this work, the focus for imposing stress was the period prior to veraison (during berry formation). This work demonstrates that the imposition of crop thinning at veraison or water stress post veraison (berry ripening) had significant effects on fruit ripening and colour. The project is relevant to growers who supply wine companies, which are limiting tonnages per hectare and applying bonus payments for quality. For these growers it may be more profitable to grow lower tonnages and aim for bonuses for higher Baume and colour. The project is particularly relevant to the situation where water restrictions have been imposed and growers need to know the effect of reducing water application post veraison.

3 Background

3.1 Preliminary work

Cabernet Sauvignon is the second most widely planted red variety in the irrigated vineyards of the warm and hot regions of the Murray-Darling Basin. At a Riverlink industry workshop in July 2001, growers reported that management strategies which reliably improved Shiraz quality, did not improve Cabernet Sauvignon quality. A scoping study was undertaken to explore the issue. This has been reported by Stevens *et al.* (2005). A further industry workshop was held in July 2003 (see Appendix 2) where the findings of the scoping study and other research were presented.

This project addressed some of the opportunities and issues emerging from the study and workshop. These included: the perception that quality wine came from early intake fruit; an association between higher fruit colour and rapid ripening (shorter hang time); concern that harvest decisions based on fruit colour and sugar were not capturing information that may have a bearing on wine style (for instance presence of jammy flavours and herbaceous flavours, and absence of astringency) and; concern about post vinification colour stability; and an interest in the effect of viticultural practices on fruit and wine tannin.

In the past, the effect of viticultural practices on fruit quality has been assessed by organoleptic assessment of the resultant wine, or more rapidly, by assessing a presumed analogue of these quality scores, fruit colour. During the scoping study, the suitability of this analogue was questioned with regard to its inability to capture problems associated with style, undesirable flavour and wine colour stability.

Issues like undesirable astringency and lack of wine colour stability suggest a role for tannins. In part, achieving improvements in quality may be related to management of tannins. The current chemical characterisation of tannins in juice and wine is based on cleaving tannin polymers and analysing sub-units. This approach quantifies the different sub-units. However it is likely that many of the impugned properties of tannins are unique properties of the original polymers rather than their constituent sub-units.

Winemakers rely on sensory rather than chemical perception of tannins and commonly within Australia and overseas they invest considerable resources in detecting attainment of ‘tannin ripeness’ within the vineyard prior to harvest. This change sees disappearance of astringency and green flavour characters in the grape.

Analysis of tannin sub-units over berry development and maturation showed that their synthesis is complete prior to veraison. Further that there is no abrupt change in the concentration of these sub-units during late ripening. Therefore the in-vineyard perception of ‘tannin ripeness’ can not be readily attributed to change in the concentrations of the sub-units. Post veraison, researchers have detected changes indicating oxidation of tannin polymers and this suggests that changes in ‘tannin ripeness’ may be associated with this process altering tannin extractability and with re-configuration of polymers containing extant tannin sub-units.

The issue of physiological ripeness was raised in concert with that of undesirable flavour and loss of flavour intensity. Traditionally, the effect that treatments reflecting different viticultural practices have on wine quality, is assessed by vinification of fruit picked at a particular sugar ripeness equating to the alcohol level desired in the final wine, for example 13.5^{o} Baume equating approximately with 13.5% alcohol. However, the peak in expression of a desirable favour intensity may not coincide with the fruit reaching desirable sugar levels. The issue of physiological ripeness or style ripeness was raised to indicate that factors, which change the relative rates that astringency and flavour progress toward and decline from their peak states of desirability for the envisaged end-use (style), are also important in the production of quality wine. Winter *et al.* (2004) described a method of berry sensory assessment which can capture information about the development of a wide range of flavour and mouth-feel attributes over the fruit ripening period.

In this project we subjected Cabernet Sauvignon vines during the ripening period to water stress (to reduce the rate of carbohydrate production) and removal of fruit (to reduce the demand for carbohydrates) to determine whether these treatments affect fruit quality (determined by standard measures and berry sensory assessment), wine quality (determined by spectral and organoleptic analysis) and fruit and wine tannins and anthocyanins (determined by HPLC).

3.2 Objective

The objective was to set up a field experiment to investigate vineyard management practices, which might be used to improve the quality of Cabernet Sauvignon grown in warm and hot regions. Specifically the aims were:

- To determine whether the quality of Cabernet Sauvignon berries (assessed by standard analysis of colour, sugar, acid) is affected by water stress and alteration to crop load during the ripening period.
- To determine whether the quality of Cabernet Sauvignon wine (assessed by organoleptic and spectral analysis) made from fruit picked at a specific level of sugar ripeness is affected by water stress and alteration to crop load during the ripening period.
- To explore the concept of physiological ripeness by using berry sensory assessment (BSA) to determine whether the temporal courses of the development of sugar, and BSA concepts of skin, pulp and seed maturity and seed colour are affected by water stress and alteration to crop load during the ripening period. Further to test whether these treatments affect the scores of sensory assessment attributes associated with tannin perception and, fruity and herbaceous aromas in the berry.
- In conjunction with the AWRI tannin project, to determine whether changes in berry sensory assessment scores, in particular, the progression from the field perception of 'unripe tannins' to 'tannin ripeness' align with changes in the tannin concentrations in berry homogenate and wine.

4 Project aims and performance targets

Output	Performance Targets
1. Field experimental program to address the limitations to ripening in post lag phase	Establish field trial (2003-04)
2. Sample vines established with differing plant water deficit and crop load.	Impose irrigation and crop thinning treatments at veraison (2003-04, 2004-05, 2005-06)
3. Quantify effects of stress on canopy and growth and photosynthesis	Regular measurement of canopy size and leaf photosynthesis during berry ripening (2003-04, 2004-05, 2005-06)
4. Characterising effects of transient water deficit and crop load on colour and sugar accumulation and anthocyanin profiles	Weekly collection and analyses of berry samples from experimental plots (2003-04, 2004-05, 2005-06)
5. Impact on wine quality quantified	Harvest fruit for small lot winemaking and sensory analysis/profiling of previous vintage wines (2003-04, 2004-05, 2005-06)
6. Final report submitted	Data analysis completed (2006)

5 Methods

5.1 Trial location and treatments

The trial was conducted on drip irrigated own rooted vines (*Vitis vinifera* L. cv. Cabernet Sauvignon) at McGuigan Simeon's Coldridge vineyard (Latitude: -34.25; Longitude: 140.35), near Loxton in the Riverland of South Australia. The climate at the site is Mediterranean with an annual average of winter-dominant rainfall of 264.1mm. The plantings were established in 1996 and are orientated in an east-west direction. They were planted at 1.83 m row spacing and 2.75 m inter-row spacing (1987 vines per hectare). The vines are trained on a two wire vertical trellis with the top wire at 1.6m and are mechanically hedge pruned to 10cm from the cordon.

In 1995 four soil pits were described and sampled within or directly next to the trial. The soil was classified by the Australian Soil Classification (Isbell 1996) as a centeric, rendic, supracalcic, calcarosol, with thick, non-gravelly, sandy to loamy topsoil and moderate depth rootzone, and a clay loamy BK horizon. The soil pH of soil samples varied between 9.0 and 9.5.

The treatments in the trial were a combination of bunch thinning at veraison and the application of two rates of irrigation between veraison and harvest (see Table 5-1). The control treatment was standard management for the vineyard with no change to normal irrigation or crop load. We defined veraison as the time when half of the total berries were coloured. Bunch thinning involved removing 30% of bunches in a random pattern throughout the canopy at veraison.

The irrigation treatments were applied by modifying the irrigation system, so that output was varied by using different drippers. The control treatment, which was as used in the adjacent vineyard was applied with 2.0L/hr output Netafim DL2025 drippers at 0.6m spacings giving an application rate of 1.21mm/hr. The high irrigation treatment drippers were originally applied using 2.2L/hr Hydrogold 2040 drippers at 0.6m spacings, but these were changed after the first season (see below) to 2.9L/hr Netafim DL2025 drippers at 0.6m spacings, which applied 1.76mm/hr. For the low irrigation treatment 0.85L/hr Typhoon 150 drippers were used at 0.6m spacings applying 0.52mm/hr. The system operating pressure was 20psi/138kPa. Irrigation was scheduled by the vineyard staff using an Enviroscan soil moisture monitoring system and by visual assessment and the use of hand augers.

The trial design was a 2 x 2 factorial laid out as a randomised block containing a control (which was standard grower practice) replicated six times. Each plot consisted of 3 rows of nine vines. Data were recorded from the five centre vines in the centre row. The trial was assessed over the growing seasons 2003-04, 2004-05 and 2005-06.

Irrigation water applied was recorded using an ARAD model WMR 50 flow meter (Israel) and by dripper output testing. In 2003-2004 dripper output tests revealed that the irrigation applied in treatments T3 and T5 (2.2L/hr) was 1.12x control, which was lower than intended. This was increased in 2004-2005 by installing higher output drippers (2.9L/hr). A subsequent check of dripper outputs showed the desired 1.45x control irrigation application rate was achieved.

5.2 Trial environmental and vine conditions

Water and soil salinity

Irrigation water for the vineyard was drawn from the River Murray near Lock 4 and the Department of Water, Land and Biodiversity Conservation water salinity readings were monitored regularly at this location.

Soil salinity was measured early in the growing season and post harvest to look for any treatment affects. Samples were taken in 20 plots at 25, 50 and 100cm depths. Soil salinity (ECe) was determined by drying the soil sample at 40˚C in an oven then crushing it to pass a 2mm screen and recording the ECe on the saturation paste extract using the method described in Rayment and Higginson (1992).

Vine nutritional status

Petioles were sampled opposite basal bunches at 80% flowering from each of the plots. The samples were dried at 65˚C then ground to pass a 0.8mm screen prior to analysis. The elements phosphorus, potassium, calcium, sodium, zinc, magnesium, manganese, iron, copper and boron were determined by ashing the sample in a furnace at 620˚C then dissolving in 6 N HCl. For elements other than potassium, the sample was analysed using an inductively coupled plasma optical emission spectrophotometer. An atomic absorption spectrophotometer was used to analyse for potassium.

Chloride percentage was determined colorimetrically with a digital chloridometer (Labconco Corporation, Kansas City, Missouri, USA). Nitrate-N was determined using a LECO FP 528 protein/nitrogen determinator (LECO Corporation, St. Joseph, Michigan, USA), with a selective ion electrode as described in Milham *et al.* (1970). Total nitrogen was measured using the Dumas method.

Volumetric water content

Volumetric water content was monitored using time domain reflectometry (TDR100 model, Campbell Scientific, Logan Utah, and a model CR10x datalogger and a SDMX50 model 50 ohm multiplexer). A test-well was installed and regularly monitored to check for the presence of a watertable.

Table 5-1 Bunch thinning and irrigation treatments

Treatment	Bunch thinning at veraison	Irrigation application during irrigation switch	Veraison irrigation switch on	Harvest	Days from irrigation switching to harvest	Post harvest irrigation switch off	Irrigation applied budburst to irrigation switching on (ML/ha)	Irrigation applied switching on to harvest (ML/ha)	Irrigation applied budburst to 1st May (ML/ha)	Total season irrigation applied (July-June) (ML/ha)	Effective rainfall switching on to harvest (mm)	Effective rainfall budburst to May (mm)	Total season effective rainfall (July-June) (mm)	Total season irrigation & effective rainfall (ML/ha)
2003-04														
T1	30% thinning	0.43 x control	22-Jan-04	17-Feb-04	26	24-Feb-04	3.06	0.57	5.56	5.63	0.0	57.0	136.8	7.00
T2	No thinning	0.43 x control	22-Jan-04	20-Feb-04	29	24-Feb-04	3.06	0.64	5.46	5.53	0.0	57.0	136.8	6.90
T3	30% thinning	1.12 x control	22-Jan-04	17-Feb-04	26	25-Mar-04	3.06	1.48	6.47	6.54	0.0	57.0	136.8	7.91
T4	Control	Control	NA	23-Feb-04	32	NA	3.06	1.59	6.31	6.38	0.0	57.0	136.8	7.75
T5	No thinning	1.12 x control	22-Jan-04	08-Mar-04	46	25-Mar-04	3.06	2.51	6.58	6.65	0.0	57.0	136.8	8.02
2004-05														
T1	30% thinning	0.43 x control	18-Jan-05	02-Mar-05	43	15-Mar-05	2.70	0.76	4.58	4.86	33.6	145.0	261.4	7.47
T2	No thinning	0.43 x control	18-Jan-05	11-Mar-05	52	15-Mar-05	2.70	0.88	4.58	4.70	42.8	145.0	261.4	7.32
T3	30% thinning	1.45 x control	18-Jan-05	02-Mar-05	43	15-Mar-05	2.70	2.58	6.55	6.67	33.6	145.0	261.4	9.29
T4	Control	Control	NA	11-Mar-05	52	NA	2.70	2.06	5.75	5.87	42.8	145.0	261.4	8.49
T5	No thinning	1.45 x control	18-Jan-05	11-Mar-05	52	15-Mar-05	2.70	2.98	6.68	6.80	42.8	145.0	261.4	9.41
2005-06														
T1	30% thinning	0.43 x control	19-Jan-06	07-Mar-06	47	08-Mar-06	2.67	0.93	6.83	7.04	5.2	176.0	222.8	9.26
T2	No thinning	0.43 x control	19-Jan-06	07-Mar-06	47	08-Mar-06	2.67	0.93	6.83	7.04	5.2	176.0	222.8	9.26
T3	30% thinning	1.45 x control	19-Jan-06	07-Mar-06	47	08-Mar-06	2.67	3.14	9.04	9.25	5.2	176.0	222.8	11.47
T4	Control	Control	NA	07-Mar-06	47	NA	2.67	2.17	8.06	8.27	5.2	176.0	222.8	10.50
T5	No thinning	1.45 x control	19-Jan-06	07-Mar-06	47	08-Mar-06	2.67	3.14	9.04	9.25	5.2	176.0	222.8	11.47

5.3 Canopy measurements

Shoot and inflorescence counts

Shoot and inflorescence counts were recorded after flowering in the 2003-04 and 2004-05 seasons. A marker in 20cm sections was placed on the ground and the nine 20cm positions were randomly allocated for each of the 30 vines. Shoot and inflorescence counts were determined by placing a 20cm wide rope ladder across the canopy at the allocated positions, and within the area defined by the ladder, we counted: the number of one year old canes or spurs, and on this wood, the number of non-burst buds, and for burst buds, the number of shoots and the number of inflorescences per shoot.

Light intensity

Light intensity in the fruiting zone was recorded using a model PAR80 AccuPAR ceptometer, (Decagon Devices Incorporated, Pullman, Washington, USA). Twelve readings per vine for one core treatment vine from each of the 30 plots were taken at pre-determined positions in the canopy on four occasions during the trial.

Leaf water potential, photosynthesis and transpiration

Leaf water potential, photosynthetic rate, stomatal conductance and transpiration rate were measured as indicators of stress during the period that treatments were applied.

Midday leaf water potential (Ψleaf) was determined using a model 3005 plant water status console pressure bomb (Soilmoisture Equipment Corporation, Santa Barbara, California, USA). An Olympus microscope at 10x magnification was used to assist with end-point determination. The method followed was based on that of Scholander *et al.* (1965). Measurements were taken in the field within 3 hours of solar noon, on sun exposed, healthy, mature leaves. Leaves were placed in a foil covered plastic bag, cut at the base of the petiole and then placed into the pressure chamber for measurement within 10 seconds. Three measurements were taken for each of the 30, 5-vine plots.

A LI-6400 portable photosynthesis system (LI-COR Biosciences, Lincoln, Nebraska, USA) was used to record photosynthetic rate, stomatal conductance (g_s) and transpiration (E) simultaneously when midday leaf water potential was measured. A 6400-02B red/blue external light source and CO_2 mixer were used. Five measurements were taken for each of the 30 plots on the central vine in each plot on fully sun exposed, healthy, mature leaves under light-saturated conditions. Ambient temperature, relative humidity and photosynthetically-active radiation (PAR) were measured before sampling commenced using the LI-6400 and conditions within the sample chamber were set to mimic the ambient conditions as closely as possible. Sample chamber CO_2 concentration was kept constant at 370ppm at all times with the mixer using food grade CO_2 (Seltz, ISI GmbH, Austria). Readings were logged when all readings had become stable (determined as the point where the combined coefficient of variation for flow, CO_2, and H_2O in the sample chamber was less than 1%). LI-6400 and pressure bomb measurements were taken on 6 and 7 occasions respectively during the trial.

5.4 Yield and berry quality

Yield and number of bunches were recorded on four vines in each plot. For berry maturity and colour analyses, two 100 berry samples were taken uniformly from bunches and within the canopy from the five central vines in each of the 30 plots. One sample was used to monitor maturity and the other colour. The maturity sample was weighed and crushed using a hand-held tomato juicer and then centrifuged (Eppendorf 5810) at 3500 rpm for 10 minutes. Analyses were done at McGuigan-Simeon winery in Loxton. °Brix was measured with a digital refractometer (Atago model RX-5000) kept at 20ºC with a circulating water bath. Titratable acidity and pH were measured using a Radiometer Autotitrator model TIM850 (Radiometer Analytical SAS, Lyon, France) calibrated at pH 4 and 7 and titrated to an endpoint of 8.2 with 0.333M NaOH. The colour sample was homogenised for 15 seconds at 10,000 rpm in a GM200 Grindomix Blender (Retsch, Germany). Red pigments (colour) and total phenolics of grape berries were determined from the homogenate using the method described in Iland *et al.* (2000).

5.5 Wine quality

We aimed to pick each treatment when the majority of replicates were at 23.4-24.3 °Brix (13-13.5 °Baume). The fruit from the five central vines in each plot was picked, counting bunches and weighed. For each plot 25kg of fruit was kept and fruit from two plots of the same treatment were mixed to make a single wine ferment.

Small lot wines were made by Provisor Pty Ltd at the CSIRO Plant Industry facilities at Merbein using the method described by Antcliff and Kerridge (1975). For each of the five treatments, three 25kg ferments were produced. Wine quality analyses given in Iland *et al*. (2000) and tasting scores from an industry panel were also provided by Provisor.

5.6 Berry sensory assessment

Berry sensory assessment was conducted in a laboratory between mid-February and early March in 2003-04 and 2004-05 using the methods of Winter *et al.* (2004). Four sets of attributes were investigated: berry maturity, pulp maturity, skin maturity and seed maturity. All attributes were rated from 1 to 4, with 1 representing the least mature and 4 the most mature expression of the attribute.

In 2003-04, the assessment scoring sheet was still under development and differed slightly from that published later that year and used in 2004-05. In both years, berry maturity was based on scoring the attributes berry deformability (softness), ease of stalk removal and colour. In 2003-04 pulp maturity was assessed by scoring for pulp detachment, sweetness, acidity, grassy aromas, and fruity aromas, whereas in 2004-05 it was assessed by scoring for pulp detachment, juiciness of pulp, sweetness, acidity, herbaceous aromas, and fruity aromas. In 2003-04 skin maturity was assessed by scoring for laceration, tannins, acidity, astringency, dryness, grassy and fruity aromas, whereas in 2004-05 it was assessed by scoring for disintegration, acidity, herbaceous aromas, fruity aromas, tannic intensity, and astringency. Note that for the assessment of skin tannic intensity in 2003-04, the assessors scored presence of tannic intensity ‘tongue slides over the roof of mouth with difficulty’ as low and its absence ‘tongue slides effortlessly over the roof of mouth’ as high. The converse approach to scoring was taken in 2004-05 when assessors followed guidelines in Winter *et al* (2004).

In both years seed colour in one or more treatments remained at or near 2. Ratings at this level or lower are associated with strong astringency. Conducting seed maturity assessment with this level of astringency interferes with subsequent assessments of other sensory attributes. In order to avoid such interference, seed maturity was not assessed unless colour scored 3 or above. In both years, some treatments did not develop seed colour values higher than 2 and seed maturity was not assessed in these treatments. As a consequence the seed maturity component of the trial data set contained more than 50% missing values and was not analysed.

On all sample dates in 2003-04, samples were tested by two assessors. In 2004-05, on all but 1/3/2005, samples were tested by two assessors. No seed colour assessment was undertaken on the fourth sample date. Different assessors were used in each year.

Our capacity to assess every treatment in 2003-04 at every sample date was compromised by the effect that the extended period of high temperature during maturation had on fruit attributes. The maximum temperatures on 7 of the 10 days preceding harvest of fruit from T1 were 40^{o}C or above. In this treatment, °Brix increased from 22.6^{o} to 26.2^{o} over the 4 days between 10 and 14 February. By 14 February, the fruit from T1 had developed a jammy rotten flavour and its attributes no longer aligned with the descriptors in the assessment procedure. Assessors found the fruit odour repulsive and ceased assessment because they were unsure as to whether placing the fruit in the mouth presented a hazard to health. Fruit from T2 began to develop similar character on 19 February and assessment ceased. By 5 March, some of the fruit from T3 began to develop similar character. Assessment of treatment T3, T4 and T5 continued through to 15 March.

In 2003-04, records for all treatments were present in the data sets from sampling on the 12 and 14 February; for treatments T2 through to T5 records were present in data sets from sampling on 19 and 23 February; and records from treatments T3 through to T5 were present in all data sets. In 2004-05 the data sets from each sampling date contained records for all treatments.

In both 2003-04 and 2004-05, berry sensory assessment data was prepared for analysis by equating each of three properties (berry, pulp and skin maturities) to the average of the scores for all attributes of the property. This operation produces a categorical variable with a minimum of 24 possible values (average of 2 scorers, with 3 attributes for berry maturity, each of which can be scored 1 to 4). The effect of treatment and sampling time on the means of taster's scores was assessed by repeated measures analysis of variance. The same approach was taken to analysis of attributes relating to changes in fruity and herbaceous aromas and tannin perception. The attributes of interest were: scores for grassy/herbaceous and fruit aromas in the pulp and scores for tannic intensity, dryness (2003-04 only) and astringency in the skin. It is worth noting that progressing from low to high scores for the attributes grassy/herbaceous, dryness and astringency equated to a diminution in intensity of these attributes, whereas for fruity it equated to an intensification of this attribute. In 2003-04, progressing from low to high scores for the attributes tannic intensity equated to a diminution in intensity and in 2004-05 to an intensification of this attribute.

The effect that treatment had on average scorer values, coinciding with dates that treatments were harvested, was assessed by one-way analysis of variance. Treatment effects were identified by comparing means using protected least significant differences and by constructing contrast between thinning and irrigation treatments with control treatment (T4) excluded. In 2003-04, T1 and T3 were harvested on 17 February; treatment effects were analysed using measures of sensory assessment data collected on 14 February and °Brix on 16 February. In T2, harvested 20 February, treatment effects were analysed using measures of sensory assessment data collected on 19 February and T5 harvested 8 March treatment effects were analysed using measures of sensory assessment data collected on 5 March. In T4, berry sensory assessment data and measures of °Brix were based on samples taken to coincide with harvest. In 2004-05, T1 and T3 were harvested on 2 March and treatment effects were assessed using measures of sensory assessment data and °Brix collected on 1 March. Treatments T2, T4 and T5 were harvested on 11 March and treatment effects were assessed using measures of sensory assessment data and °Brix collected on 8 March.

The dependence that the scores on each sample date had on taster identity was investigated by subjecting data to analysis of variance with treatment as the main plot and taster identity as the sub-plot.

