Project title: The effect of irrigation scheduling on vine growth, grape composition, wine composition and wine flavour intensity for cv. Shiraz

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The effect of irrigation scheduling on vine growth, grape composition, wine composition and wine flavour intensity for cv. Shiraz

Summary

Introduction

In 1991 an irrigation experiment was established on Vitis vinifera cv. Shiraz in a mature vineyard in the Waikerie region of South Australia, a region characterised by dry to hot summers. The experiment was set up by Dr Michael McCarthy of SARDI and formed the basis for two GWRDC funded projects which investigated the effects of irrigation scheduling on vine growth, berry composition and wine sensory properties. The experiment was conducted over four growing seasons (1991-95).

The randomised complete block experiment included a treatment in which no water stress occurred (fully irrigated) (Trt 1), an unirrigated treatment (rainfall only) (Trt 8), and six other treatments irrigated as in the fully irrigated treatment apart from specific periods without irrigation. Four of these six treatments had periods of about four weeks duration where irrigation water was withheld:- after anthesis (Trt 2), before veraison (Trt 3), after veraison (Trt 4) or before harvest (Trt 5). In the other two treatments vines received no irrigation water for either the entire period between anthesis and veraison (Trt 6) or for the entire period between veraison and harvest (Trt 7). At the end of each period where irrigation water was withheld, sufficient irrigation water was applied to refill the top 1.2 metres of soil to a predetermined full point.

Objectives

In this project the objectives were:

1) to determine the effects of three of the irrigation treatments (fully irrigated, post- veraison deficit and unirrigated) on vine growth characteristics and berry composition for the four years of the trial.
2) to assess if measures of berry composition, and particularly the new measure of glycosyl glucose (G-G), could act as predictors of wine composition and wine sensory properties.
3) to determine which of the eight irrigation treatments resulted in wines with the most intense flavour. These sensory evaluation studies were conducted in the last two years of the trial.

Results

The significant findings were:

Vine growth characteristics and berry compositional studies

a) The measures of berry total G-G and colour were more consistent in showing differences between treatments than the measure of red-free G-G, and are therefore regarded as being the more useful G-G measures to assess berry composition.
b) The responses in berry composition due to the three different irrigation treatments varied between the four years, therefore it was not possible to indicate one treatment which would consistently perform better than any of the other two.

However, based on comparisons made on berries sampled within a narrow juice oBrix range at harvest and on pairs of treatments where juice oBrix was not significantly different at harvest in any one year, the concentration of total G-G and colour in berries of the unirrigated and post-veraison deficit treatments were generally higher than those of the fully irrigated treatment. On average the berry colour (on a concentration basis) of the fully irrigated, post-veraison deficit and unirrigated treatments were 1.09, 1.27 and 1.24 mg/g berry weight.

The improvement in berry composition caused by restricting irrigation for one month after veraison was associated with a small increase in canopy openness and a small decrease in berry size compared to the fully irrigated treatment in most years of the trial, and with more efficient leaf photosynthesis compared to the unirrigated treatment in the last two years of the trial. In years 1 and 2 when natural rainfall was sufficient to maintain vine function, the yields and berry composition of the unirrigated treatment were similar to that of the post-veraison deficit treatment. In the last year of the trial, the unirrigated treatment had severe effects on vine growth and yield, vines being water stressed and low yielding, 5kg/vine compared to 12 and 11 kg/vine for the fully irrigated and post-veraison deficit treatments respectively.

Sensory evaluation studies

a) In the sensory evaluation studies where G-G measures were taken on berries from each of the eight irrigation treatments prior to small-lot winemaking and where sensory assessment of wine flavour intensity was conducted on wines made from the separate lots of fruit, measures of berry total G-G and colour both acted as good predictors of wine flavour intensity. An increase in these components in berries (on a concentration basis) was associated with a higher perception of wine flavour intensity. Berry total G-G and colour measures were more satisfactory in predicting wine composition and wine sensory properties than berry red-free G-G measures. It is important to appreciate that any conclusions are only valid for this viticultural region and for the range of values investigated, eg for values of berry colour from 1.4 to 1.6 mg/g berry weight in 1994 and 0.9 to 1.3 mg/g berry weight in 1995. Further studies are required to test relationships for other viticultural regions and years and for other varieties.