5.7 Tannins in grapes and wine

In 2003-04, wine (just after bottling) and berry homogenates (all treatments sampled on 10 February, T5 sampled again on 1 and 8 March) were submitted to the Australian Wine Research Institute for HPLC analysis of anthocyanins, tannins or grape derived tannins (proanthocyanidins), and pigmented polymers (wine only), following the method of Eglinton *et al.* (2004).

Data from the 10 February sample were analysed by one-way analysis of variance. Treatment effects were identified by comparing means using protected least significant differences and by constructing contrast between thinning and irrigation treatments with control treatment (T4) excluded. Data from sampling T5 on 3 dates were also analysed by one-way analysis of variance with time as a variable.

5.8 Statistical Analysis

Canopy, yield, berry and wine quality data were statistically analysed using GenStat release 8.1 (Lawes Agricultural Trust, UK 2005). Data from a single year was analysed by performing an analysis of variance and comparing means using protected least significant difference. Where data was recorded for three years, a repeated measures analysis of variance was also conducted.

Berry sensory assessment (BSA) data and data from HPLC analysis of berry homogenates and wine were analysed by ANOVA using Statistix Version 8.0 (Analytical Software). Assumptions regarding normality of data distribution were tested by calculation of the Shapiro-Wilks statistic and inspection of plots of the fitted values on the residuals.

6 Results/discussion

6.1 Trial environmental and vine conditions

6.1.1 Seasonal differences in weather

Weather data recorded at the Australian Bureau of Meteorology weather station located at the Loxton Research Centre, for the years of the trial are given in Table 6-1. The station is located 8.5km from the trial site. Long term weather data are shown in Figure 6-1 and for the years of the trial in Figure 6-2 to Figure 6-4.

Table 6-1 Weather data recorded at the Loxton Bureau of Meteorology weather station for the years of the trial and long term averages collected from 1984 to 2004.

	Month											
	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Highest maximum temperature (°C)												
2003-04	21.4	22.7	35.3	34.4	41.3	41.0	42.0	45.5	40.0	35.3	22.9	23.0
2004-05	20.8	28.6	34.5	40.1	40.8	40.0	43.6	40.8	38.4	36.4	28.2	24.5
2005-06	21.5	28.1	27.6	31.2	36.7	44.2	44.3	38.1	41.2	30.1	21.6	19.5
Long Term Average	21.2	24.8	29.9	35.0	37.5	38.6	41.8	40.6	37.5	32.1	26.4	22.1
Mean daily maximum temperature (°C)												
2003-04	16.4	16.3	19.9	21.2	29.4	31.8	28.9	33.9	28.4	24.9	19.1	16.6
2004-05	15.4	18.3	19.8	26.3	26.9	29.5	31.0	28.9	27.5	27.0	21.2	17.1
2005-06	16.1	18.8	19.8	22.9	27.6	31.2	35.0	30.4	29.9	21.5	17.4	15.6
Long Term Average	15.8	17.3	20.4	23.8	27.1	29.5	31.4	31.1	28.0	23.9	19.5	16.3
Mean daily pan evaporation (mm)												
2003-04	1.9	2.6	4.3	5.4	8.2	8.7	9.1	9.1	7.0	4.4	2.3	2.1
2004-05	1.9	3.1	3.6	6.8	7.9	8.5	9.4	7.9	6.3	5.4	2.9	1.9
2005-06	1.6	3.5	3.8	5.3	7.9	9.9	11.2	9.2	7.5	3.8	2.3	1.7
Long Term Average	1.7	2.6	3.9	5.7	7.5	8.6	9.4	8.4	6.4	4.0	2.3	1.7
Monthly rainfall (mm)												
2003-04	10.4	43.2	18.8	27.0	13.0	27.8	5.0	2.2	4.8	1.6	12.4	40.0
2004-05	21.0	53.2	15.0	3.2	24.2	71.0	43.8	10.2	9.4	10.4	0.6	69.0
2005-06	23.2	18.6	40.8	71.6	24.4	11.6	6.4	7.6	36.4	41.4	9.4	2.8
Long Term Average	28.8	30.0	28.3	29.0	21.0	21.4	15.2	18.2	10.6	15.5	22.3	29.9

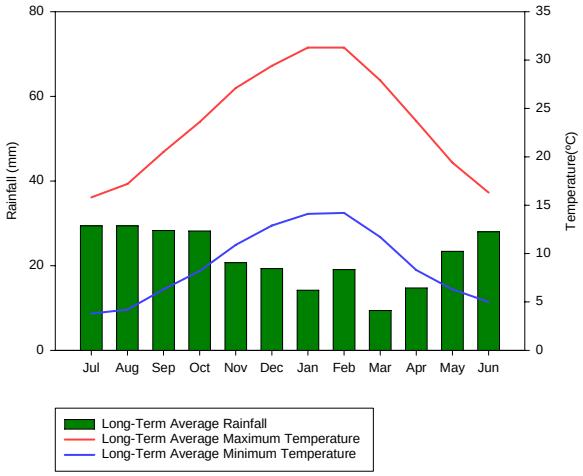


Figure 6-1 Loxton long-term weather data

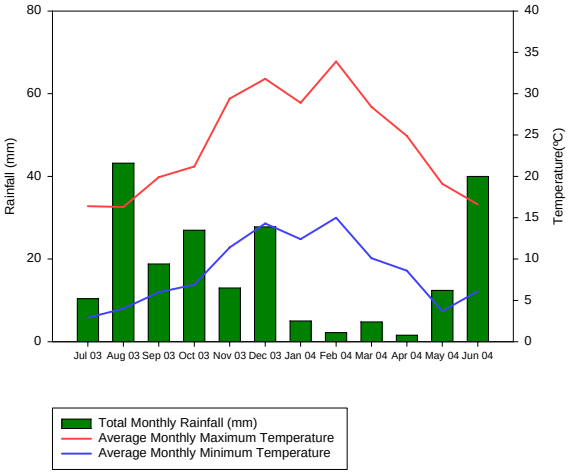


Figure 6-2 Loxton weather data in the 2003-2004 season

The 2003-04 growing season had a cooler than average January and an extremely hot February with nine days exceeding 40°C. It was also significantly drier than the long-term average rainfall of 264.1mm, receiving only 206.2mm with an effective rainfall of 137.0mm* for the 12 months. The only months that received higher than average rainfall were August, December and June. The total Class A pan evaporation for the same period was 1986.6mm.

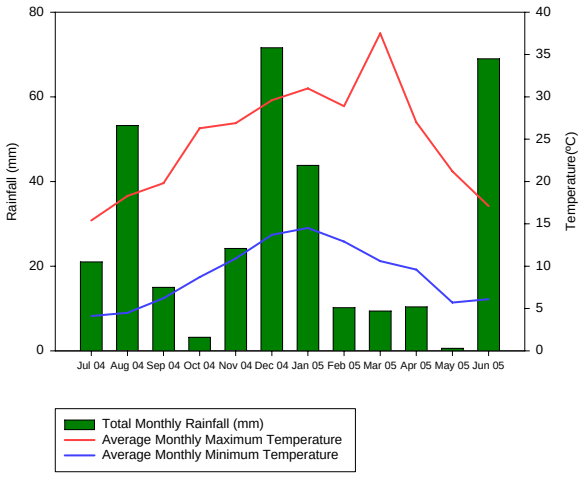


Figure 6-3 Loxton weather data in the 2004-2005 season

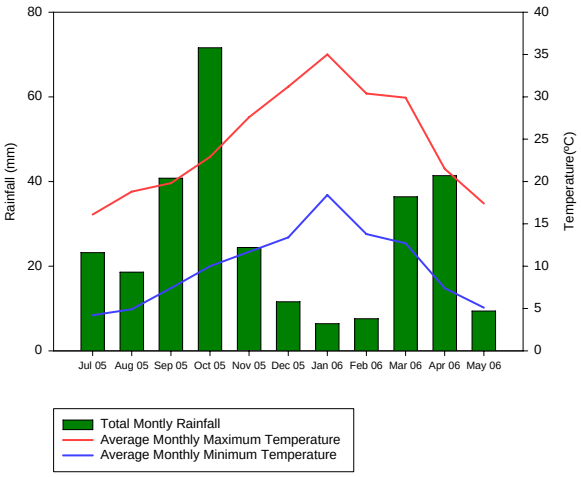


Figure 6-4 Loxton weather data in the 2005-2006 season

In the 2004-05 season, Loxton received a much higher than average rainfall in December and January and also in June. The total over the season was 331.6mm, with an effective rainfall of 261.4mm and 1990.4mm of Class A pan evaporation. February temperatures were cooler than average and were followed by a much warmer than average March.

* Effective rainfall is defined in this report as from budburst to leaf fall (Summer), 5mm or more over a 24hr period, from leaf fall to budburst (Winter), 5mm or more over a 48hr period.

The 2005-06 season had some record high temperatures during December and January was consistently warmer than average, including the average minimum temperatures. Loxton received much higher than average rainfall in September and October and also higher than average rainfall in March and April. May and June were colder than average.. The annual rainfall was 294.2mm with an effective rainfall of 222.8mm. June was especially dry, receiving only 2.8mm compared to the average of 29.9mm. The total Class A pan evaporation was 2042.4, which was slightly higher than other seasons.

6.1.2 Water and soil salinity

The average irrigation water salinity over the 2003-04 season was 0.30 dS/m, the 2004-05 season 0.26 dS/m and the 2005-06 season 0.24 dS/m.

Soil salinity data measured at 25cm and 50cm depth at the beginning and end of the 2004-05 and 2005-06 growing seasons is summarised in Table 6-2. The higher 1.45 x control water applications led to a reduction in soil salinity at 50cm depth.

Table 6-2 Effect of irrigation treatment on soil salinity (dS/m)

	0.43 x control	**Control**	**1.45 x control**	**Average**
Pre-irrigation treatment salinity (October 2004)				
25 cm	1.63	1.34	1.10	1.36
50 cm	1.68	1.8	1.06	1.51
Post-harvest soil salinity (June 2005)				
25 cm	1.32	1.08	0.61	1.00
50 cm	1.73	3.48	0.58	1.93
Pre-irrigation treatment salinity (November 2005)				
25 cm	0.89	0.83	0.93	0.88
50 cm	1.12	1.57	0.94	1.21
Post-harvest soil salinity (May 2006)				
25 cm	0.83	1.23	0.74	0.93
50 cm	1.42	1.6	0.68	1.23

Salinity values shown are means are of six replicates.

6.1.3 Vine nutritional status

Analyses of petioles sampled at flowering each season are given in Table 6-3. (All replicates were sampled, then bulked for each treatment).

Table 6-3 Analysis of petioles sampled at flowering each season.

	NO_3-N mg/kg	P%	K%	Ca%	Mg%	Na%	Cl%	Zn mg/kg	Mn mg/kg	Fe mg/kg	Cu mg/kg	B mg/kg	N %
Nutrient concentration guidelines (Robinson *et al.* 1997)													
Adequate range	500-1200	0.25-0.50	1.8-3.0	1.2-2.5	>0.4	<0.5	<1.0	>26	30-60	>30	6-11	35-70	0.8-1.1
17/11/2003													
T4	543	0.35	4.7	2.5	0.28	0.06	0.43	38	54	33	46	N/A	N/A
Rating	A	A	H	A	D	A	A	A	A	A	H	N/A	N/A
22/11/2004													
T1	170	0.30	5.1	2.1	0.27	0.04	0.24	81	38	21	51	51	N/A
T2	270	0.24	4.8	2.0	0.39	0.07	0.35	78	38	43	73	73	N/A
T3	240	0.30	4.4	2.1	0.34	0.07	0.33	72	44	32	70	70	N/A
T4	210	0.30	5.7	2.1	0.27	0.07	0.30	59	44	25	52	52	N/A
T5	180	0.33	5.1	2.1	0.28	0.06	0.28	140	41	24	57	57	N/A
Mean	214	0.29	5.0	2.1	0.31	0.06	0.30	86	41	29	61	61	N/A
Rating	D	A	H	A	M	A	A	A	A	M	H	A	N/A
16/11/2005													
T1	340	0.72	4.4	1.8	0.31	0.14	0.31	25	32	34	70	35	0.84
T2	500	0.64	4.7	1.8	0.34	0.09	0.38	26	27	24	107	35	0.88
T3	360	0.76	4.9	1.8	0.28	0.04	0.30	26	40	20	73	33	0.88
T4	400	0.67	4.1	1.8	0.30	0.15	0.36	28	36	44	73	33	0.85
T5	330	0.74	4.5	1.9	0.31	0.12	0.33	28	39	36	74	32	0.82
Mean	386	0.71	4.5	1.8	0.31	0.11	0.34	27	35	32	79	34	0.85
Rating	M	H	H	A	M	A	A	A	A	A	H	M	A

D = deficient, M = marginal, A = adequate, H = high.

T1 = 0.43 irrigation, 30% thinning, T2 = 0.43 irrigation, no thinning, T3 = 1.45 irrigation, 30% thinning, T4 = 1.0 irrigation, no thinning, T5 = 1.45 irrigation, no thinning.

Petiole sodium and chloride concentration did not reach excessive values (critical concentrations being Sodium > 0.5%, and chloride >1.0%)

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6.1.4 Water stress applied

Uncalibrated outputs from the Campbell Scientific TDR100 in Figure 6-5 demonstrate that the 0.43x, 1.0x and 1.45x irrigation treatments gave expected differences in soil water contents ie different water stresses were applied by the treatments. Data from the Coldridge vineyard irrigation records for the control treatment during the period are also included.

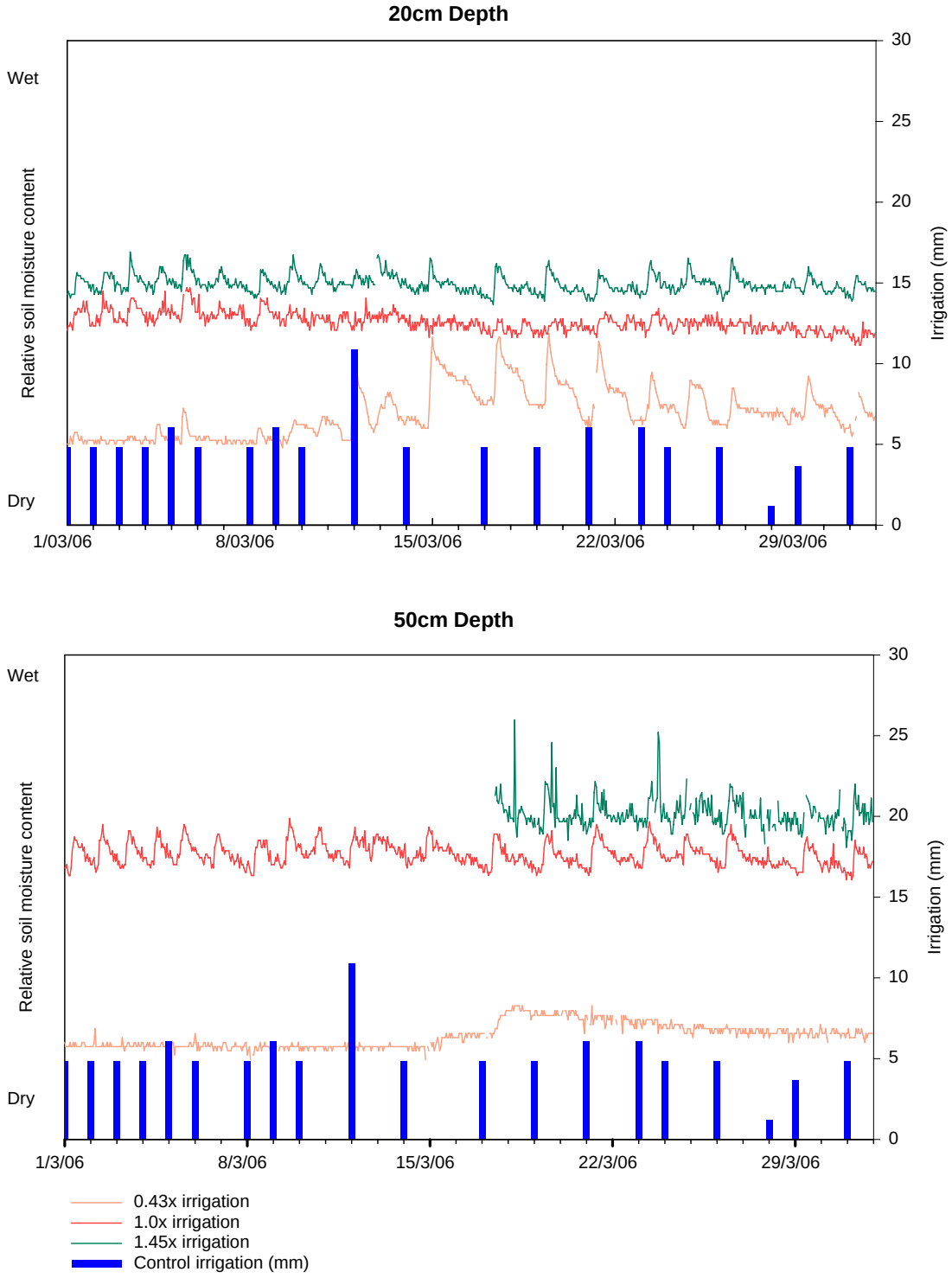


Figure 6-5 Uncalibrated TDR probe outputs of relative soil water content for each irrigation treatment and irrigation applied for the control treatment in 2006 at 20cm and 50cm depths.

6.2 Canopy measurements

6.2.1 Shoot and inflorescence counts

There were no significant differences in shoot and inflorescence count measurements recorded in November in the years 2003-04 and 2004-05 (Table 6-4). This indicates that there was no initial variation across the trial site. Also, there was no reduction in fruiting or non-fruiting shoots or inflorescences per vine in 2004-05 following the irrigation and thinning treatments applied the previous year ie there was no 'carry-over' effect on productivity.

Table 6-4 Shoot and inflorescence count measurements

	T1	T2	T3	T4	T5	Mean	Significance
Number of nodes/vine							
2003-2004	426	502	432	479	495	467	ns
2004-2005	570	482	569	465	515	520	ns
Number of non-fruiting shoots/vine							
2003-2004	60	69	60	96	68	71	ns
2004-2005	132	105	142	126	124	126	ns
Number of shoots with inflorescence/vine							
2003-2004	231	267	254	225	275	250	ns
2004-2005	277	234	259	219	231	244	ns
Budburst %							
2003-2004	69	66	74	68	70	69	ns
2004-2005	73	71	71	75	70	72	ns
Shoots with one inflorescence/vine							
2003-2004	105	93	75	70	99	88	ns
2004-2005	133	126	132	99	104	119	ns
Shoots with multiple inflorescences/vine							
2003-2004	126	174	178	155	176	162	ns
2004-2005	144	110	128	120	128	126	ns
Total inflorescences/vine							
2003-2004	357	441	435	381	447	412	ns
2004-2005	421	345	387	339	358	370	ns
Proportion of fruiting nodes/vine							
2003-2004	55	53	60	48	57	55	ns
2004-2005	75	73	69	75	72	73	ns
Number of inflorescences/cane							
2003-2004	2.67	3.17	3.17	2.83	3.50	3.07	ns
2004-2005	2.25	2.25	2.11	2.04	2.21	2.17	ns

T1 = 0.43 irrigation, 30% thinning, T2 = 0.43 irrigation, no thinning, T3 = 1.45 irrigation, 30% thinning, T4 = 1.0 irrigation, no thinning, T5 = 1.45 irrigation, no thinning.

6.2.2 Light intensity

Light intensity measurements made during the water deficit periods in the 2004-05 and 2005-06 seasons using an AccuPAR ceptometer showed no significant difference in light interception between treatments in either year (Table 6-5).

Table 6-5 Proportion of light interception

	T1	T2	T3	T4	T5	Mean	Significance
14/01/04	0.393	0.416	0.418	0.436	0.362	0.405	ns
14/02/05	0.503	0.494	0.487	0.510	0.494	0.497	ns
22/02/06	0.502	0.525	0.536	0.556	0.536	0.531	ns
02/03/06	0.509	0.521	0.549	0.534	0.532	0.529	ns
Mean	0.477	0.489	0.497	0.509	0.481	0.491	

Proportion of light interception = 1 - (below canopy PAR/above canopy PAR)

T1 = 0.43 irrigation, 30% thinning, T2 = 0.43 irrigation, no thinning, T3 = 1.45 irrigation, 30% thinning, T4 = 1.0 irrigation, no thinning, T5 = 1.45 irrigation, no thinning.

6.2.3 Leaf water potential, photosynthesis and transpiration

The effects of water stress was quantified using a Scholander pressure bomb and a LI-COR photosynthesis meter. The pressure bomb was used to record leaf water potential (a measure of the availability of water for growth processes). The LI-COR photosynthesis meter, was used to measure photosynthesis (the rate at which CO_2 is fixed by the plant), stomatal conductance (a measure of the leaf conductance of the vapour transfer between the leaf sub-stomatal cavity and the atmosphere) and transpiration (the rate of water loss from the leaf). Although there were differences in vapour pressure deficit on the days on which measurements were taken (Figure 6-6), the treatment effects appear to be independent of VPD e.g. leaf water potential and photosynthesis for T1 and T2 were substantially lower than other treatments on both 10th Feb 2006, with a VPD less than 2kPa, and 16th Feb 2006 with a VPD greater than 5 kPa (Figure 6-7 and Figure 6-8).

Reduced irrigation on vines in treatments T1 (low irrigation, thinned) and T2 (low irrigation, no thinning) resulted in reduced leaf water potential (Figure 6-7) photosynthetic rate (Figure 6-8) stomatal conductance (Figure 6-9) and transpiration rate (Figure 6-10) over T4 (control) on the three days readings were taken. T3 (high irrigation, thinned) and T5 (high irrigation, no thinning) increased leaf water potential over the T4 on all days and resulted in a higher photosynthetic rate, stomatal conductance and transpiration rate on all days (T5) or two days (T3). Figure 6-11 shows that the greater the water stress ie the more negative the leaf water potential, the lower the photosynthetic rate.

Table 6-6 Vine water stress indicators

	T1	T2	T3	T4	T5	Mean	Significance
Leaf water potential (Ψ_{leaf}) (MPa)							
10/02/2006	-1.743b	-1.917a	-0.928d	-1.337c	-0.998d	-1.385	***
16/02/2006	-1.771a	-1.916a	-1.142c	-1.516b	-1.142c	-1.497	***
01/03/2006	-1.480a	-1.536a	-1.003c	-1.120b	-1.067bc	-1.241	***
Photosynthetic rate (µmol CO_2 m^2s)							
10/02/2006	5.66c	5.47c	12.90ab	12.00b	14.44a	10.10	***
16/02/2006	2.01c	0.35c	10.29ab	8.01b	11.34a	6.40	***
01/03/2006	7.85c	7.81bc	11.71ab	12.56a	12.87a	11.40	***
Stomatal conductance (mol H_20 m^2s)							
10/02/2006	0.053c	0.054c	0.248ab	0.186b	0.294a	0.167	***
16/02/2006	0.033c	0.010c	0.225a	0.137b	0.284a	0.138	***
01/03/2006	0.122b	0.106b	0.241a	0.262a	0.296a	0.205	***
Transpiration (mmol H_20 m^2s)							
10/02/2006	1.57c	1.47c	4.77ab	3.84b	5.49a	3.43	***
16/02/2006	1.86c	1.28c	7.16b	5.75b	9.20a	5.05	***
01/03/2006	4.21b	3.77b	6.67a	6.78a	7.41a	5.77	***

T1 = 0.43 irrigation, 30% thinning, T2 = 0.43 irrigation, no thinning, T3 = 1.45 irrigation, 30% thinning, T4 = 1.0 irrigation, no thinning, T5 = 1.45 irrigation, no thinning.

Mean values followed by the same letter are not significantly different (p=0.05).

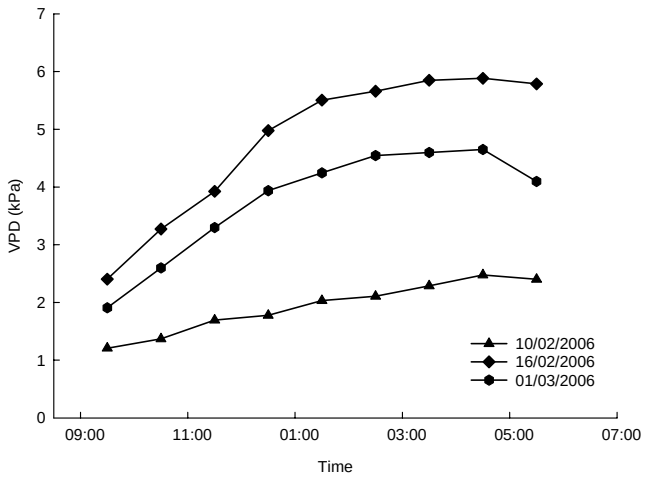


Figure 6-6 Vapour pressure deficit recorded at the Bureau of Meteorology weather station at Loxton Research Centre on the sampling days during ripening 2006.

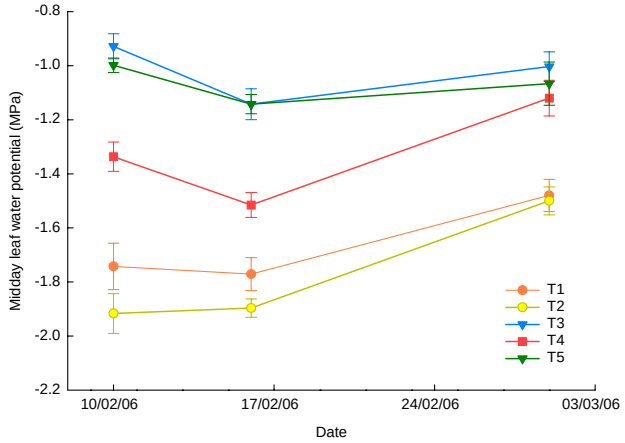


Figure 6-7 Midday leaf water potential (MPa) on three sampling dates during ripening in 2006.

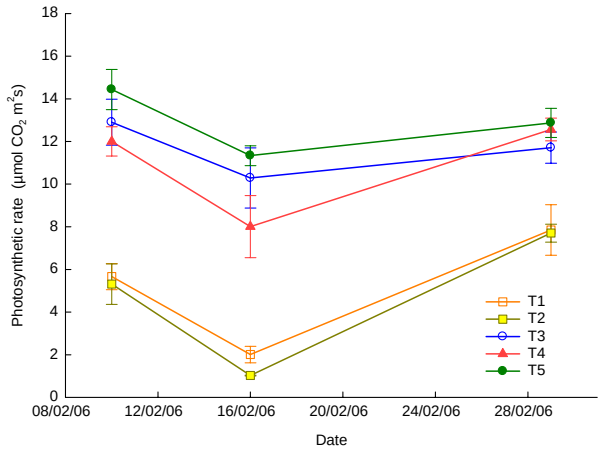


Figure 6-8 Photosynthetic rate (µmol CO_2 m^2s) on three sampling dates during ripening in 2006.

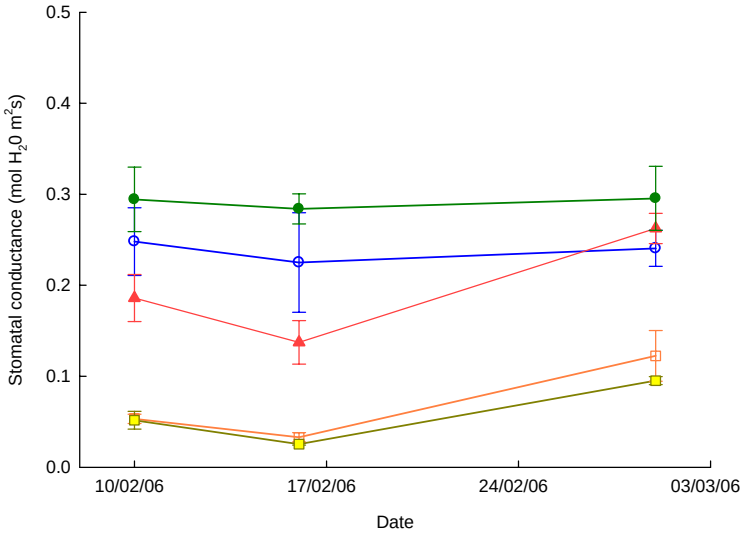


Figure 6-9 Stomatal conductance (mol H_2O m^2s) on three sampling dates during ripening in 2006.

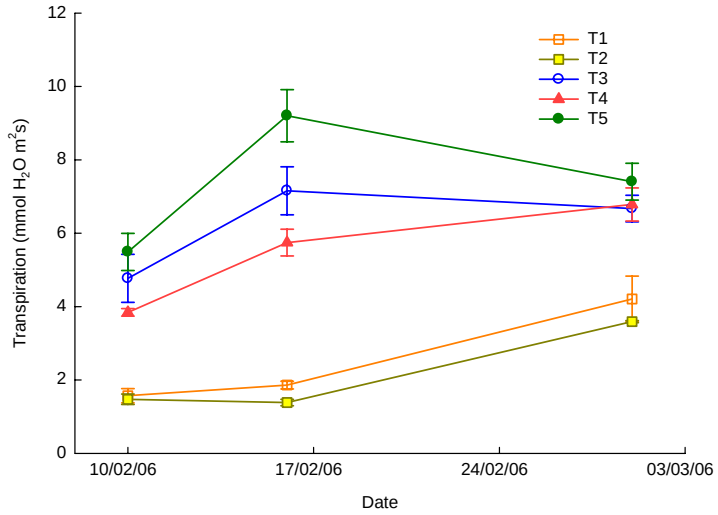


Figure 6-10 Transpiration rate (mmol H_2O m^2s) on three sampling dates during ripening in 2006.

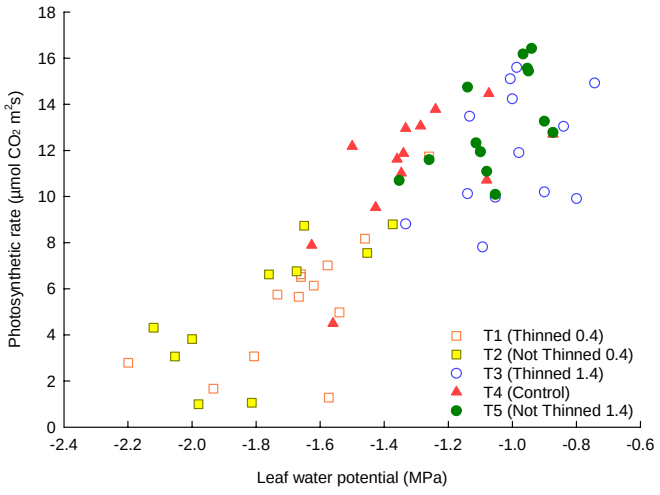


Figure 6-11 Plot of photosynthetic rate (µmol CO_2 m^2s) vs. leaf water potential (MPa)

6.2.4 Visual assessments

Visual observations were conducted on 18/2/04, 21/2/05 and 27/2/06 to check for stress symptoms. Generally, the reduced irrigation treatments showed the most stress. Leaf senescence symptoms appeared about two weeks earlier in 2003-04 than later years, due to the extremely hot weather in February 2004. The closest recorded °Brix to each of these dates is given to indicate maturity. All photographs shown were taken on 27/2/06.

T1 (low irrigation, thinned)

There was extensive yellowing of leaves (estimated 15%), particularly basal leaves (Figure 6-12). Approximately 1-3% of the leaves had died and fallen (Figure 6-13. Outer-canopy leaves were curled and had slight yellow tinges (Figure 6-14). In 2003-04, when ripening was faster, most berries had shrivelled to some extent by 18/2/04. This was not obvious in other years. Berries appeared uniformly dark coloured with no immature green or pale-red berries. No new leaf growth was observed. The closest dates to the days visual observations were conducted were 16/02/04, 22/02/05 and 27/02/06 with ^{o}Brix of 26.2, 22.7 and 24.0 respectively.



Figure 6-12 T1 treatment vine showing yellow and dead leaves.



Figure 6-13 Vineyard floor near a T1 treatment vine showing the extent of defoliation.



Figure 6-14 Outer canopy leaves showing leaf curling and yellowing (seen in T1 and T2 treatment vines).

T2 (low irrigation, no thinning)

There was also extensive yellowing of leaves (estimated 15%) particularly basal leaves see Figure 6-15 and Figure 6-17). Approximately 5% of leaves had died and fallen on the ground (Figure 6-16). Some of the outer leaves had yellow tinges and some were curled upward (Figure 6-14). No new leaf growth was observed. Berries were uniformly dark coloured. In the 2003-04, there was a high proportion of shrivelled berries. The closest dates to the days visual observations were conducted were 16/02/04, 22/02/05 and 27/02/06 with ^{o}Brix of 23.0, 20.9 and 22.5 respectively.



Figure 6-15 T2 treatment vine showing yellow leaves.



Figure 6-16 Vineyard floor showing extent of defoliation in T2 treatment vine.



Figure 6-17 Inside the canopy of a T2 treatment vine.

T3 (high irrigation, thinned)

The leaves remained dark green with very little yellowing (less than 2%) and these were mainly basal leaves. There were some slight yellow tinges on outer leaves (Figure 6-19). There were few dead leaves (Figure 6-20). New growth was observed on the tips. Berries were not uniformly coloured like T1 and T2 (Figure 6-18). The closest dates to the days visual observations were conducted were 16/02/04, 22/02/05 and 27/02/06 with ^{o}Brix of 23.7, 22.6 and 23.6. respectively.



Figure 6-18 T3 treatment vine showing non-uniform berry colour.



Figure 6-19 Outer leaves of T3 treatment vine showing very little yellowing.



Figure 6-20 Vineyard floor under a T3 treatment vine showing less dead leaves.

T4 (control)

The leaves were mainly dark green (Figure 6-21) with less than 2% showing yellowing. There were some slight yellow tinges on the tips of outer leaves and few curled leaves. There were few dead leaves (Figure 6-22). There was some new growth on the tips of canes. The berries were not uniformly coloured (Figure 6-23). The closest dates to the days visual observations were conducted were 16/02/04, 22/02/05 and 27/02/06 with ^{o}Brix of 22.4, 20.9 and 23.2 respectively.



Figure 6-21 T4 treatment vine showing mainly dark green leaves.



Figure 6-22 Vineyard floor under a T4 treatment vine, showing few dead leaves.



Figure 6-23 T4 treatment vine bunch showing variation in berry maturity.

T5 (high irrigation, no thinning)

The majority of leaves were dark green with less than 2% showing yellowing and very few dead leaves (Figure 6-24). There were few outer leaves with yellow tinges on the tips and few curled leaves. There was new growth on the tips of canes. Berry maturity varied greatly with some light red and small immature green berries present (Figure 6-25). The closest dates to the days visual observations were conducted were 16/02/04, 22/02/05 and 27/02/06 with ^{o}Brix of 22.1, 21.5 and 22.8. respectively.



Figure 6-24 Vineyard floor under a T5 treatment vine showing few dead leaves.



Figure 6-25 T5 treatment vine showing variation in berry maturity.

6.3 Yield and berry quality

Yield, components of yield and fruit quality measurements at harvest are given in Table 6-7 and Table 6-8 and maturity data in Figure 6-26 to Figure 6-46.

Table 6-7 Yield and components of yield measurements at harvest

	T1	T2	T3	T4	T5	Mean	Significance	Interaction
Yield (kg/vine)								
2003-04	5.5c	11.1b	6.5c	12.7a	12.0ab	9.5	***	
2004-05	8.8c	13.4b	9.9c	15.2a	13.6b	12.2	***	
2005-06	9.2b	14.8a	9.0b	14.7a	14.8a	12.5	***	
Mean	7.8	13.2	8.5	14.2	13.5	11.4		ns
Yield (t/ha)								
2003-04	10.8c	22.0b	12.8c	25.2a	23.8ab	18.9	***	
2004-05	17.5c	26.7b	19.7c	30.2a	27.0b	24.2	***	
2005-06	18.3b	29.5a	17.9b	29.3a	29.5a	24.9	***	
Mean	15.5	26.3	16.8	28.2	26.8	22.7		ns
Bunches/vine								
2003-04	190c	289a	185c	243b	261ab	234	***	
2004-05	184c	233a	192c	239a	216b	213	***	
2005-06	176b	244a	158b	229a	216a	205	***	
Mean	183	256	179	237	231	217		*
Bunch weight (g)								
2003-04	28.7d	38.2c	35.1c	52.3a	46.2b	40.1	***	
2004-05	47.8d	57.5b	51.8c	63.6a	63.1a	56.8	***	
2005-06	52.6d	60.5bc	57.5cd	64.5ab	68.8a	60.8	***	
Mean	43.0	52.3	48.1	60.2	59.4	52.5		*
Berries/bunch								
2003-04	40c	53b	44c	59a	56ab	51	***	
2004-05	48b	55a	49b	59a	58a	54	***	
2005-06	58c	69b	60c	67b	75a	66	***	
Mean	49	59	51	62	63	57		ns
Berry weight (g)								
2003-04	0.71c	0.72c	0.79b	0.89a	0.82b	0.79	***	
2004-05	0.99	1.05	1.06	1.09	1.09	1.06	ns	
2005-06	0.91	0.88	0.96	0.96	0.92	0.93	ns	
Mean	0.87	0.89	0.94	0.98	0.94	0.92		ns

T1 = 0.43 irrigation, 30% thinning, T2 = 0.43 irrigation, no thinning, T3 = 1.45 irrigation, 30% thinning, T4 = 1.0 irrigation, no thinning, T5 = 1.45 irrigation, no thinning.

Analyses presented are those conducted on single year data sets. A repeated measures analysis was also conducted on the entire data set (for multiple seasons) and interaction indicates whether there was a significant interaction over years ie if treatments have behaved differently in different years.

Mean values followed by the same letter are not significantly different (p=0.05).

Table 6-8 Fruit quality measurements at harvest

	T1	T2	T3	T4	T5	Mean	Significance	Interaction
Date of harvest								
2003-04	17-Feb	20-Feb	17-Feb	23-Feb	8-Mar			
2004-05	2-Mar	11-Mar	2-Mar	11-Mar	11-Mar			
2005-06	7-Mar	7-Mar	7-Mar	7-Mar	7-Mar			
TSS °Brix								
2003-04	26.2a	24.1b	23.7bc	23.2c	24.4b	24.3	***	
2004-05	24.8a	23.7bc	24.1b	23.4c	23.5c	23.9	***	
2005-06	26.5a	24.9b	25.0b	25.1b	24.2c	25.2	***	
Mean	25.9	24.2	24.3	23.9	24.0	24.5		***
pH								
2003-04	3.38a	3.20c	3.14c	3.18c	3.28b	3.24	***	
2004-05	3.28a	3.22b	3.27a	3.17c	3.20bc	3.23	***	
2005-06	3.52a	3.47abc	3.48ab	3.41c	3.41c	3.46	*	
Mean	3.39	3.29	3.30	3.25	3.30	3.31		***
Titratable acidity (g/L)								
2003-04	9.2b	9.6ab	9.8a	8.1c	6.2d	8.6	***	
2004-05	7.4	7.4	7.1	7.4	7.1	7.3	ns	
2005-06	4.8c	5.0bc	5.3ab	5.3ab	5.5a	5.2	*	
Mean	7.1	7.3	7.4	6.9	6.3	7.0		***
Anthocyanins (mg/g)								
2003-04	2.29a	2.27ab	2.16abc	2.04c	2.11bc	2.18	*	
2004-05	1.52a	1.49a	1.24b	1.22b	1.10c	1.31	***	
2005-06	1.53a	1.50a	1.14bc	1.17b	1.02c	1.27	***	
Mean	1.78	1.77	1.51	1.48	1.41	1.59		**

T1 = 0.43 irrigation, 30% thinning, T2 = 0.43 irrigation, no thinning, T3 = 1.45 irrigation, 30% thinning, T4 = 1.0 irrigation, no thinning, T5 = 1.45 irrigation, no thinning.

Analyses presented are those conducted on single year data sets. A repeated measures analysis was also conducted on the entire data set (for multiple seasons) and interaction indicates whether there was a significant interaction over years ie if treatments have behaved differently in different years.

Mean values followed by the same letter are not significantly different (p=0.05).

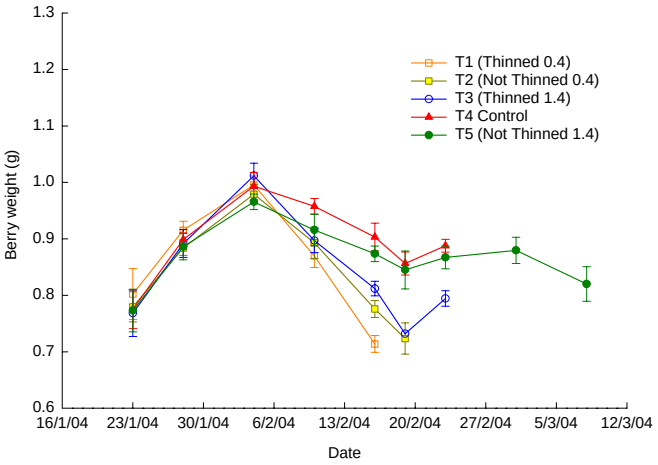


Figure 6-26 The effect of irrigation and crop load on berry weight in the 2003-04 season

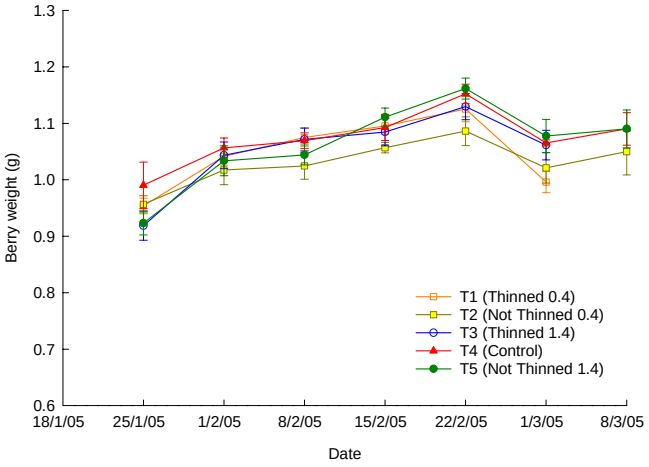


Figure 6-27 The effect of irrigation and crop load on berry weight in the 2004-05 season

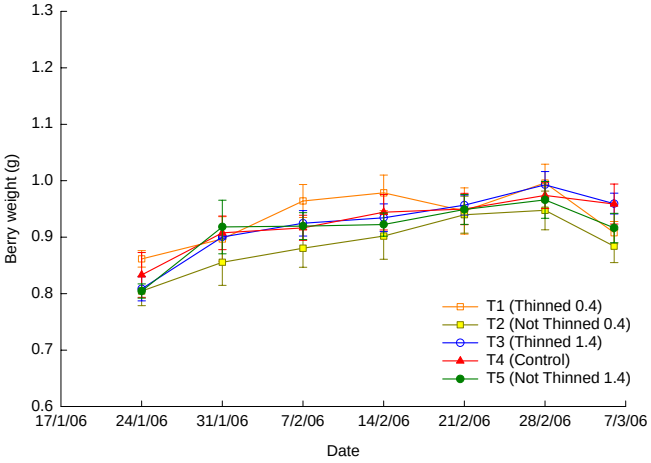


Figure 6-28 The effect of irrigation and crop load on berry weight in the 2005-06 season

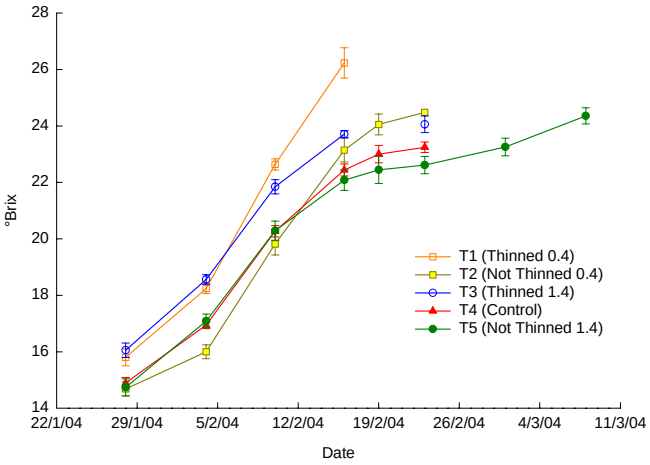


Figure 6-29 The effect of irrigation and crop load on TSS °Brix in the 2003-04 season

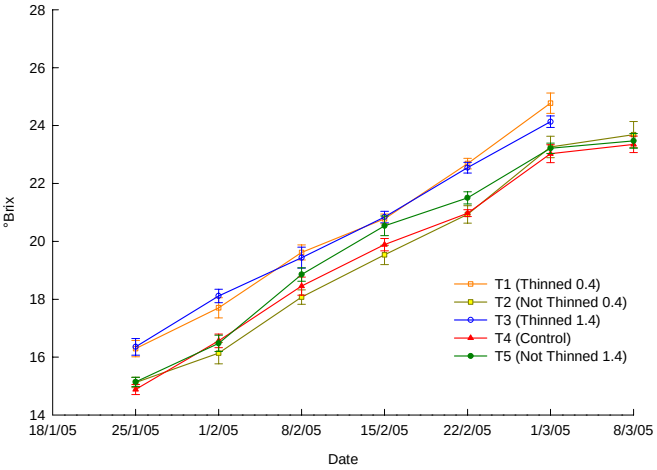


Figure 6-30 The effect of irrigation and crop load on TSS °Brix in the 2004-05 season

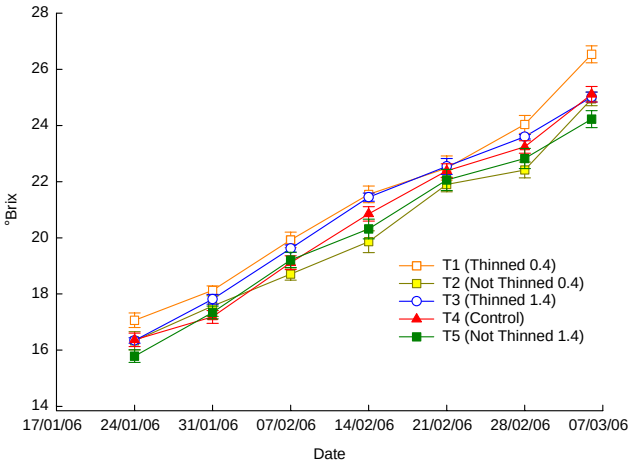


Figure 6-31 The effect of irrigation and crop load on TSS °Brix in the 2005-06 season

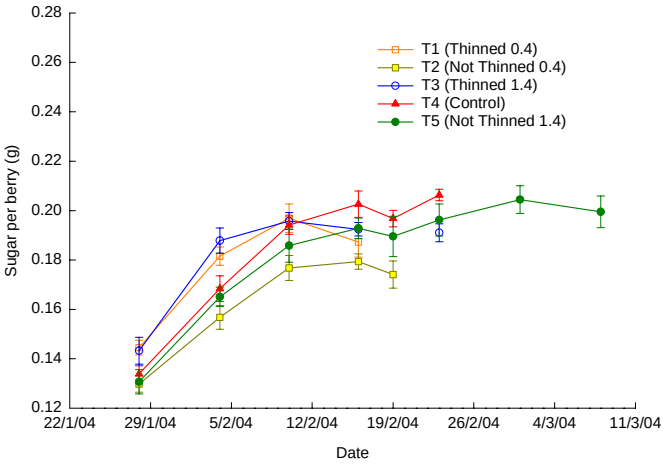


Figure 6-32 Effect of irrigation and crop load on sugar per berry in the 2003-04 season

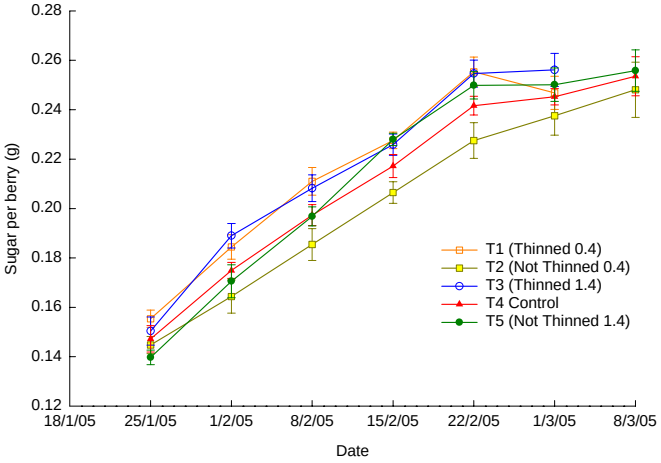


Figure 6-33 Effect of irrigation and crop load on sugar per berry in the 2004-05 season

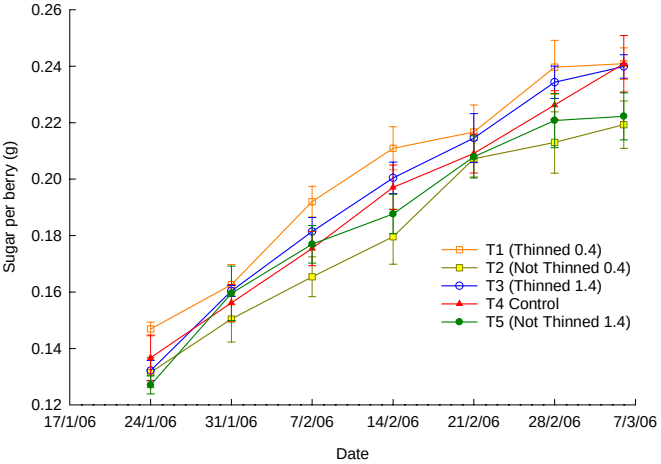


Figure 6-34 Effect of irrigation and crop load on sugar per berry in the 2005-06 season

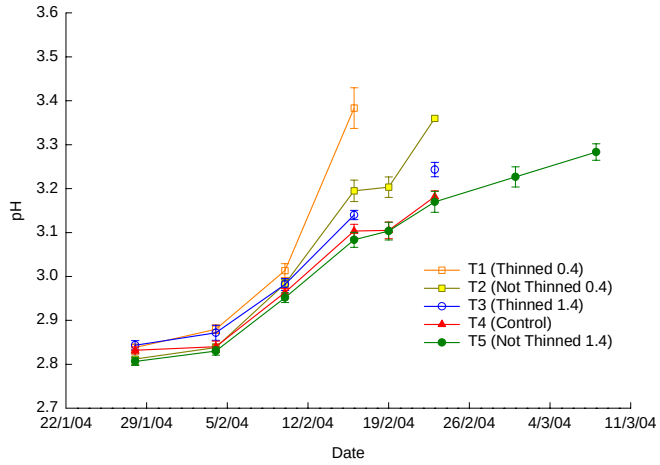


Figure 6-35 The effect of irrigation and crop load on juice pH in the 2003-04 season

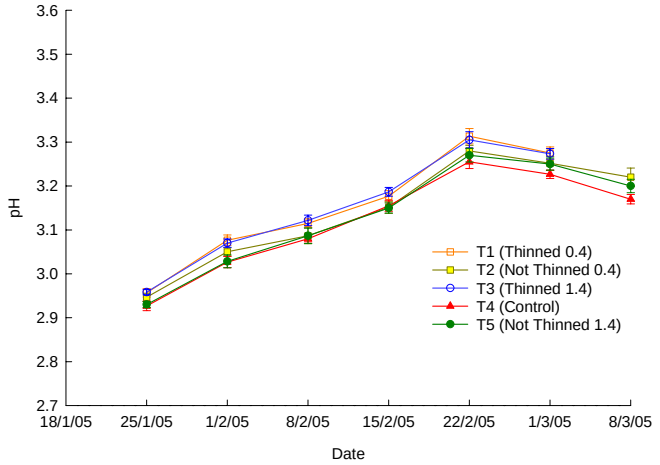


Figure 6-36 The effect of irrigation and crop load on juice pH in the 2004-05 season

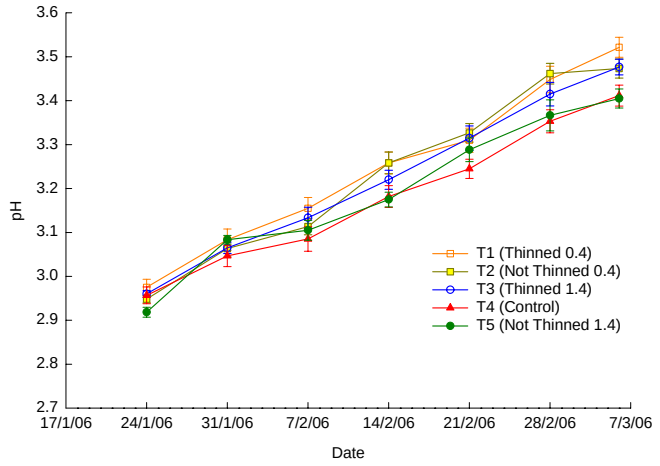


Figure 6-37 The effect of irrigation and crop load on juice pH in the 2005-06 season

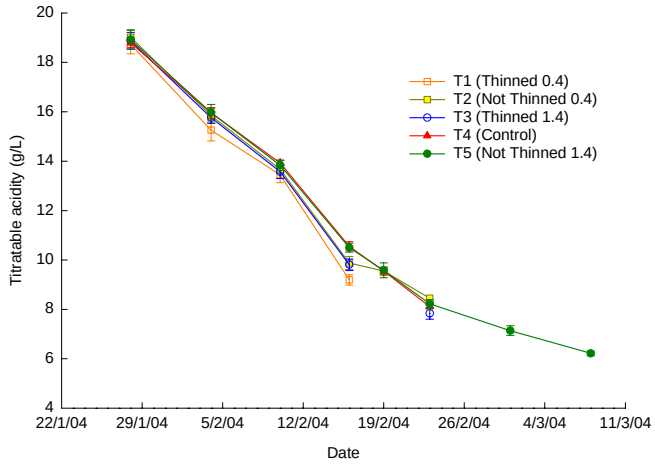


Figure 6-38 The effect of irrigation and crop load on juice titratable acidity in the 2003-04 season

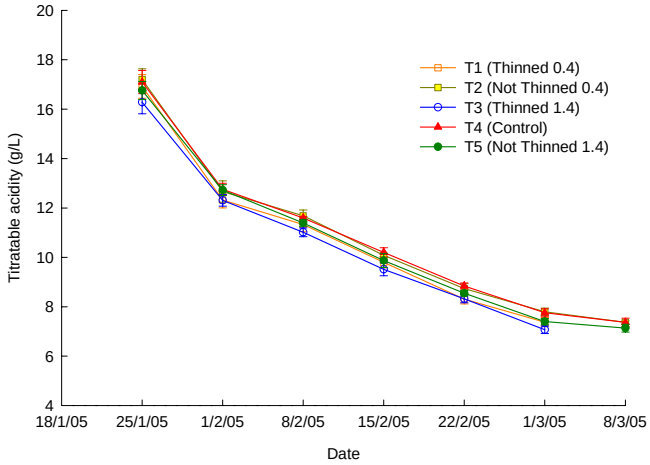


Figure 6-39 The effect of irrigation and crop load on juice titratable acidity in the 2004-05 season

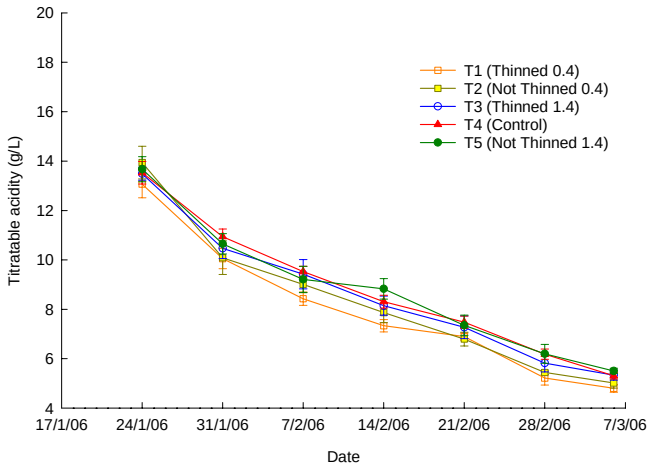


Figure 6-40 The effect of irrigation and crop load on juice titratable acidity in the 2005-06 season

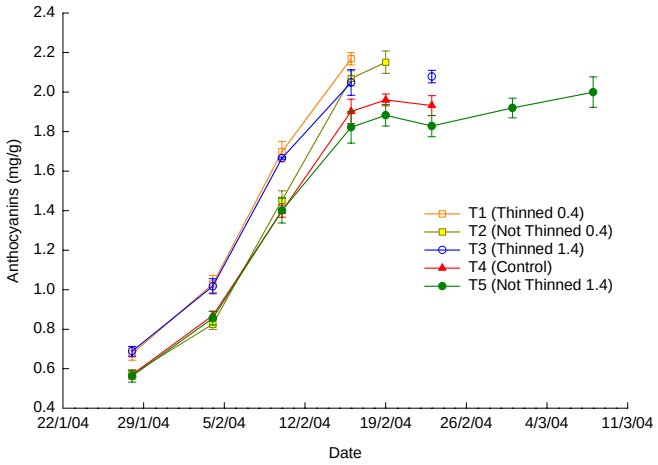


Figure 6-41 Effect of irrigation and crop load on berry anthocyanins in the 2003-04 season

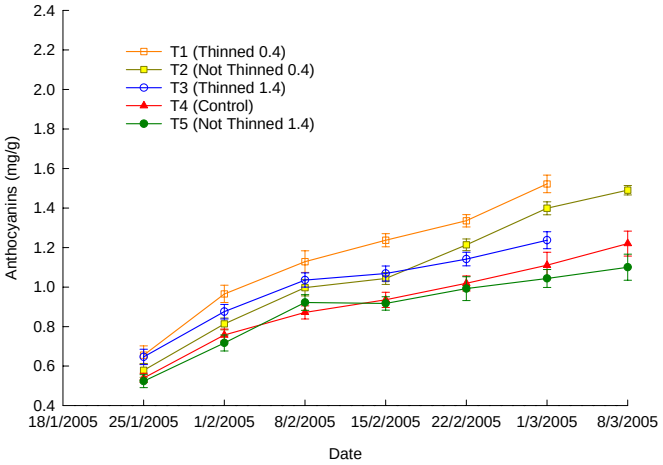


Figure 6-42 Effect of irrigation and crop load on berry anthocyanins in the 2004-05 season

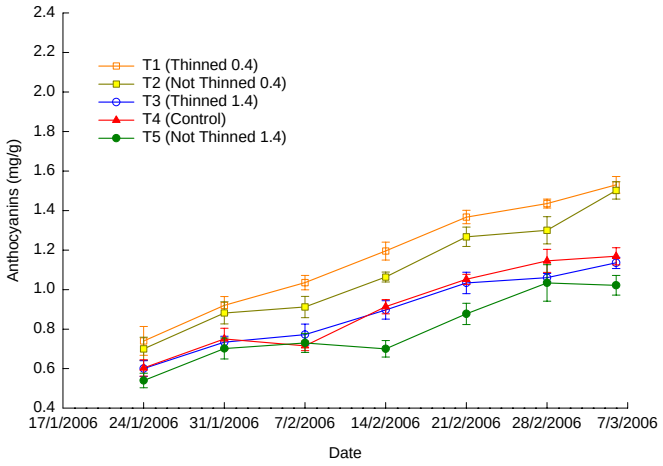


Figure 6-43 Effect of irrigation and crop load on berry anthocyanins in the 2005-06 season

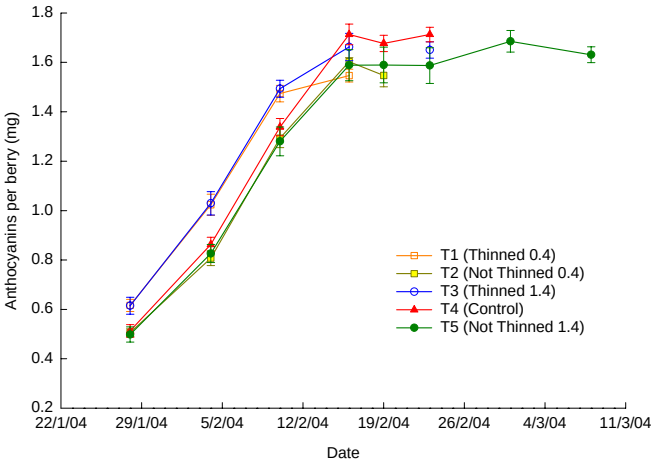


Figure 6-44 Effect of irrigation and crop load on anthocyanins per berry in the 2003-04 season

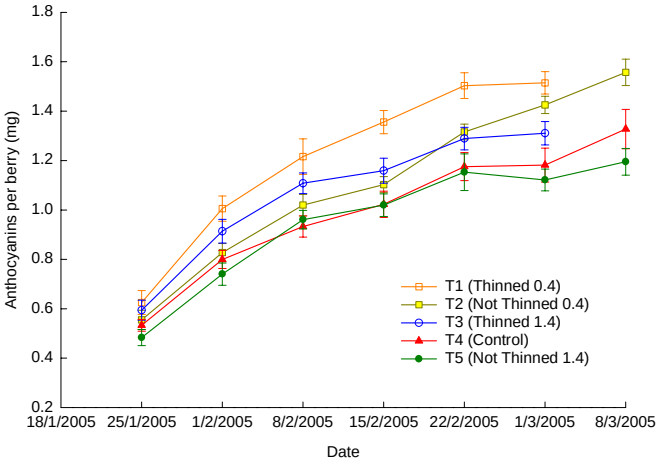


Figure 6-45 Effect of irrigation and crop load on anthocyanins per berry in the 2004-05 season

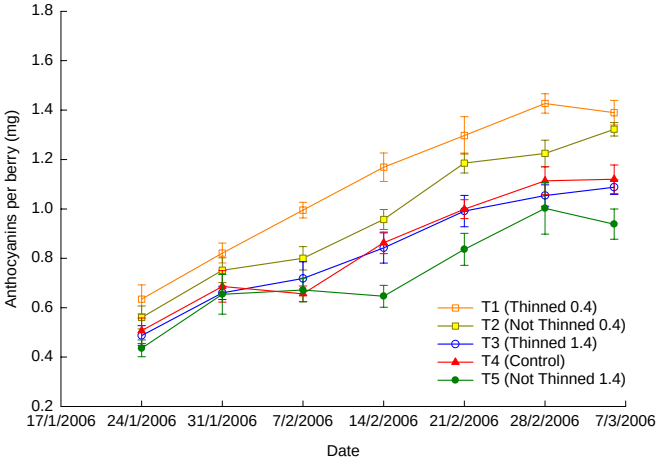


Figure 6-46 Effect of irrigation and crop load on anthocyanins per berry in the 2005-06 season

6.3.1 Discussion

Yield

T1 (low irrigation, thinned) and T3 (high irrigation, thinned) resulted in greatly reduced yield in all three years due to the reduced number of bunches per vine (Table 6-7). T2 (low irrigation, no thinning) gave only a slight reduction in yield compared with T4 (control) in 2003-04 and 2004-05 (due to reduced bunch weight), but there was no difference in yield in 2005-06. T5 (high irrigation, no thinning) gave a slight reduction in yield compared with T4 in 2004-05, but no difference in yield in 2003-04 and 2005-06.

Berry weight

Berry weights increased to a peak on the 4 February in 2003-04 (Figure 6-26), 22 February in 2004-05 season (Figure 6-27) and 28 February in 2005-06 (Figure 6-28), and subsequently decreased in all years. T1 (low irrigation, thinned) and T2 (low irrigation, no thinning) gave a large reduction in berry weight at harvest in 2003-04 (Table 6-7), possibly due to the days with extremely high temperatures in February 2004. There were no significant differences in berry weight at harvest between any of the treatments in 2004-05 and 2005-06.

Total soluble solids °Brix

T1 (low irrigation, thinned) and T3 (high irrigation, thinned) generally gave higher TSS °Brix (ie earlier maturity) than T4 (control) during the treatment period in all years, except just prior to harvest in 2005-06 when TSS °Brix of T3 (high irrigation, thinned) was equivalent to T4 (Figure 6-29, Figure 6-30 and Figure 6-31). The deficit irrigated treatment T2 (low irrigation, no thinning) gave lower or similar TSS °Brix to T4 except just prior to harvest in 2003-04 when it was higher. T5 (high irrigation, no thinning) gave lower TSS °Brix than T4 in the second half of the treatment period in 2003-04 and 2005-06, but not in 2004-05 when it was higher. T1 (low irrigation, thinned) gave higher TSS °Brix than T3 (high irrigation, thinned) at harvest in all years (Table 6-8).

The stage when sugar accumulation per berry peaks indicates a change in the berry ripening. Although TSS °Brix continued to increase in all treatments in all years, sugar accumulation stopped for some treatments. In 2003-04 (Figure 6-32), sugar per berry peaked for treatments T1 (low irrigation, thinned), T2 (low irrigation, no thinning) and T3 (high irrigation, thinned) between 10 and 16 February. T1 peaked in 2004-05 on 22 February (Figure 6-33). In 2005-06 sugar per berry was close to peaking in T1 and T5 (high irrigation, no thinning) on 7 March (Figure 6-34). In all years the deficit irrigation treatment T2 gave the lowest sugar per berry during ripening of all the treatments and the thinning treatments T1 and T3 gave the highest sugar per berry before peaking.

pH

T1 (low irrigation, thinned), T2 (low irrigation, no thinning), T3 (high irrigation, thinned) generally gave higher pH than T4 (control) during the treatment period in all years (Figure 6-35, Figure 6-36 and Figure 6-37).

Titratable acidity

Thinning treatments T1 (low irrigation, thinned) and T3 (high irrigation, thinned) generally gave a lower titratable acidity than the T4 (control) during the treatment period in all years (Figure 6-38, Figure 6-39 and Figure 6-40).

Anthocyanins

T1 (low irrigation, thinned) and T2 (low irrigation, no thinning) increased berry anthocyanins (mg/g) over T4 (control) for the treatment periods in all three years (Figure 6-41, Figure 6-42 and Figure 6-43). T5 (high irrigation, no thinning) resulted in lower anthocyanins than T4 at most sampling points for the three years. T3 (high irrigation, thinned) resulted in higher anthocyanins than T4 in 2003-04 and 2004-05. In the second and third season of the trial, low irrigation did not affect berry weight. Therefore the positive effect that low irrigation had on anthocyanin concentration was not caused by alteration in the skin surface area to pulp volume ratio.

A peak in anthocyanins calculated on a mg per berry basis is considered to indicate when anthocyanin metabolism ceases. Anthocyanin production slowed down or ceased for most treatments from 15 February in 2003-04 (Figure 6-44), for T1 (low irrigation, thinned), T3 (high irrigation, thinned) and T5 (high irrigation, no thinning) from 22 February in 2004-05 (Figure 6-45), and for T1 and T5 from 28 February in 2005-06 (Figure 6-46).

6.4 Wine quality

Analyses of wines made in years 2003-04 and 2004-05 are given in Table 6-9. Results from 2005-06 wines are not presented due to issues related to the winemaking process.

Table 6-9 Analyses conducted on 2003-04 and 2004-05 small lot wines post bottling and after 10 months.

	Age (months)	T1	T2	T3	T4	T5	Mean	Significance
Wine colour density								
2003-04	0	16.18a	14.79ab	12.72c	13.91bc	14.54b	14.43	**
2003-04	10	16.02a	15.87a	12.67d	13.83c	14.56b	14.59	***
2004-05	0	11.44a	7.21c	9.49b	6.11c	6.23c	8.09	***
2004-05	10	11.09a	7.63bc	8.29b	6.66c	6.55c	8.04	***
Wine colour hue								
2003-04	0	0.54	0.55	0.55	0.53	0.53	0.54	ns
2003-04	10	0.66b	0.66b	0.67a	0.66b	0.64c	0.66	**
2004-05	0	0.56bc	0.62a	0.54c	0.60ab	0.59b	0.58	*
2004-05	10	0.66	0.73	0.66	0.70	0.71	0.69	ns
Total anthocyanins								
2003-04	0	718.0	779.2	729.8	709.6	699.1	727.1	ns
2003-04	10	399.1	456.4	443.9	425.6	427.5	430.5	ns
2004-05	0	515.8a	449.6b	362.5c	320.9d	322.6cd	394.3	***
2004-05	10	487.5a	429.5ab	373.9bc	368.3bc	323.0c	396.4	**
Ionised anthocyanins								
2003-04	0	117.8	110.0	97.5	110.8	110.8	109.4	ns
2003-04	10	100.1a	100.4a	83.1c	87.5bc	91.5b	92.5	***
2004-05	0	106.1a	60.2b	96.1a	55.8b	50.7b	73.8	**
2004-05	10	68.4a	37.6c	50.2b	31.9c	28.7c	43.4	***
Total phenolics								
2003-04	0	63.7ab	64.6a	58.7c	58.0c	59.5bc	60.9	*
2003-04	10	65.5	67.9	62.3	62.5	64.9	64.6	ns
2004-05	0	66.3a	58.3b	54.3c	48.0d	50.0d	55.4	***
2004-05	10	48.8a	41.0b	40.0b	39.3b	36.5b	41.1	*

T1 = 0.43 irrigation, 30% thinning, T2 = 0.43 irrigation, no thinning, T3 = 1.45 irrigation, 30% thinning, T4 = 1.0 irrigation, no thinning, T5 = 1.45 irrigation, no thinning.

Mean values followed by the same letter are not significantly different (p=0.05).

Age months 0 = post bottling, 10 = after 10 months

Wine tasting scores from an industry panel at CSIRO Plant Industry at Merbein are given in Table 6-10. Each year the panel consisted of 8 winemakers but these varied from year to year. Wines were scored using the 20 point system used in Australian wine shows, which awards a maximum of three points for colour and clarity, a maximum of seven points for bouquet and a maximum of ten points for taste for a total score out of 20.

Table 6-10 Wine tasting scores

	T1	T2	T3	T4	T5	Mean	Significance
Year							
2004	15.15a	14.56b	14.48bc	14.06c	14.35bc	14.52	*
2005	14.71	13.88	14.45	13.34	13.60	14.00	ns
Breakdown of scores							
2004							
Colour and Clarity (/3)	2.94	3.00	2.88	2.92	2.94	2.93	ns
Bouquet (/7)	5.10a	4.96abc	4.98ab	4.71bc	4.69c	4.89	*
Palate (/10)	7.10a	6.60b	6.63b	6.44b	6.73b	6.70	*
2005							
Colour and Clarity (/3)	2.95a	2.86a	2.83ab	2.66bc	2.62c	2.79	*
Bouquet (/7)	4.98	4.69	4.79	4.47	4.64	4.71	ns
Palate (/10)	6.79	6.33	6.83	6.21	6.33	6.50	ns

T1 = 0.43 irrigation, 30% thinning, T2 = 0.43 irrigation, no thinning, T3 = 1.45 irrigation, 30% thinning, T4 = 1.0 irrigation, no thinning, T5 = 1.45 irrigation, no thinning.
Mean values followed by the same letter are not significantly different (p=0.05).

6.4.1 Discussion

Wine colour density

Wine analyses are given in Table 6-9. Wines generally had much higher colour density in 2003-04 than in 2004-05. Wines with the highest colour density were T1 (low irrigation, thinned) in both 2003-04 and 2004-05 and T2 (low irrigation, no thinning) in 2003-04. In 2004-05, T3 (high irrigation, thinned) resulted in higher colour density than T4 (control), but T2 was not significantly different from T4. There was no reduction in colour density 10 months after bottling in either year.

Wine colour hue

In 2003-04 in post bottling wines, there was no significant difference in hue between treatments. In 2004-05 T3 (high irrigation, thinned) gave lower hue than T4 (control). After 10 months, all treatments in both years gave higher hues ie the wines were less bright. In 2003-04, T3 (high irrigation, thinned) gave a higher hue and T5 (high irrigation, no thinning) gave a lower hue than T4.

Wine total anthocyanins

In 2003-04 there were no significant differences in anthocyanins between treatments either post bottling or after 10 months, but there was a large reduction in anthocyanins between the post bottling and 10 month. In 2004-05, T1 (low irrigation, thinned) gave the highest anthocyanins, followed by T2 (low irrigation, no thinning), then T3 (high irrigation, thinned). There was not the consistent reduction in anthocyanins between post bottling and 10 months as seen in the previous year.

Ionised anthocyanins

In 2003-04 there were no significant differences in ionised anthocyanins between treatments post bottling, but after 10 months T1 (low irrigation, thinned) and T2 (low irrigation, no thinning) gave higher ionised anthocyanins than T4 (control). In 2004-05, post bottling and after 10 months T1 and T3 (high irrigation, thinned) gave higher ionised anthocyanins than T4.

Wine total phenolics

In 2003-04, T1 (low irrigation, thinned) and T2 (low irrigation, no thinning) gave higher total phenolics than T4 (control) post bottling, but after 10 months there was no significant difference. In 2004-05, T1, T2 and T3 (high irrigation, thinned) gave higher total phenolics than T4 (control) post bottling, but after 10 months only T1 was higher.

Wine tasting

Wine tasting scores are given in Table 6-10. In 2003-04, T1 (low irrigation, thinned) and T2 (low irrigation, no thinning) gave higher overall tasting scores than T4 (control). T1 had higher scores for bouquet and palate than T4. In 2004-05 there were no significant differences between overall scores, but T1 and T2 had higher colour and clarity than T4.

6.5 Berry sensory assessment

6.5.1 Berry, pulp, and skin maturities and seed colour

Effect of sample date

The development of the standard measure of fruit maturity °Brix, and the average of the ratings of the two assessors for berry, pulp and skin maturity, and seed colour over the same time period in 2003-04 and 2004-05 are presented in Figure 6-47. In 2003-04 berry assessment was conducted over a 25 day period and in 2004-05 over a 20 day period. Over these periods, the ranges of values in °Brix, skin maturity and seed colour in 2003-04 were about one and a half times those in 2004-05.

In 2003-04, between the first and second sampling dates (12 and 14 February), a period for which the records for all treatments were complete, decreasing irrigation (T1 and T2) increased berry maturity scores, and decreasing irrigation combined with fruit thinning (T1) increased both pulp maturity and skin maturity. Treatment effects were independent of sampling date. Neither treatment nor sampling date affected seed colour.

For the period covering the first four sampling dates (12, 14, 19 and 23 February), when complete records were available for treatments T2 through to T5, reducing irrigation (T2) increased berry maturity on all sample dates after 12 February. Over this period reducing irrigation (T2) caused berry maturity to increase twice, between 14 and 19 February , and between 19 and 23 February, whereas increases in the values in treatments receiving control and higher irrigation (T3, T4 and T5) occurred once between 14 and 19 February. The effect of treatments on pulp maturity was dependent on sampling date. On the 12 February, pulp maturity in the treatment receiving higher irrigation and thinning (T3) was higher than that in the treatment receiving reduced irrigation (T2). Treatment had no effect on 14 and 19 February, and by 23 February pulp maturity in the reduced irrigation (T2) was above that in the treatment receiving higher irrigation but no thinning (T5). Treatment had no effect on skin maturity. Its values increased between 14 and 19 February. Treatment had no effect on seed colour at the first 2 sampling dates. After this date, reducing irrigation (T2) increased seed colour.

For the period covering the entire eight sampling dates (12, 14, 19, and 23 February, 1, 5, 10 and 15 March) complete records were available for treatments T3, T4 and T5. Treatment did not affect berry maturity until 1 March, on this date maturity in T3 was greater than T5, and on 5, 10 and 15 March T3 maturity was greater than T4 and T5 which were equivalent. In all 3 treatments, berry maturity increased between 14 and 19 February. T3 increased again between 23 February and 1 March and between 1 March and 5 March. T4 increased again between 1 and 5 March. T5 increased between 1 and 15 March. Treatment did not affect pulp maturity; it increased three times over the period: between 12 and 14 February, between 14 and 19 February, and between 23 February and 1 March. Likewise, treatment did not affect skin maturity. It also increased three times over the period: between 19 and 23 February, between 23 February and 1 March, and between 1 and 5 March. Treatment initially affected seed colour on 1 March when colour in T3 was greater than T5. On 5, 10 and 15 March colour in T3 was greater than T4 and T5 which were equivalent. Seed colour increased twice in treatment T3, between 14 and 23 February and between 23 February and 15 March. It increased once in T4, between 14 and 23 February, and once in T5, between 12 and 23 February. Higher colour scores for T4 and T5 were not sustained with scores on 10 March equivalent to those on 12 February.

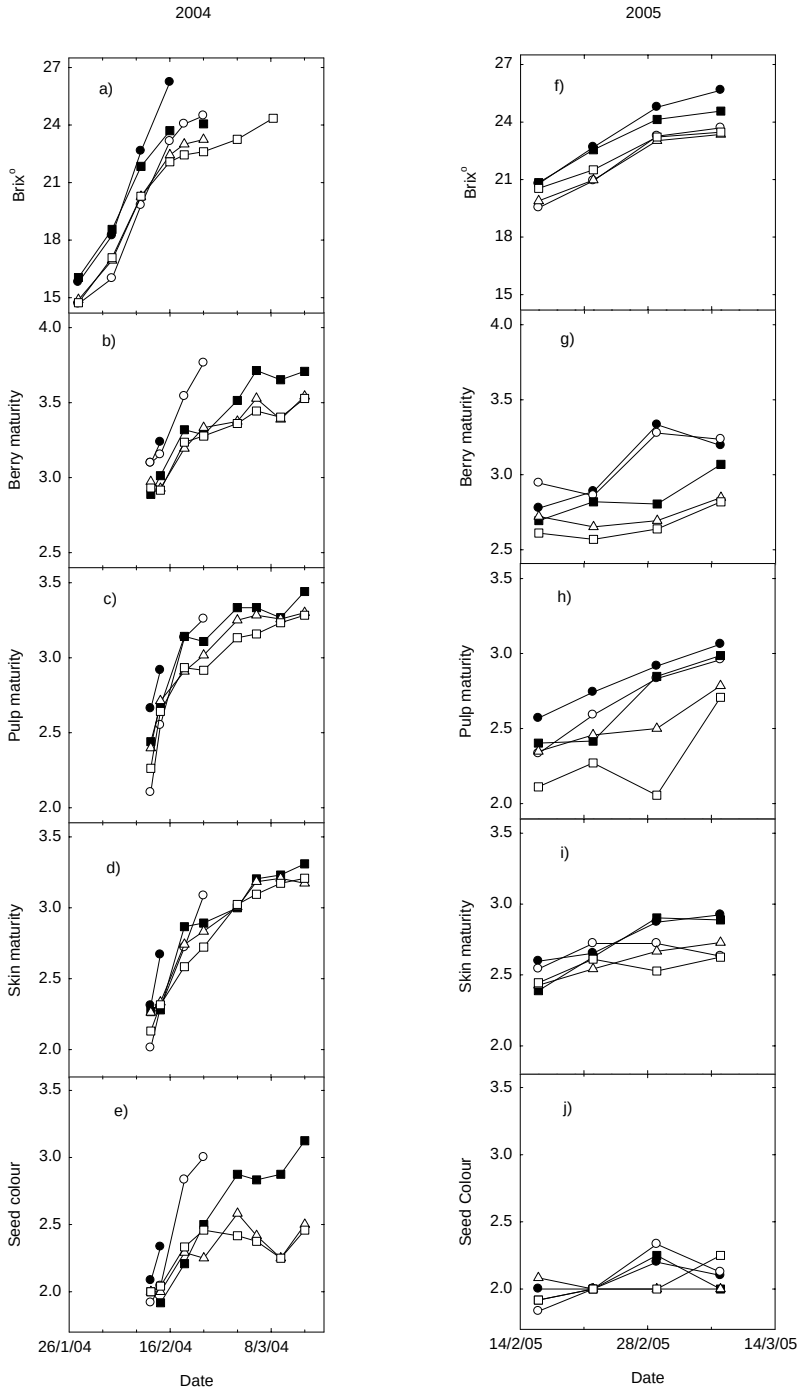


Figure 6-47 Time course of TSS °Brix and berry sensory assessment scores in 2004 (a-e) and 2005 (f-j). T1 ●, T2 ○, T3 ■, T4 Δ, and T5 □.

In 2004-05, the effect of treatment on berry maturity scores was dependent on sample date. On 16 February, reduced irrigation and thinning (T1) was scored higher than high irrigation (T3 and T5); on 22 February, reduced irrigation (T1 and T2) scored higher than high irrigation and non thinning(T5); on 1 March, reduced irrigation (T1 and T2) were scored higher than high irrigation and the control (T3, T4 and T5); on 8 March scores in reduced irrigation (T1 and T2) were higher than control and high irrigation no thinning (T4 and T5). The effects of treatment on pulp and skin maturity were independent of sample date. Pulp maturity in T1 was equal to T2 and greater than T3, T4 and T5. Pulp maturity on 8 March was greater than the equivalent values on 22 February and 1 March which were greater than that on 16 February. Skin maturity in T1 was equal to T3 and greater than T2, T4 and T5. Values were equivalent on 1 and 8 March, and were greater than that on 22 February, which in turn was greater than that on 16 February. Treatment did not affect seed colour. Its value on 1 March was equal to that on 8 March and greater than those on 16 and 22 February.

6.5.2 Taster effect

In 2003-4 taster identity affected the scores for pulp and skin maturity on all 8 sampling dates, scores for berry maturity on 5 dates and those for seed colour on 3 dates (data not shown). Taster bias remained static across all properties on all dates, that is the taster scoring high consistently scored higher.

In 2004-05, scores for skin maturity were dependent on taster identity on 3 sampling dates, those for pulp maturity on 2 samplings and those for seed colour on one sampling (data not shown). With regard to scores of skin maturity, taster bias remained static across the three sample dates at which 2 tasters undertook assessments.

6.5.3 Treatment effect at harvest

The target °Brix range for harvest was 23.4-24.3°. In 2003-04, the harvest period extended over 20 days; thinned treatments (T1 and T3) were harvested at the start of this period and the high irrigation no thinning (T5) at the end. At harvest, the high irrigation no thinning treatment (T5) and low irrigation no thinning (T2) had the highest berry maturity scores (Figure 6-48). T5, the control (T4) and treatment T2 had the higher pulp maturity scores. T5 had the highest skin maturity score. T2 had the highest seed colour score. Use of contrasts to investigate effects of thinning and irrigation amongst T1, T2, T3, and T5 showed that:

- Thinning the crop decreased berry and pulp maturity.
- Thinning decreased the skin maturity score under high irrigation, but did not affect it under low irrigation.
- Reducing irrigation increased seed colour, whereas crop thinning decreased it.
- Thinning the crop under low irrigation was associated with a higher °Brix.

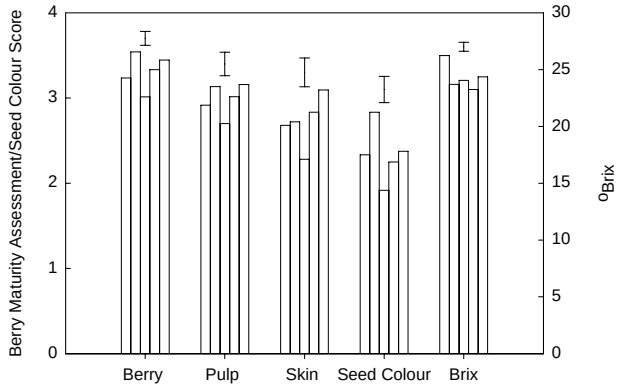


Figure 6-48 The scores for berry pulp and skin maturity assessment and seed colour and TSS °Brix at the 2004 harvest. (Bars from left to right T1 to T5, error bars LSD P= 0.05).

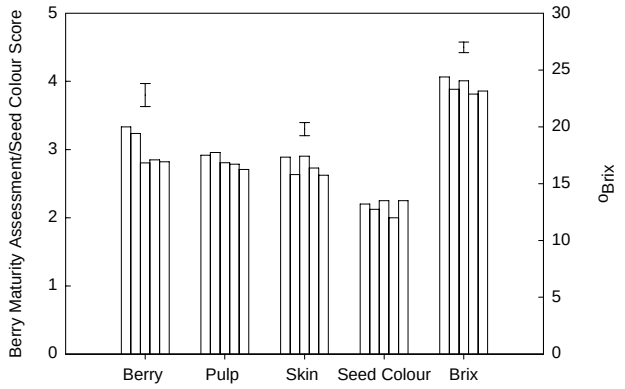


Figure 6-49 The scores for berry pulp and skin maturity assessment and seed colour and TSS °Brix at the 2005 harvest. (Bars from left to right T1 to T5, error bars LSD P= 0.05).

In 2004-05, T1 and T3 reached target °Brix range (23.4-24.3^{o}) on 2 March, 9 days before T2, T4 and T5. At harvest °Brix for T1, 24.4^{o}, was equal to that in T3, 24.0^{o}, and greater than that in T2, T5 and T4, at 23.3^{o}, 23.1^{o}, and 22.9^{o}, respectively. Low irrigation treatments (T1 and T2) had higher scores for berry maturity (Figure 6-49). Thinned treatments (T1 and T3) had higher skin maturity values than the non-thinned treatments (T2 and T5); the score in the control (T4) was equivalent to those in all other treatments. Treatment did not affect the scores for pulp maturity and seed colour.

Use of contrasts to investigate effects of thinning and irrigation amongst T1, T2, T3, and T5 showed:

- Low irrigation increased berry and pulp maturity.
- Thinning increased skin maturity score.
- Neither irrigation, nor crop thinning affected seed colour.
- Thinning the crop was associated with a higher °Brix.

6.5.4 Berry pulp and skin aroma and skin tannin

Effect of sample date

The average of the ratings from two assessors for attributes pulp fruity and herbaceous aromas, skin fruity and herbaceous aromas, skin astringency, tannic intensity and dryness (2003-04 only) are presented in Figure 6-50. In 2003-04, between the first and second sampling dates (12 and 14 February), a period for which the records for all treatments were complete, low irrigation with thinning (T1) had more advanced scores for fruity and herbaceous aromas in both pulp and skin. Scores for these four attributes were more advanced at the second sampling. Over this period neither treatment nor sampling time affected the scores for skin astringency, tannic intensity and dryness; the mean values were 2.8, 2.2 and 2.1 respectively.

For the period covering the first 4 sampling dates (12, 14, 19 and 23 February), when complete records were available for T2 through to T5, the effect of treatment on pulp fruity and herbaceous aromas, and on skin fruity aromas were dependent on sample date. On 12 February fruity aromas in low irrigation treatment (T2) were less than those in high irrigation and control treatments (T3-T5). On 19 and 23 February, low irrigation treatment (T2) had more mature fruity aromas than high irrigation and control treatments. Low irrigation (T2) had more mature pulp herbaceous aromas than the control treatment on 19 and 23 February; treatment had no effect at earlier dates. Pulp fruity aromas score in low irrigation (T2) treatment increased between 14 and 19 and again between 19 and 23 February; fruity aromas score in high irrigation and thinning (T3) increased between 14 and 19 February; the score in treatments receiving control (T4) increased between 12 and 19 February; and the score in high irrigation and no thinning (T5) did not increase over this period. Scores for pulp herbaceous aromas increased between 14 and 19 February in low and high irrigation treatments (T2, T3, T5) and between 12 and 14 February in control and high irrigation no thinning (T4 and T5). Treatment had no effect on scores for the attribute skin fruity aroma until 19 February when low irrigation no thinning (T2) had a higher score than high irrigation no thinning (T5); on 23 February T2 had a higher score than those in other treatments. Values increased between 14 and 19 February in T2 and T3, and again between 19 and 23 February in T2, and between 12 and 19 February in T4. Over these four dates the score remained equivalent in T5. Treatment did not affect scores for skin herbaceous aromas, they increased between each sampling date, nor did it affect scores for skin astringency which increased between 14 and 19 February. The high irrigation and no thinning treatment (T5) had a lower score for skin tannic intensity than the other treatments, and a lower score for skin dryness than all except the control treatment (T4). Scores for the skin tannic intensity attribute increased between 14 and 19 February; and those for the skin dryness between these 2 dates and again between 19 and 23 February.

For the period covering the entire 8 sampling dates (12, 14, 19, and 23 February, 1, 5, 10 and 15 March) when complete records were available for T3, T4 and T5, treatment did not affect skin astringency, skin tannic intensity, skin dryness and skin herbaceous aromas. Scores for pulp fruity and herbaceous aromas and skin fruity aromas in the high irrigation and thinned treatment (T3) were greater than high irrigation no-thinning treatment (T5). Values for all attributes increased at least three times during between 12 February and 15 March.

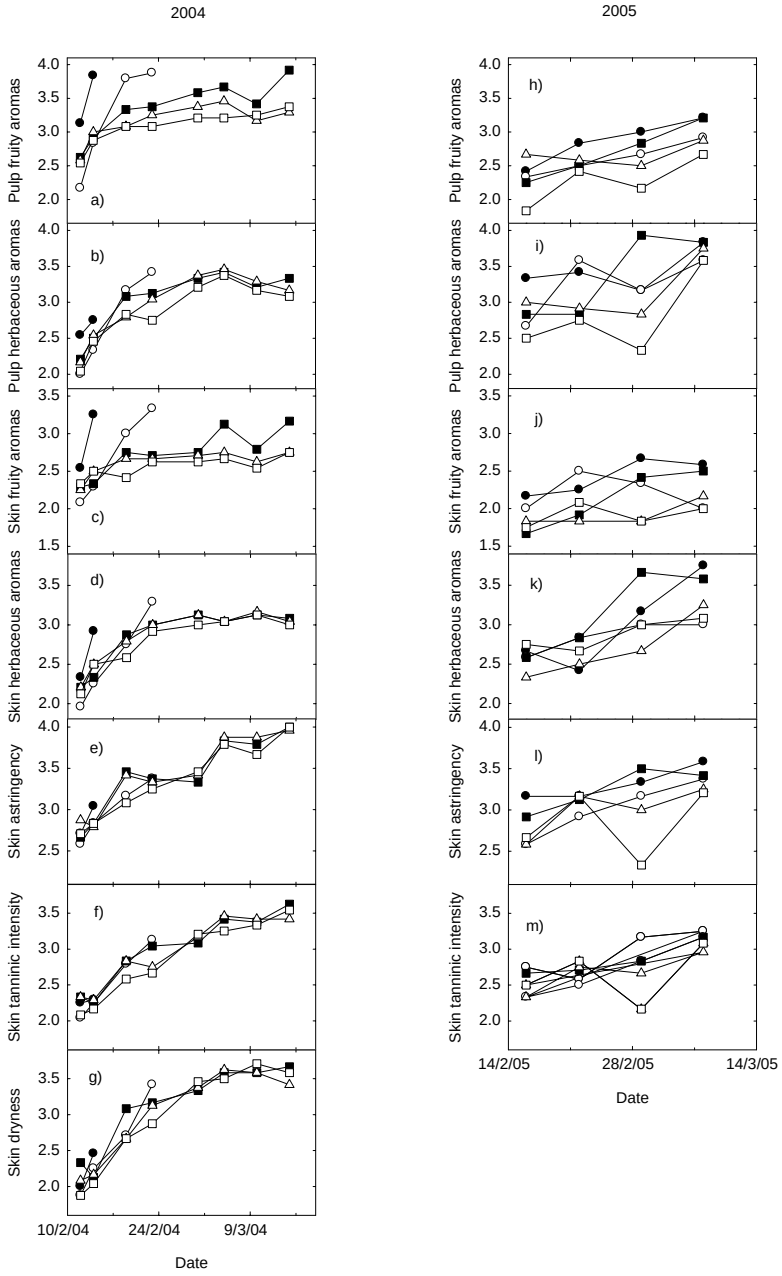


Figure 6-50 Time course of berry sensory assessment scores for pulp fruity and herbaceous aromas, skin fruity and herbaceous aromas, skin astringency, tannic intensity and dryness (2004 only) in 2004 (a-g) and 2005 (h-m). T1 ●, T2 ○, T3 ■, T4 Δ, and T5 □ .

In 2005, treatment effects were independent of sampling date. The high irrigation and non thinning treatment (T5) had a lower score for pulp fruity aromas than the other treatments. For the attributes pulp herbaceous aromas and skin fruity aromas, scores for T5 were also less than those in all other treatments excepting the control. Treatment did not affect skin tannic intensity. Skin astringency scores in the low and high irrigation treatments (T1 and T3) were greater than that in the high irrigation non thinned treatment (T5). Over the sampling period, pulp fruity aromas scores increased between 16 and 22 of February and between 1 and 8 March; pulp herbaceous aromas increased between 1 and 8 March; skin fruity aromas scores increased between 16 February and 1 March; skin herbaceous aromas increased between 22 February and 1 March; skin tannic intensity scores decreased between 1 and 8 March; skin astringency scores increased between 16 and 22 February.

Developments in high irrigation no thinning treatment (T5) berry pulp and skin aromas, and skin tannin scores between 12 February and 8 March 2004

Berry homogenates from samples collected on 10 February and 1 and 8 March were analysed by HPLC for anthocyanin and tannin concentrations (Figure 6-55). Analysis of berry sensory assessment scores for pulp fruit and herbaceous aromas and skin herbaceous aromas (analyses conducted on 12 February and 1 and 8 March) showed that their values increased between 12 February and 1 March. Scores for skin fruity aromas did not change over this period. Scores for skin tannic intensity and astringency also increased between 10 February and 1 March; those for skin dryness increased between 10 February and 1 March and again between 1 and 8 March.

Treatment effect at harvest

In 2003-04, low irrigation (T1 and T2) increased the score for pulp and skin fruity aromas (Figure 6-51). Pulp herbaceous aromas in the high irrigation and no thinning treatment (T5) were higher than in the thinned treatments (T1 and T3). In high irrigation and no thinning and the control treatments (T5 and T4) skin herbaceous aromas were equivalent to each other and to that in the low irrigation and thinned treatment (T1); scores in all these treatments were greater than that in high irrigation thinned treatment (T3). Skin dryness and tannic intensity in the non-thinned treatments (T2, T4 and T5) were greater than those in the high irrigation thinned treatment (T3). For skin astringency, the high irrigation and no thinning treatment (T5) scored highest; the score in the control treatment was greater than that in the high irrigation thinned treatment (T3). Use of contrasts to investigate effects of thinning and irrigation amongst T1, T2, T3, and T5 showed that low irrigation had higher scores for pulp and skin fruit aromas and that thinning reduced scores for pulp herbaceous aromas. With high irrigation, thinning reduced scores for skin herbaceous aromas, astringency and dryness, but did not affect these attributes under low irrigation. Thinning reduced skin tannic intensity and the effect was greater under high irrigation.

In 2004-05, analysis of variance did not identify significant treatment effects on: pulp fruity and herbaceous aromas, mean scores were 2.9 and 3.6; skin fruity and herbaceous aromas, mean scores were 2.2 and 3.2; skin astringency and tannic intensity, mean scores were 3.3 and 2.0 (data not shown). Use of contrasts to investigate effects of thinning and irrigation amongst T1, T2, T3, and T5 identified that thinning increased the skin fruity aromas score.

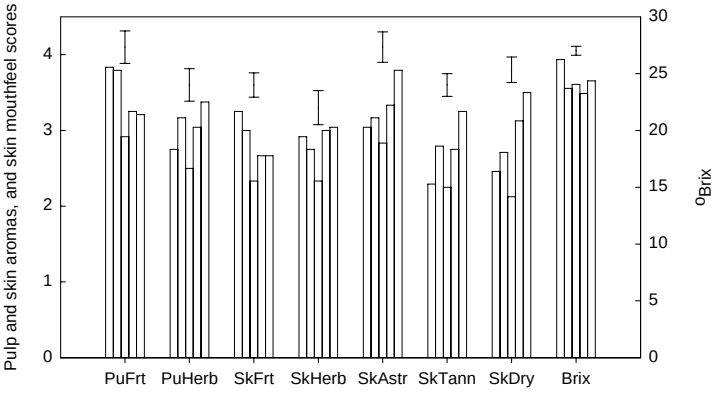


Figure 6-51The scores for berry sensory assessment scores for pulp fruity (PuFrt) and pulp herbaceous (PuHerb) aromas, skin fruity (SkFrt) and skin herbaceous (SkHerb) aromas, skin astringency (SkAstr), skin tannic (Sktann) intensity and skin dryness (SkDry), and Brix at the 2004 harvest. (Bars from left to right T1 to T5, error bars LSD P= 0.05).

6.6 Tannins in grapes and wine

6.6.1 Berry anthocyanins, tannins – effect of treatments

Chromatograms of homogenates made from berries sampled on 10 February 2004 are presented in Figure 6-52 and Figure 6-53. Thirteen anthocyanins and tannins were detected. The results from HPLC analysis of anthocyanins and tannins in berry homogenates are shown in Figure 6-54. Peonidin-3-glucoside concentration in T2 was higher that those in T3 and T5. Malvidin-3-glucoside concentration was higher in the thinned treatments, T1 and T3. T1 had the highest concentration of malvidin-acetyl-glucoside; the concentrations in T2 was higher than that in T5 but equivalent with those in T3 and T4. Concentrations of delphinidin –3-coumarate and malvidin-coumaryl-glucoside in T2 were equal with those in T1 and higher than those in T3, T4 and T5. Use of contrasts to investigate effects of thinning and irrigation amongst T1, T2, T3, and T5 showed that: reducing irrigation increased the concentrations of delphinidin-3-glucoside, cyanidin-3-glucoside, petunidin-3-glucoside, peonidin-3-glucoside, delphinidin-acetyl-glucoside, petunidin-acetyl-glucoside, malvidin-acetyl-glucoside, malvidin-coumaryl-glucoside, and tannins. Removing 30% of bunches at veraison increased malvidin-3-glucoside and malvidin-acetyl-glucoside. Under low irrigation, thinning reduced the concentrations of delphinidin –3-coumarate, petunidin-coumaryl-glucoside and peonidin-coumaryl-glucoside, whereas under high irrigation, thinning increased the concentrations.

The sum of the 13 anthocyanins was strongly positively correlated with UV/vis colour measures ($P = 0.01$). The berry homogenates were produced from samples taken on 10 February 2004, when colour in T1 and T3, 1.70 and 1.66 mg/g respectively, were much higher than those in T2, T4 and T5, 1.45, 1.40 and 1.40 mg/g, respectively. This sample was taken between 7 and 27 days prior to harvest of grapes for vinification. In between this sampling and the respective harvest dates, the UV/Vis colour concentrations in T2 and T5 rose to lie nearer those in T1 and T3 (Table 6-8).

6.6.2 Berry anthocyanins, tannins – effect of sampling time

Figure 6-55 shows for T5 berries the changes in berry anthocyanins and tannins between 10 February, 1 March and 8 March in these constituents. Between the first two dates, the °Brix increased by 0.8^{o} and berry weights remained equivalent 0.91 g to 0.88 g. Associated with these small changes were large changes in colour and even larger changes in its constituents. Colour (UV/Vis) increased by 40%, malvidin-3-glucoside by 109%, malvidin-acetyl-glucoside by 140%, and malvidin-coumaryl-glucoside by 169%. Tannins showed no change

6.6.3 Wine anthocyanins, tannins and pigmented polymers – effect of treatments

Figure 6-56 and Figure 6-57 show chromatograms of wines made in 2004. Three major anthocyanins were quantified along with pigmented polymers and tannins.

The treatment effects on the concentrations of anthocyanins, tannin and pigmented polymers in wine just after bottling in 2004 are shown in Figure 6-58. Comparison between all treatments showed that the concentration of the main anthocyanin, malvidin-3-glucoside, in wine from treatment T5 was equal to that in T4 and higher than those in T1, T2 and T3. The concentration of malvidin-acetyl-glucoside was highest in treatment T2 and least in T1 and T3. That of malvidin-coumaryl-glucoside was highest in T5 and least in T1. Treatments T1 and T2 had higher concentrations of pigmented polymers than that in T5 which in turn had higher concentrations than those in T4 and T3. Tannin

concentrations in T1, T2, and T5 were equivalent and greater than that in T4 which in turn was greater than that in T3. Use of contrasts to investigate effects of thinning and irrigation amongst T1, T2, T3, and T5 showed that: either low irrigation or thinning decreased the concentrations of malvidin-3-glucoside and malvidin-coumaryl-glucoside. The effects of thinning and irrigation on the concentrations of malvidin-acetyl-glucoside, pigmented polymers and tannins were interactive. Thinning decreased the concentration of malvidin-acetyl-glucoside and between non-thinned treatments the concentration in the low irrigation treatment was greater than that in high. Thinning under high irrigation decreased the tannin concentration. Low irrigation increased the concentration of pigmented polymers and, under high irrigation, thinning decreased pigmented polymer concentration.

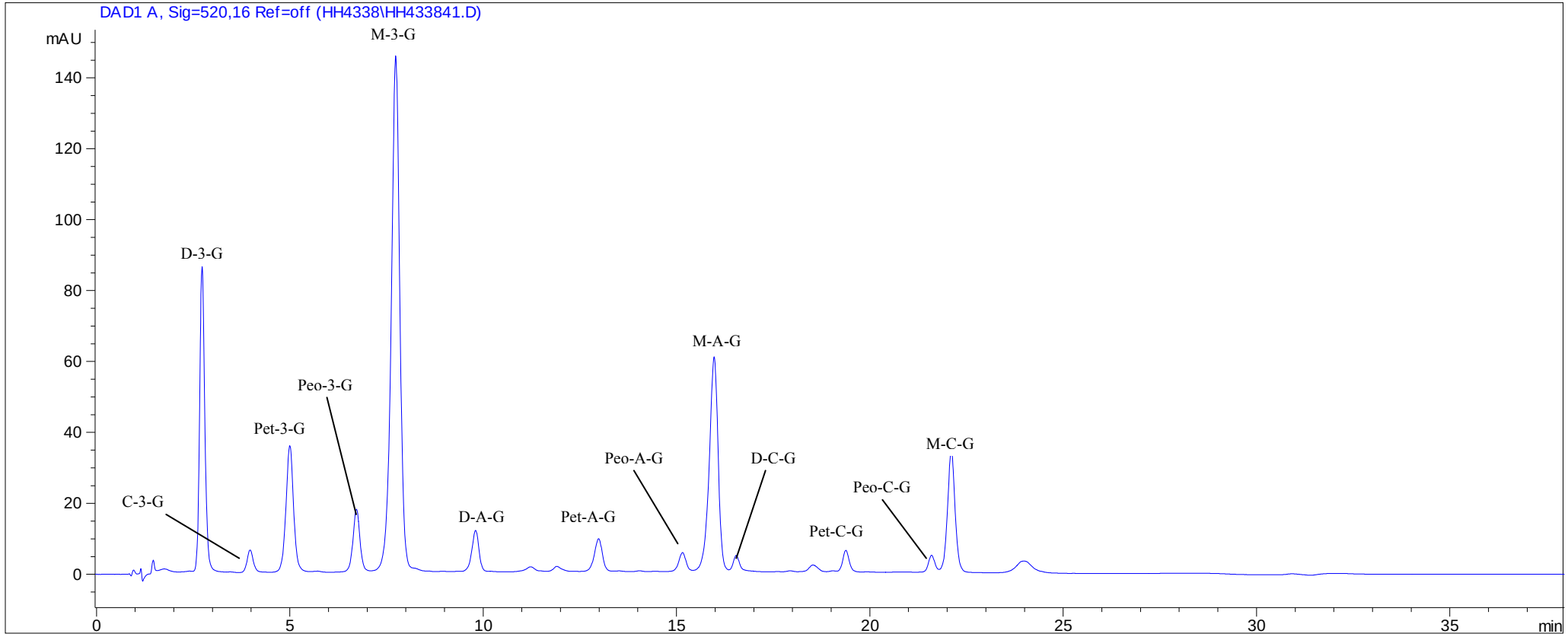


Figure 6-52 Typical chromatogram of berry homogenate, 520nm signal (anthocyanins and pigmented polymers).

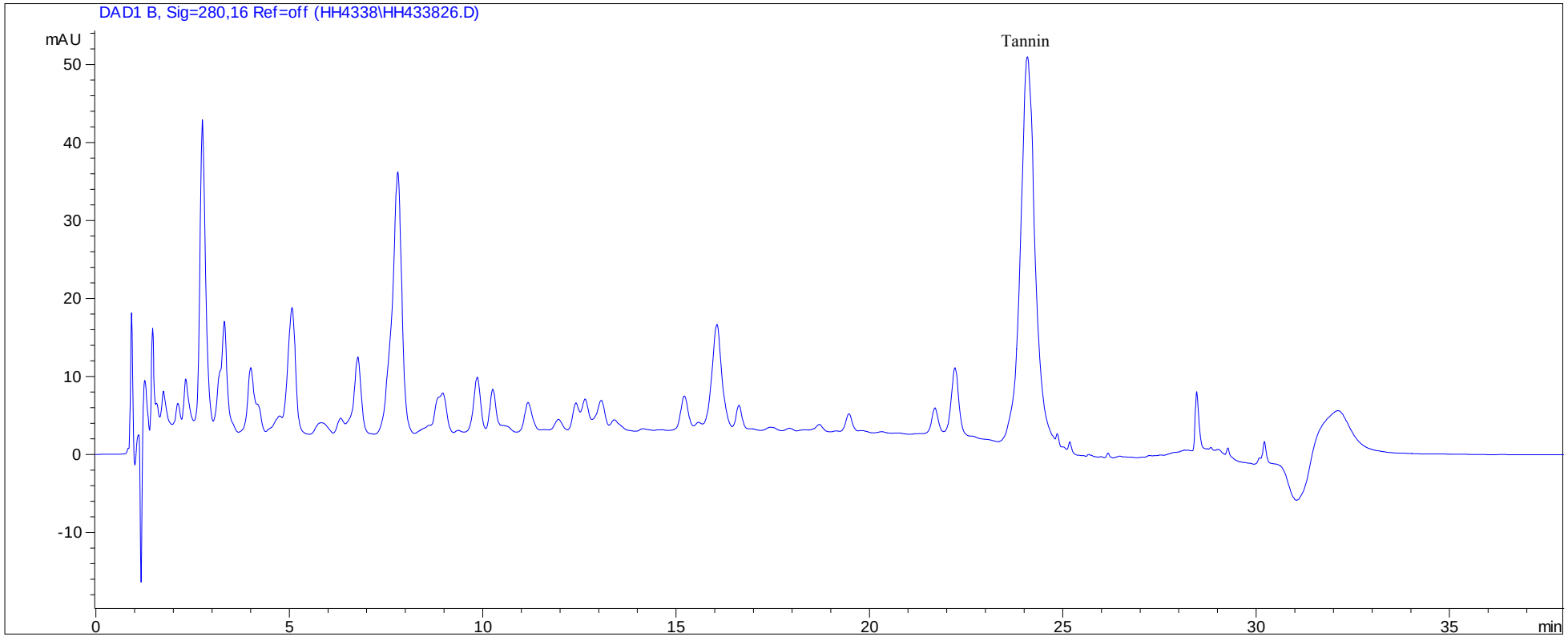


Figure 6-53 Typical chromatogram of berry homogenate, 280nm signal (tannin).

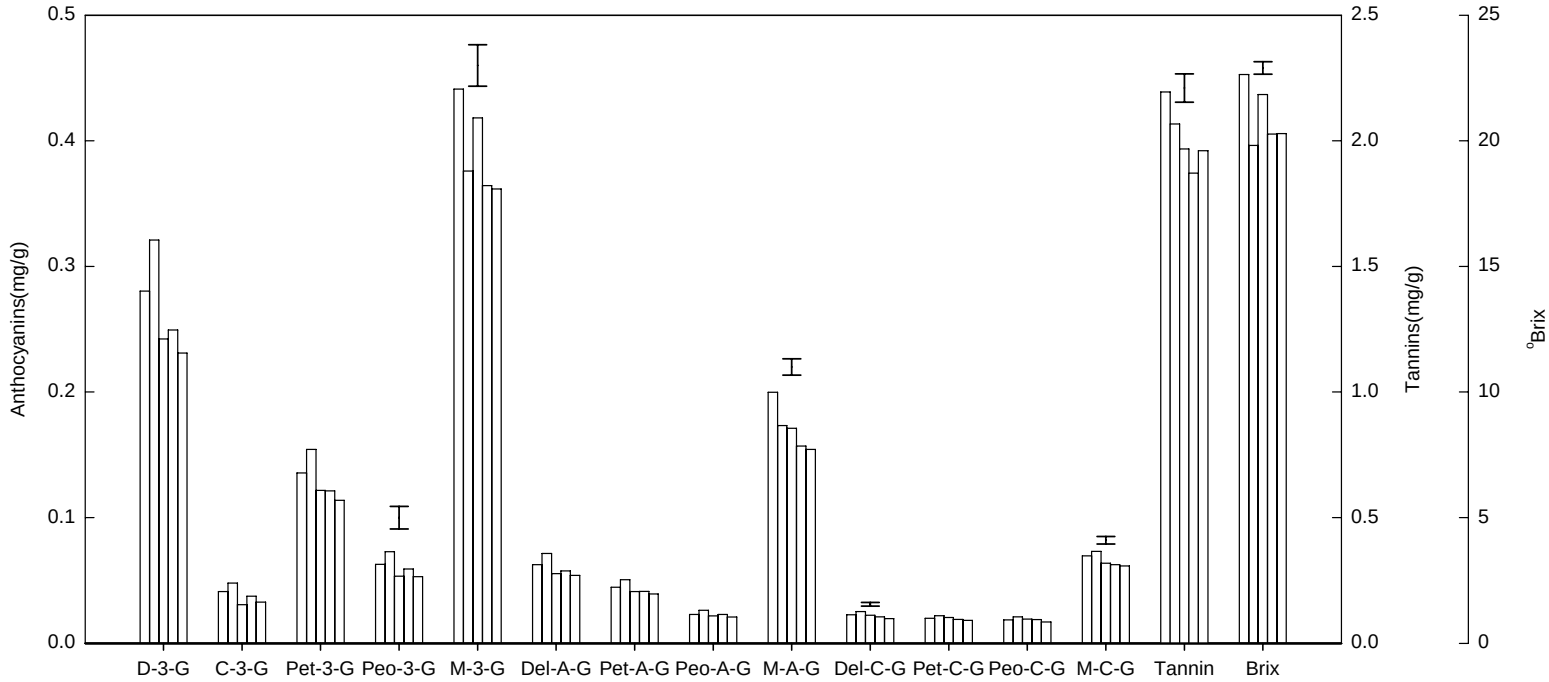


Figure 6-54 The juice °Brix, and anthocyanin concentration (mg/g, malvidin-3-glucoside equivalents), delphinidin-3-glucoside, cyanidin-3-glucoside, petunidin-3-glucoside, peonidin-3-glucoside, malvidin-3-glucoside, delphinidin-acetyl-glucoside, petunidin-acetyl-glucoside, peonidin-acetyl-glucoside, malvidin-acetyl-glucoside, delphinidin–3-coumarate, petunidin-coumaryl-glucoside, peonidin-coumaryl-glucoside, malvidin-coumaryl-glucoside, and tannins in homogenate from berries sampled 10 February 2004 (Bars from left to right T1 to T5, error bars LSD *P= 0.05*).

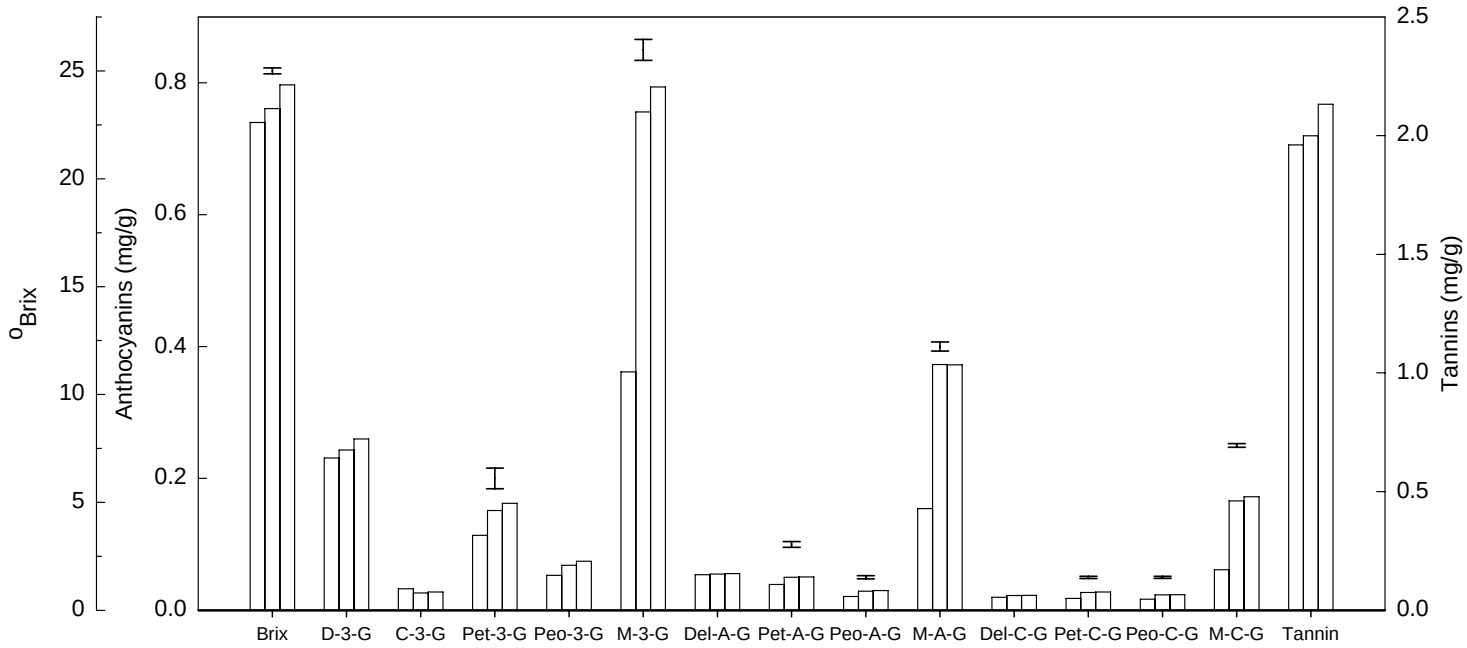


Figure 6-55 For the high irrigation and no thinning treatment (T5) the juice °Brix, and anthocyanin concentration (mg/g, malvidin-3-glucoside equivalents), delphinidin-3-glucoside, cyanidin-3-glucoside, petunidin-3-glucoside, peonidin-3-glucoside, malvidin-3-glucoside, delphinidin-acetyl-glucoside, petunidin-acetyl-glucoside, peonidin-acetyl-glucoside, malvidin-acetyl-glucoside, delphinidin–3-coumarate, petunidin-coumaryl-glucoside, peonidin-coumaryl-glucoside, malvidin-coumaryl-glucoside, and tannins (mg/g, proanthocyanidin equivalents) in homogenate from berries sampled, from left to right, on 10 February, 1 March and 8 March 2004. (Bar indicates LSD *P=0.05)*.

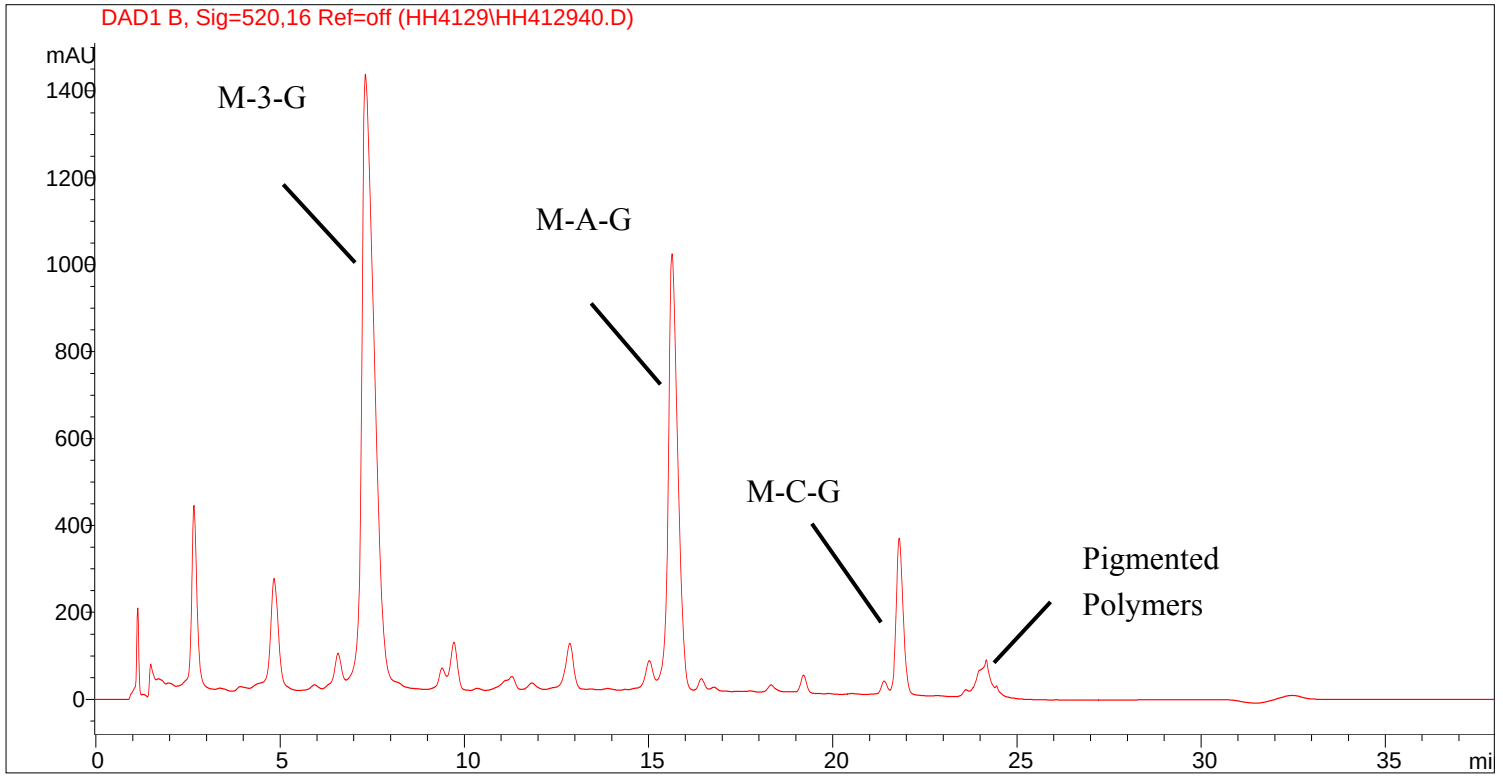


Figure 6-56 Typical chromatogram of wine, 520nm signal (anthocyanins and pigmented polymers).

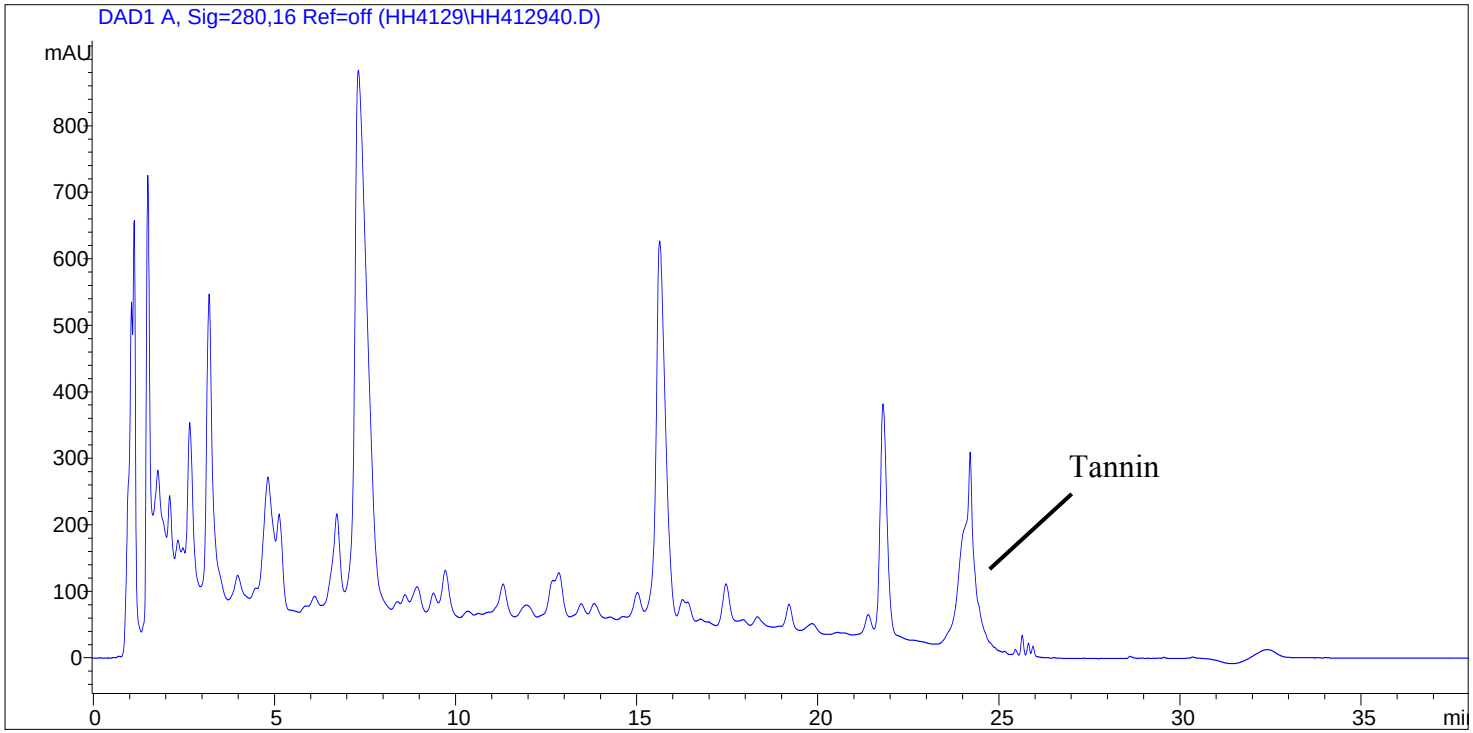


Figure 6-57 Typical chromatogram of wine, 280nm signal (tannin).

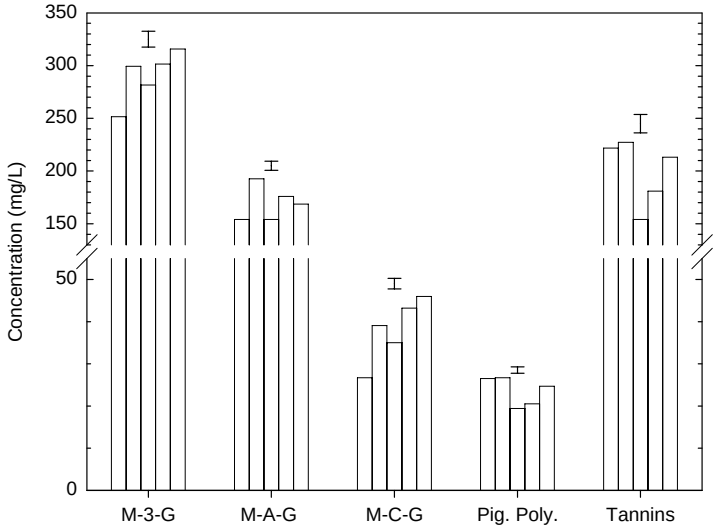


Figure 6-58 The concentrations (malvidin-3-glucoside equivalents) of malvidin-3-glucoside, malvidin-acetyl-glucoside, and malvidin-coumaryl-glucoside, tannins (proanthocyanidin equivalents) and pigmented polymers (malvidin-3-glucoside equivalents) in wine from 2004 vintage. (Bars from left to right T1 to T5, error bars LSD *P=0.05*).

6.6.4 Discussion

In 2004, organoleptic assessment of wine revealed that vines which had undergone low irrigation and crop thinning (T1) gave the most preferred wine. At 2004 harvest, T1 was at least 1.8^{o} Brix riper than other treatments and it is likely that the higher alcohol content of T1 wine resulted in a superior organoleptic assessment. Thus our assessment of treatment effects on wine quality may have been confounded by differences between treatments in the fruit °Brix at their respective harvest dates. Again during 2005 harvest, °Brix were not equivalent across the treatments with T1, being 1.4 ^{o}Brix greater than T4, and, again, it is likely that the higher °Brix led to elevated alcohol content. However, in 2005, neither differences in °Brix nor manipulation of irrigation and crop load affected the organoleptic scores. The absence of an effect of elevated °Brix on wine assessment supports a contention that treatment effects on the 2004 assessment cannot be solely attributed to differences in °Brix. It is likely that low irrigation and crop thinning in the post veraison period can in some seasons improve wine quality.

Analysis of wine in 2004 by HPLC showed that crop thinning at veraison and changing irrigation during ripening affected the concentrations of the major anthocyanins, pigmented polymers and tannins. The differences were present amongst wines which had been made from grapes harvested at identical °Brix (T2-T5). Therefore, unlike the effect seen in wine organoleptic assessment, these effects are not confounded by the harvest maturity of vinified fruit. The treatment receiving high irrigation in the absence of crop thinning (T5) had high concentrations of all major anthocyanins as did the control (T4), however, unlike the control, T5 also had high concentrations of tannins and pigmented polymers. This result supports a

contention that the grower irrigation practice (T4) was insufficient to meet vine requirements and that additional irrigation during veraison increased tannins and pigmented polymers.

Analysis of berry homogenates in 2004 by HPLC showed that the effect of irrigation and crop thinning was anthocyanin specific. Crop thinning increased the concentration of the two major anthocyanins. Reducing irrigation promoted the concentration of many of the minor anthocyanins and for some of the minor anthocyanins the effect of thinning on concentration was dependent on irrigation, with thinning reducing under low irrigation, but promoting under high irrigation. Analyses of homogenates from sequential berry samples in 2004 revealed that large changes in the concentration of major anthocyanins were not associated with large changes in °Brix. This response may be have been due to extremely hot conditions during ripening.

In both 2003-04 and 2004-05, there was a 0.5 unit difference between treatments for berry sensory assessment scores at harvest. The differences were present amongst treatments harvested at identical °Brix (T2-T5), for example compare T2 with T3 in either year. Therefore, unlike the organoleptic assessment, these effects are not confounded by the maturity of vinified fruit. Application of berry sensory assessment coincident with harvest in 2004 showed that thinning the crop reduced berry maturity and pulp maturity, thinning under high irrigation reduced skin maturity and low irrigation without thinning increased seed colour. In 2004-05, low irrigation increased berry and pulp maturity and crop thinning increased skin maturity. In 2004-05 the high irrigation treatment was 1.4-fold the control whereas in 2003-04 it was 1.1-fold the control; the low irrigation was the same in both years, 0.4-fold the control. The emergence of irrigation as the dominant factor affecting berry sensory assessment values in 2004-05 may have been due to changes in the high irrigation treatment specification.

Proponents of the use of berry sensory assessment believe that these measures will add to the information on the fruit maturation provided by measurement of TSS. Our data supports this contention with results from the 2004 and 2005 harvests showing that irrigation and crop thinning effects on the berry, pulp and skin maturity, seed colour and aroma tannin attributes were unlike those on ^{o}Brix. The larger treatment effect on scores for sensory assessment occurred in 2004. Although there were differences in the order of 0.5 between treatments in 2004, compare T3 and T5 for example, these differences did not translate through to differences in organoleptic assessment of wine quality.

With regard to the temporal course of BSA attributes, the data shows that changing irrigation and thinning at veraison can alter the relative rates at which fruit advances toward mature expression of tannin and aromas as assessed by scoring the attributes for fruity and herbaceous aromas and astringency and tannic intensity.

Berry sensory assessment on 12 February 2004, identified neither irrigation nor thinning treatments affecting scores of attributes associated with action of tannins in the mouth ie skin astringency, skin dryness and skin tannic intensity. In contrast HPLC analysis of homogenates

of berries sampled on 10 February showed that reducing irrigation increased tannin concentration. In the sequential samples of berry homogenate taken from high irrigation and no thinning treatment (T5) in 2004, analysis of tannins by HPLC showed no effect of sampling date on tannin concentration. Analysis of berry sensory assessment conducted over the same sampling period showed that sampling date had strong effects on the values of attributes associated with action of tannins in the mouth, that is skin astringency, skin dryness and skin tannic intensity. In 2004, sensory assessment of berries at times coincident with harvest identified that thinning reduced skin tannic intensity and the effect was greater under high irrigation, and that under high irrigation, thinning reduced skin astringency and dryness, but did not affect these attributes under low irrigation. These findings on the values of attributes associated with action of tannins in the mouth align with those in the HPLC analysis of wine, that under high irrigation, thinning decreased pigmented polymer and tannin concentrations. However analysis of HPLC measurements in wine also identified an effect of irrigation viz. that low irrigation increased the concentrations of pigmented polymers and tannins. No effect of low irrigation on the action of tannins in the mouth was identified in sensory analysis of fruit at harvest. There was no concordance between values of attributes associated with action of tannins in the mouth in fruit and the concentration of tannins in the associated berry homogenates, however there was some concordance between values of attributes associated with action of tannins in the mouth in harvest fruit and the concentration of tannins in the associated wine.

In berry homogenates, low irrigation increased the concentration of malvidin-acetyl-glucoside and malvidin-coumaryl-glucoside; and thinning increased the concentration of malvidin-acetyl-glucoside and malvidin-3-glucoside. In contrast, within wines, low irrigation decreased the concentrations of malvidin-coumaryl-glucoside and malvidin-3-glucoside, and thinning decreased the concentrations of malvidin-acetyl-glucoside, malvidin-coumaryl-glucoside and malvidin-3-glucoside. There was no concordance between treatment effects on malvidin-acetyl-glucoside, malvidin-3-glucoside and malvidin-coumaryl-glucoside in wine and in homogenates. Unlike the response with anthocyanins, low irrigation increased the concentration of tannins in both berry homogenates and wine.

7 Outcome/conclusions

Management strategies which could be used to overcome reported problems of Cabernet Sauvignon wine quality were investigated in a large field trial as outlined. Treatments were designed to affect the rate of ripening by either reducing carbohydrate availability during ripening through the imposition of water stress after veraison, or by increasing carbohydrate availability during ripening through reducing the crop load at veraison. These treatments were applied in a trial of factorial design which included a control treatment representing standard management practice for the vineyard.

Soil moisture monitoring showed that reducing irrigation after veraison quickly led to the development of a soil water deficit. This deficit increased vine water stress as indicated by changes in leaf water potential and photosynthetic rate, however, water deficit did not effect light interception between treatments. Visual changes to the canopy were recorded for each treatment and are provided to give indications that growers could use to determine stress levels.

The report presents the effects of reduced irrigation and crop thinning on the time course of the development of grape maturity and colour between veraison and harvest and the effects on yield and its components recorded at harvest. Thinning treatments resulted in reduced yield, and in two of the three years fruit ripened more quickly than the control treatment. Application of 43% of the irrigation applied in the vineyard standard management practice between veraison and harvest gave little or no reduction in yield, but increased berry anthocyanins (red colour) in all years. There was no significant difference in berry weight at harvest between any of the treatments in two of the three years.

Berry sensory assessment in the first two seasons of the trial found that at harvest in 2004, thinning decreased berry and pulp maturity and decreased skin maturity in the absence of irrigation cut back. Irrigation cut back advanced seed colour maturity. In 2005, irrigation cut back increased berry and pulp maturity, thinning increased skin maturity; and neither irrigation cut back nor thinning affected seed colour. In 2004, irrigation cut back increased pulp and skin fruity aromas; thinning reduced skin tannic intensity; thinning increased pulp herbaceous aromas (a lower score equates to less mature expression of this attribute) and in the absence of irrigation cut back, it increased skin herbaceous aromas and reduced skin astringency and dryness. In 2005, thinning increased the skin fruity aromas.

In 2004, berry homogenates and wines were analysed by HPLC. In homogenates, 13 anthocyanins and tannins were quantified. Individual anthocyanin concentrations responded differently to treatments. In wine three anthocyanins, pigmented polymers and tannins were quantified. Either irrigation cutback or thinning decreased the concentrations of malvidin-3-glucoside and malvidin-coumaryl-glucoside. Thinning decreased the concentration of malvidin-acetyl-glucoside while irrigation cutback increased the concentration of pigmented polymers and tannins, and, in the absence of irrigation cut back, thinning decreased pigmented polymer and tannin concentrations.

Fruit from each treatment was harvested at similar maturity and made into small lot wines for two of the years to assess wine quality. Low irrigation treatments gave higher wine colour density in both years and higher anthocyanins in one year.

Prior to this work the focus for imposing stress was the period prior to veraison (during berry formation) as is common practice for Shiraz. This work demonstrates that the imposition of water stress post veraison to harvest and crop thinning at veraison had significant effects on fruit and wine quality. The project is relevant to growers who supply wine companies which award bonuses for quality as results suggest quality can be improved without significant yield loss penalty. For these growers it may be more profitable to grow similar tonnages and aim for bonuses for higher Baume and colour. The project is particularly relevant to the situation where water restrictions have been imposed and growers need to know the effect of reducing water application post veraison.

8 Recommendations

The most important result from this project is that the application of post veraison water stress can be used in the management program of Cabernet Sauvignon vines to increase berry colour with little or no reduction in yield.

The berry sensory assessment (BSA) techniques outlined by Winter *et al* (2004) has the potential to provide viticulturists and winemakers with a common language with which they can exchange information about fruit condition at harvest. The language is much richer than that currently used to describe fruit (TSS, pH, titratable acidity and colour) and that used in this report to describe wine (colour, clarity, bouquet and palate).

Application of linear mixed modelling to data sets of berry attributes collected over ripening would probably further elucidate treatment effects.

9 Appendix 1: Communication

Publications related to the project

Nicholas, PR, Stevens, RM, Taylor EJ, Pech JM Improving the quality of Cabernet Sauvignon grown in warm and hot regions. Poster prepared for the Australian Wine Industry Technical Conference, Adelaide 28 July-2 August 2007.

Nicholas PR, Taylor EJ Research into improving Cabernet Sauvignon quality. Sunraysia Daily 10/5/06.

Sadras VO, Stevens RM, Pech J, Taylor E, Nicholas PR., McCarthy MG (2007) Anthocyanins and sugars in berries of *Vitis vinifera:* Trade-off between duration and rate of accumulation. Accepted for publication by Australian Journal of Grape and Wine Research.

Stevens RM, Jones JA, Nicholas PR, Pech JM (2005) Factors affecting Cabernet Sauvignon quality in warm to hot regions. In 'Proceeding Twelfth Australian Wine Industry Technical Conference'. Melbourne. (Eds R Blair, P Williams, S Pretorius) pp. 62-67. (Australian Wine Research Institute, Glen Osmond, South Australia).

10 Appendix 2 Riverlink workshop on Cabernet Sauvignon quality

Proceedings of Riverlink workshop on Cabernet Sauvignon quality held at CSIRO Merbein 29 July 2003

Industry perspective - what are the problems with Cabernet Sauvignon from warm-hot climates?

David Thompson

Production Manager, McGuigan Simeon Wines Ltd

McGuigan Simeon's Buronga Hill winery crushes approximately 12,000 tonnes of Cabernet Sauvignon each year. This is our second largest red intake after Shiraz.

Over the last three vintages the variety has come into an oversupply situation. Due to a difficult 2001 vintage, Cabernet has become more difficult to sell. The competing varieties, Shiraz and Merlot, are more generous in flavour, and more readily accepted by wine buyers.

Cabernet has generally shown poorer colour and some greener weedy flavours. With a cooler year in 2002, and a year of generally low crops in 2003, we have seen an increase in wine quality, which has subsequently led to an improvement in saleability of Cabernet wine.

Quality improvements are also due to improved irrigation management and canopy management. Winemakers are also pushed to use more winemaking adjuncts to develop a product which is commercially acceptable.

With improved wine quality the task of selling the product is becoming easier, however it is crucial that we continue to improve in order to regain market share for this variety.

Warm climate Cabernet Sauvignon studies

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Average yields of Cabernet Sauvignon across Sunraysia and the Riverland increased significantly over the past 30 years (ie from 6-10 t/ha in the 1970's to 13-17 t/ha in recent years). This response can be attributed to the combined effects from adoption of larger trellises, improved clones, high vigour rootstocks, lighter hand and mechanical pruning and improved water management. Wine companies report that Cabernet Sauvignon grown in warm regions gives inconsistent wine quality from season to season and from grower to grower. CSIRO studies, involving production of small-scale wine lots have addressed various production and quality issues with warm climate Cabernet Sauvignon over the past 30 years. In general these studies showed that yields could be increased by adoption of large trellises, close row spacings, lighter hand or mechanical pruning and improved clones without negative impacts on wine attributes. By contrast, high yields with high vigour rootstocks (eg. Ramsey) compared to own rooted vines were associated with negative effects on fruit and final wine quality, eg high pH, low colour and phenolics and dull, 'browner', less stable wines.

Long-term, seasonal trends were studied for own-rooted, spur pruned vines growing at Merbein over the period, 1988-2001. Over the seasons, there was a wide range (ra.) in all harvest, juice and wine parameters (see below). Significant correlations ($r>0.5$) with time identified increases over the seasons in yield (ra. 5.7-17.8 kg vine^{-1}), bunch weight (ra. 66-206 g), juice pH (ra. 2.96-3.78) and wine hue (ra. 0.35-0.86) and decreases in wine titratable acidity (ra. 5.3-8.3 g L^{-1}), colour density (ra. 2.0-13.0 a.u.), ionised anthocyanins (ra.19-160 mg L^{-1}), total anthocyanins (ra. 237-583 mgL^{-1}) and total phenolics (ra. 22-51 a.u.). Correlations between time and harvest date (ra. 25th Feb.- 17th March), berry weight (ra. 0.91-1.26 g) and sugar level (ra. 23.4-25.1 ^{0}Brix) were not significant. Further significant correlations showed that the negative wine spectral attributes were linked to the development of high yields, large bunches with large berries and high juice pH. These changes appear to be consequences of changes in management practices that reduced vine stress (ie conversion from flood to undervine sprinkler irrigation and adoption of non-cultivation practices).

Differences in fruit composition and wine quality between growers were investigated by analysis of commercial data sets and in more detailed research studies across sites. The commercial analyses showed that there was no relationship between grower yield (ra. 9.0-50.0 t ha^{-1}) and berry anthocyanins (ra. 0.3-1.3 mg g^{-1}) over three years, 1997-1999. Low yielding vineyards often had low levels of berry anthocyanins. There was however a significant (R^2 = 0.67) negative curvilinear relationship between anthocyanins and berry weight (ra. 0.8-1.3 g). Berry weights below 1.0 g produced the highest anthocyanins. The research studies were conducted across ten grower sites with a range in harvest dates from 14th March- 2nd April and yields from 19.0-39.3 t ha^{-1}. Similar negative curvilinear relationships were found between berry anthocyanins (ra. 0.8-1.6 mg g^{-1}) and bunch weight (ra. 48.5-66.9 g, R^2 = 0.62) and berry anthocyanins and berry weight (ra. 0.58-0.92 g, R^2 = 0.44). Late maturing vineyards had low yield and low berry anthocyanins. Significant correlations indicated that negative wine quality attributes were related to harvest parameters (ie. titratable acidity correlated negatively with yield and bunch number; pH correlated positively with bunch and berry weight and negatively with bunch number; hue correlated positively with yield; colour density correlated negatively with yield and bunch number; ionised anthocyanins correlated negatively with yield and bunch weight; % ionised anthocyanins correlated negatively with bunch weight and berry weight and

positively with bunch number; total anthocyanins and total phenolics correlated negatively with yield and bunch number and sensory score correlated negatively with bunch weight).

Effects of within vineyard yield variability on juice composition and wine quality have also been studied. For example, in one vineyard a five-fold difference in yield between vines (ra. 5-22 kg vine^{-1}) had little effect on fruit maturity but produced significant differences in berry anthocyanins (ra. 0.8-0.2.4 mg g^{-1}) that were negatively correlated with yield ($R^2 = 0.53$) and berry weight ($R^2 = 0.29$). These results have important implications where mean yield values are used to assess vineyard performance and fruit quality. In the example, the 33% of the vines that were high yielding (ie >16 kg vine^{-1}) produced 47% of the total crop. By contrast, 35% of the vines with low yields (<10 kg vine^{-1}) produced 20% of the total crop. Fruit from low vigour, low yielding vines compared to high yielding vines in the same vineyard produced wines with enhanced quality attributes (ie lower pH, higher titratable acidity, higher colours and phenolics and higher sensory scores).

Early studies with mechanical pruning were underpinned by detailed hand pruning studies with varying bud numbers. In one such study over three seasons (1979-1981) the length of the fruiting unit on own rooted vines varied from 2-bud spurs to 14-bud canes, giving retained node numbers from 48- 336 nodes per vine. Yields increased asymptotically with increasing node numbers (ie from 12 - 20 t ha^{-1}) in response to lower budburst (ie from 1.24 to 0.61 shoots node^{-1}) and the development of smaller bunches (ie from 80.4 to 42.3 g). This was accompanied by a significant decrease in pruning weight from 2.0 to 0.5 kg vine^{-1}. There were minimal effects on wine quality. In more recent studies, hand spur pruning was compared to mechanical hedging (severe and light) and minimal pruning. Compared to hand pruning, lighter pruning treatments had higher yields (ie.16.5 cf. 18.0, 20.0, 23.5 t ha^{-1} respectively), more bunches (70 cf. 150,190, 270 respectively), smaller bunches (65 cf. 38, 30, 25 g respectively) and smaller berries (1.0 cf. 0.85, 0.85, 0.75 g respectively). Berries from hand spur pruning had the lowest levels of anthocyanins when compared to the mechanical pruning treatments at similar levels of maturity.

The combined effects of rootstock (own roots and Ramsey) and pruning system (cane and minimal) on vine performance, juice and wine quality were studied over a number of seasons across three clones. In general there were very few significant interactions between rootstock and pruning effects across the measured parameters. In response to higher yields there were significant reductions in maturity of fruit from Ramsey vines compared to own roots (ie 23.2 cf. 24.5 ^{0}Brix) and minimal pruning compared to cane pruning (ie 23.1 cf. 24.6 ^{0}Brix) without significant effects on pH. Fruit from Ramsey vines had higher titratable acidity. Compared to own roots, all spectral properties of wines from Ramsey rootstock were lower even after adjustment for maturity differences were removed using sugar as a covariate. By contrast negative spectral attributes associated with delayed ripening of minimal pruning compared to cane pruning were reversed when adjusted for fruit maturity giving higher colour density (28%), ionised anthocyanins (54%) and phenolics (14%). These results indicate that lighter pruning systems, that reduce shoot growth, bunch and berry size enhance wine quality and reduce the negative effects associated with adoption of high vigour rootstocks provided that adequate ripening levels are achieved.

Fruit was harvested from different parts of the canopy of minimal pruned vines grafted on Ramsey to study position and exposure effects on juice and wine quality parameters. The locations were high and low outer exposed fruit, high and low shaded inner fruit. Fruit from the high-outer position had the highest sugar level (25.2 ^{0}Brix) while fruit from the low-inner position had the lowest sugar level (23.3 ^{0}Brix). Fruit from the high-inner and low-outer positions had similar maturities of 24.2 ^{0}Brix. Juice pH was unaffected by position although the high-outer fruit had significantly lower acid levels than the other positions (ie. 6.2 cf. 6.8 g L^{-1}).

Wines from the high-outer position had enhanced spectral properties (ie. high colour density, total and ionised anthocyanins and phenolics) than from the other positions. This indicates that fruit exposure and maturity are keys to high colour development in Cabernet Sauvignon wines.

In a separate study shade-cloth was used to evaluate whole plant shading responses and effects on fruit composition and wine quality across two pruning systems (cane and minimal) and three clones. Compared to the standard treatment, fruit from the shaded vines had higher sugar levels (21.4 cf. 20.6), similar pH values (3.26) and higher titratable acid (6.75 cf. 6.15 g L^{-1}). The standard treatment had significantly higher ionised anthocyanins but there were no significant differences in total anthocyanins, phenolics or colour density.

In summary it can be concluded that the quality of Cabernet Sauvignon from warm climates can be related to achieving high levels of maturity, site and grower management practices, in particular vigour management to produce smaller vines which result in the development of small, exposed bunches with small berries rather than to yield per se.

Scoping study into problems with Cabernet Sauvignon quality in warm and hot climates

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This talk reports on findings made in a scoping study into problems with Cabernet Sauvignon quality in warm and hot climates. The issue was identified at a Riverlink workshop in July 2001. At the workshop, vignerons related how management strategies which reliably improved Shiraz quality were not improving Cabernet Sauvignon quality. The scoping study investigation was based on: conducting interviews with vineyard managers, industry technical staff and winemakers; analysing research on Cabernet Sauvignon production which had had limited distribution or was at a pre-publication stage; undertaking a small field trial; analysing large industry data sets containing descriptors of source vineyards and grape or wine quality. This presentation focuses on two questions. What, if any, are the differences between Shiraz and Cabernet Sauvignon? In the large data sets on Cabernet sauvignon collected by wineries, what are the relationships between measures of fruit quality and other variables?

To investigate the differences between Shiraz and Cabernet Sauvignon I used three unpublished data sets. The first was a set of sequential berry samples taken in 2002 from Shiraz and Cabernet Sauvignon vineyards located near Kingston–on-Murray. During the latter stages of ripening, Shiraz grapes increased berry weight and colour per berry (mg/berry) until Brix reached 19^{o}; increases in the concentration of anthocyanins during further ripening to 25^{o} Brix were associated with berry shrinkage and not with increases in the anthocyanins per berry. In contrast, during ripening of the Cabernet Sauvignon (18 to 25^{o} Brix) there was no change in berry weight and increases in the concentration of anthocyanins were associated with increases in the anthocyanins per berry. During the latter stages of ripening, increases in the concentration of anthocyanins in Cabernet Sauvignon were associated with a gain in the amount of anthocyanins per berry, whereas in Shiraz increases in the concentration were associated with loss of berry weight.

Data collected over 3 seasons (1997-99) from four rootstock trials in the Riverland, two with Shiraz and two with Cabernet Sauvignon were used to investigate the relationships between colour, Brix and yield components. Colour (concentration) was strongly positively correlated with Brix with the correlation in Cabernet Sauvignon being higher than in Shiraz. In Cabernet Sauvignon, colour was strongly negatively correlated with berry size, weakly correlated with berries per cluster and clusters per vine, but only poorly correlated with yield. In contrast, with Shiraz there was no correlation between colour and berry weight, poor correlations with berries per cluster and clusters per vine and a strong negative correlation with yield.

In 2002-03 season, I imposed two irrigation treatments on a large Cabernet Sauvignon rootstock trial located near Kingston-on-Murray. They were full irrigation and a sustained deficit applying 70% of full irrigation. A similar trial had commenced three seasons previously on a Shiraz rootstock trial which was located three rows away from the Cabernet Sauvignon trial. The 70% irrigation treatment reduced the size of Cabernet Sauvignon berries by 18%, but did not affect the colour (mg/g) or Brix. In contrast, in the first season of the 70% irrigation treatment on Shiraz vines, the berry size was reduced by 18%, colour increased by 15% even though Brix was reduced by 3%. Excepting scion, the trial vines were identical with regard to age, rootstocks mix, soils and culture.

Data on yield, Brix and juice anthocyanin concentration was obtained from two unpublished rootstock trials conducted in Riverland over three years by P Nicholas (SARDI). The rootstocks under investigation were 101-14, 140 Ruggeri, 99 Richter, J17-48, J17-69, K51-40,

Ramsey and 5C Teleki. In one of the trials, J17-69 returned the highest colour, just greater than the levels in 140 Ruggeri and 5C Teleki, which had higher colour than the remaining rootstocks; in this trial the yield of the three rootstocks with higher juice colour was equivalent. In the other trial the anthocyanin concentration in juice from scions on J17-69, 101-14, 140 Ruggeri, and 5C Teleki were equivalent, however the yield of J17-69 was 20% below that of the other 3 rootstocks which had equivalent yields. J17-69 has subsequently been shown to have poor salt exclusion tolerance. Of the rootstocks investigated, 140 Ruggeri and 5C Teleki showed the most promise to produce medium-high yields of fruit with medium colour.

Often during the scoping study I found that when vignerons discussed management of Cabernet Sauvignon they were talking in more generic terms of managing red wine grapes and in warm climates most of the knowledge in this field has been gleaned from studies on Shiraz.

Five wineries provided large data sets for Cabernet Sauvignon intakes in the 2001 and 2002 season in Riverland, Sunraysia and Griffith. The sets contain descriptors of static vineyard properties, for example rootstock and trellis; of vineyard management, for example shoot tip growth and disease status; and product quality, for example colour and Baume. Each entry represented a patch of vines. Often one grower had submitted grapes from more than one patch.

In addition, for each of the 3 regions, we obtained data sets containing sugar analysis of grower-grape samples taken at regular intervals over the month(s) preceding harvest. For each region and for each season, we developed relationships describing ripening as a function of the number of days after January 1. These relationships were used to set a date that each patch attained a ripeness of 13.5 ^{o} Be.

The variable of most interest, quality, was scored either as a continuous variate, juice colour reading, or as categorical variate, a product end-use (bottle or cask destination of vinified grapes). Most of the observations of quality based on product end-use fell into two of a possible six classes. This extreme skewing was also typical of the categorical variables relating to vineyard management. For example, with variables recording disease assessment often all observations fell into one category. The skewing and, where present, the collapse of range prevented univariate (or multivariate) analysis from uncovering information about the interdependence between continuous and categorical variates, or between categorical variates.

In data sets from the Murrumbidgee Irrigation Area quality assessment was based solely on the final product of vinification. In data sets from the Sunraysia and Riverland areas, quality was assessed on juice colour. Grapes for colour analysis were sourced either from in-vineyard sampling conducted by winery staff or directly from load during delivery. Colour was analysed by either wet chemistry or Near Infra Red Spectroscopy.

The relationships between colour, Baume, yield and sample date were analysed in ten data sets collected in either 2001 or 2002. In six of these sets colour was negatively correlated with the sample date expressed as the number of days after 1 January and in one set it was positively correlated (this was a small set collected from a single company vineyard of 19 patches). There was a positive correlation between colour and grape Baume in five of these sets. Colour was negatively correlated with yield in two of these sets. In four of the data sets, fruit exposure was scored in deciles between 0 and 100%, these scores were expressed as continuous data and in two of the sets colour was positively correlated with fruit exposure.

In summary, data from unpublished studies supports a contention that Shiraz and Cabernet Sauvignon have different physiological processes responsible for colour gain in late ripening, have different responses to water stress, have different relationships between colour and yield and yield components. Data also supports a contention that for Cabernet Sauvignon the rootstocks 140 Ruggeri and 5C Teleki showed the most promise to produce medium-high yields of fruit with medium colour. For the Riverland and Sunraysia, analysis of fruit deliveries to wineries in 2001 and 2002 showed that there was strong support for the contentions that colour was negatively correlated with the number of days that elapsed between January 1 and the date of sampling, and that colour was positively correlated with the Baume of the sample. There was weaker support for the contentions that colour was negatively correlated with yield and positively correlated with fruit exposure.

Integrated strategies to manage seasonal variation in wine grape maturation

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In recent years several wine grape producing areas of Australia have experienced problems with grapes not attaining required sugar concentrations within reasonable time frames. Fruit was often low in acid with high pH. Combinations of heat stress and water stress are believed to compound the slowdown in maturation. This project was set up to research the interaction of water stress, using regulated deficit irrigation (RDI) and a prolonged deficit (PD), with weather conditions and crop load, and their impacts on fruit maturation.

Three irrigation treatments have been set up in a Wingara Wine group Vineyard at Nangiloc, Victoria. Irrigation treatments were established in a 7 year-old, drip irrigated Cabernet Sauvignon vineyard, planted on own roots. The trial tests the hypothesis that stress associated with commercial RDI practices and a PD could alter fruit maturation. Treatments applied over the 2002/2003 season were:-

1. Control: vines watered with double the amount of water of the standard RDI treatment during the treatment period
2. RDI: standard commercial RDI applied from 21st November for 3 weeks
3. PD: standard commercial RDI applied from 21st November for three weeks. A further period with a second stress was given between 24th and 31st December

Standard irrigation regimes were implemented when treatments were complete.

The PD treatment took approximately two weeks to recover to normal photosynthetic rates after the return to a standard irrigation regime. Veraison was also delayed in this treatment. Weather conditions during the post PD period were normal, but there is the possibility that more severe weather conditions during this time could significantly delay the recovery process. Grape berry anthocyanin concentration was enhanced by the PD treatment due to reduced berry size.

These data were the first from the three year trial. Measurements will continue in the subsequent season and will include an assessment of the carbohydrate status of the different parts of the vine and how this may relate to vine recovery after RDI. It will also provide an opportunity to assess the impact of weather conditions in the pre and post RDI period across the three seasons.

Spectral Analysis of commercially graded red wines

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Samples of young, warm climate red wines were scanned by visible and near infrared transmission spectroscopy (400 to 2500 nm). Distinct variations could be seen in both spectral regions. Using these scans, chemometric calibrations for wine quality grade were prepared, using a five point commercial quality rating as reference data. Examination of the spectral loadings for the wine quality calibration revealed the importance of the visible region of the spectrum. The Somers colour density and hue values were calculated using the absorbance at 420 and 520 nm. Wine colour density had a strong positive correlation with wine quality and hue had a weaker negative correlation. Full Somers analyses were performed on the wines and ANOVA, linear regression, tree analysis and multiple regression all showed that colour density was the most important factor. Stable colour in wines is due to 'pigments polymers' – reaction products of anthocyanins and tannins. The importance of grape tannin profiles as well as anthocyanins was discussed.

Using mechanical thinning to improve maturity and anthocyanin content of Cabernet Sauvignon in a warm climate

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Mechanical thinning offers the potential to regulate yield to a target post flowering and improve fruit composition. Techniques used for crop forecasting were modified to describe the spatial distribution of fruit in the canopy and estimate yield. Specific zones of the canopy were targeted for thinning to remove a percentage of the fruit and avoid over thinning.

An experiment was established to investigate the effects of crop removal from Cabernet Sauvignon using a mechanical vine harvester, applied when the berries were small pea size. Responses were compared with control (un-thinned) vines and with hand thinned vines, on which fruit was removed from a similar portion of the canopy as the mechanical thinning treatment. The hand thinning treatment allowed separation of the benefits of reduced crop load from the potential damage caused by the mechanical harvester to the foliage and the remaining fruit.

All the thinning treatments reduced bunch number and yield and advanced fruit maturity (soluble solids accumulation). Berry weight was also increased by hand thinning. Anthocyanin concentration was higher in fruit from the mechanically thinned vines compared to the control (un-thinned). High anthocyanin concentrations are generally related to improved wine quality. Hand thinning did not improve anthocyanin concentration compared to the control. The larger berries on the hand thinned vines had a greater pulp to skin ratio. This may have diluted the anthocyanin concentration in the berries from the hand thinned vines, as most anthocyanins are located in the berry skin.

Mechanical thinning can be easily incorporated into management practices in the warm inland grape growing regions of Australia in seasons when yields are forecast to be above optimum.

Bunchstem and berry development in Cabernet Sauvignon and Merlot

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The Australian wine industry demands consistent supply of high quality fruit for wine making, therefore grape quality and its variability are seen as a high priority. Bunch development, structure and size, colour development, ripening rate and asynchronous ripening are critical issues.

It is not well understood how early bunchstem development (flowering to veraison) impacts on berry ripening and grape composition. Carbohydrate levels in the wood may affect bunchstem development. The levels of carbohydrate reserves in the wood correlate with bud fruitfulness of the winter bud. Fertilisation and flower number reflect on bunchstem and berry development. Differences in fruit set affect the variability of berry size and number. The structure and properties of the bunchstem influence the supply of minerals and carbohydrates to the berry through the vascular bundles (xylem, phloem) during development. This becomes particularly important during berry ripening. The rate of berry ripening and berry composition might be influenced by the bunchstem during the early stages of development.

Berry and bunch disorders have been related to nutritional imbalance or disrupted carbohydrates supply. Fruit set is affected by sugar (inflorescence necrosis), Zn (coulure) and B (millerandage). Bunchstem necrosis is affected by Ca, Mg, N and sugar. K and N supply affects juice pH and berry colour, N affects the mixture of nitrogenous compounds important for fermentation. The effect of other nutrients on berry composition is unknown. The variety Merlot often shows poor and uneven fruit set whereas Cabernet Sauvignon is prone to bunchstem necrosis.

Bunchstems contain the berry's vascular transport system supplying nutrients and sugar. Bunchstem development could have a large impact on grape maturation and quality. This study will contribute to the understanding of physiological processes and morphological changes involved in the development of the bunchstem in relation to berry maturation and composition.

Preliminary results show that the bunchstem length and diameter increases significantly from bloom to veraison in the two varieties, with only minor changes during berry ripening. Further, they indicate that a strong correlation between bunchstem diameter and length of the bunchstem exists. Merlot shows more variation in bunchstem length than Cabernet Sauvignon, although the range of bunch weights and berries per bunch is similar in both varieties. Grapes from small bunches in Merlot have larger berries, less TSS and colour, in contrast to Cabernet Sauvignon, were bunch size appear not to alter these berry parameters. The variation in colour is greater between Cabernet Sauvignon bunches and greater for TSS between Merlot bunches, the results also suggest that the variability in colour/TSS is not just dependent on bunch size. These findings indicate that there is a range in bunchstem morphology and anatomy during development in both varieties. Further work will be undertaken to study the structure of the bunchstem vascular system during inflorescence/bunch development. In addition, the phloem and xylem composition to the berry will be studied and its effects on berry sugar and mineral accumulation. The influence of berry set on bunch size, bunchstem development and structure as well as berry quality will also be examined.

Main points which emerged in discussion which was facilitated by DeAnn Glenn from GWRDC

Key problems with Cabernet Sauvignon quality

- Undesirable flavour characteristics – described as 'green, weedy tobacco', 'green bean', 'stalky, green bunch stem' and astringent.
- Insufficient fruit flavours.
- Insufficient colour and colour stability over 6-8 months post-vinification.

Key viticultural practices identified by the workshop that we know affect Cabernet Sauvignon quality

- Quality is enhanced by growing a balanced vine with an effective ratio of crop load to leaf area.
- Early season vigour control through water restrictions in spring sets up a balanced vine.
- A reduction in irrigation in Shiraz pre-veraison achieves a different response than in Cabernet (preliminary results from trials on Cabernet showed that severe heat/moisture stress immediately prior to veraison caused damage to vines, resulting in poor vine function ie transpiration, photosynthesis for weeks following the stress period, resulting in small increases in Brix and loss of colour).
- Light to minimal mechanical pruning (with vigour managed by water and nutrient regime) seems to avoid problems caused by hard spur pruning such as large berries.
- Small bunches and small berries (not too small – pulp/skin/seed ratio) are associated with higher quality.
- Large berries tend to have less desirable acid and colour characteristics.
- High yields tend to have lower colour, although quality and crop load are not always directly associated.
- The correlation between colour and berry weight is stronger than colour and overall yield.
- There is a stronger correlation between Brix and colour in Cabernet Sauvignon, than in Shiraz and Merlot
- Reduced nitrogen application is associated with reduced vigour – depending on water regime.
- There have been no consistent associations between particular clones or rootstocks and improved quality.

The workshop identified the things we don't know about viticulture practices on Cabernet Sauvignon quality

- What are the effects of a reduction in irrigation post-veraison on colour development and tannin ripeness in Cabernet Sauvignon?
- Is the RDI window for Cabernet Sauvignon different than for Shiraz?
- Why is berry shrinkage in Cabernet Sauvignon and Shiraz different? Increase in berry size stops earlier with Shiraz.
- Why does the association between low yields and improved quality seem to be stronger with Shiraz than Cabernet Sauvignon?
- Why does colour stability in Cabernet Sauvignon wines vary from year to year?
- Does exposure of leaves or bunches lead to improved maturation? (Trials have shown that shaded leaves had higher photosynthesis, but more exposed canopies achieved improved berry colour).
- Is colour stability in wines associated with high pH, berry size or tannin ripeness? (High pH in juice has resulted in lower anthocyanins and phenolics).
- Are the problems of Cabernet Sauvignon due to harvest of fruit before it has reached physiological ripeness?
- Why is there a stronger correlation between Brix and colour in Cabernet Sauvignon, than in Shiraz and Merlot?

11 Appendix 3: Intellectual property

There was no patentable intellectual property arising from the project.

12 Appendix 4: References

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13 Appendix 5: Staff

Staff involved

Phil Nicholas, Rob Stevens, Emily Taylor and Joanne Pech – South Australian Research and Development Institute, Loxton Research Centre

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Other contributers

- SARDI – Chris Soar
- BiometricsSA – Janine Jones
- AWRI – Markus Herderich and Helen Holt (HPLC analysis of berry homogenate and wine)
- McGuigan Simeon Coldridge vineyard – Phil Goodes, Steve Rollins, Mark Leuth and Brenton Linke
- McGuigan Simeon laboratory – Simon Odell, Brenton Porter and Sue Salmon
- GWRDC – DeAnn Glenn
- Patrick Iland Wine promotions – Patrick Iland
- SARDI assistance with the trial – Nicki Ormond, Andrew Biele, Ian Lange, Brenton Mann, Sandra Tullett and Tina MacKintosh
- CSIRO & Provisor Merbein – Chad Farrell and Peter Clingeleffer
- Western Electronic Design – Mike Western
- PIRSA ACML – Vesna Cook and Jason Young
- PIRSA ICMS – Dennis Sparrow, Jahangir Alam
- Soil survey advice – Ken Wetherby
- DWLBC – Barry Porter

14 Appendix 6: Budget reconciliation