b) As there were no consistent significant differences in the perception of wine flavour in wines of the eight different irrigation treatments over the two years in which sensory assessment was conducted, it was not possible to identify which irrigation treatment would produce grapes leading to wines with the highest flavour intensity. Also, differences in maturity of the fruit at harvest have confounded the interpretation of the sensory results. Often higher scoring wines were associated with higher oBrix fruit. However, comparing wines made from grapes with a narrow range of maturities (23.4 to 25.7 oBrix in 1994 and 24.3 to 25.1oBrix in 1995), the results indicated that wines from the fully irrigated treatment were always in the lower group of berry G-G and wine flavour intensity values and in one year were significantly lower than five of the other treatments. Wines from the vines with water deficits during the post-anthesis, post-veraison and veraison to harvest treatments were always in the higher group of berry G-G and wine flavour intensity.

Conclusion

The fully irrigated treatment resulted in vines producing grapes of lower concentration of total G-G and colour and wines of lower flavour intensity than vines where deficit irrigation schedules had been applied.

Section 1 — The effect of irrigation scheduling on vine growth and grape composition for cv. Shiraz

1.1 Introduction

In 1991 an irrigation experiment was established on Vitis vinifera cv. Shiraz in a mature vineyard in the Waikerie region of South Australia, a region characterised by dry to hot summers. The experiment was set up by Dr Michael McCarthy of SARDI and formed the basis for two GWRDC funded projects which investigated the effects of irrigation scheduling on vine growth, berry composition and wine sensory properties. The experiment was conducted over four growing seasons (1991-95).

The randomised complete block experiment included a treatment in which no water stress occurred (fully irrigated) (Trt 1), an unirrigated treatment (rainfall only) (Trt 8), and six other treatments irrigated as in the fully irrigated treatment apart from specific periods without irrigation. Four of these six treatments had periods of about four weeks duration where irrigation water was withheld:- after anthesis (Trt 2), before veraison (Trt 3), after veraison (Trt 4) or before harvest (Trt 5). In the other two treatments vines received no irrigation water for either the entire period between anthesis and veraison (Trt 6) or for the entire period between veraison and harvest (Trt 7). At the end of each period where irrigation water was withheld, sufficient irrigation water was applied to refill the top 1.2 metres of soil to a predetermined full point.

The objective of this trial was to determine the effects of three of the irrigation treatments (fully irrigated (IRR), post-veraison deficit (DEF) and unirrigated (DRY)) on vine growth characteristics and berry composition for the four years of the trial.

Measures of yield, canopy architecture, leaf area to fruit weight ratio, fruit weight to pruning weight, leaf photosynthetic activity and indices of vine balance were taken to help explain the effects of the different irrigation treatments on vine growth and berry composition. Since berry composition varies with maturity, for example measured as oBrix, an aim of this study was to compare berry composition within a narrow juice oBrix range.

1.2 Materials and methods

1.2.1 Site selection/soils/irrigation design

The experiment was part of a large irrigation trial (McCarthy 1997). The trial included eight treatments (seven different irrigation schedulings and an unirrigated); for the present study three of these treatments were used, as detailed in 1.2.3. The experimental site was located at Sunlands (Lat. 34o 08’ S, Long. 139o 52’E) near Waikerie, South Australia. The environment is described as hot, with mean January temperature in the range 23 to 24.9 oC, growing season evaporation of about 1300 mm and an aridity index of about 510 mm.

The experimental site was within a 30 ha block of Vitis vinifera cv. Shiraz as part of a commercial vineyard of about 400 ha. The vines in this block were spaced 2 m apart in rows 4 m wide, planted on own-roots in an east-west direction in 1969 and trained to a horizontally divided canopy 1 m wide. The planting had been irrigated with over-canopy impact sprinklers since

establishment. Irrigation, pest and disease control, soil management and fertiliser applications were done according to local accepted practice. The choice of the site was guided by information from a soil survey done in 1986, three years before establishing the irrigation experiment. This survey classified soil texture, some soil physical characters, potential rootzone depth, estimated soil water holding capacity and the presence of any water table. The criteria used in selecting the experimental site were that there was no water table within 2 m of the soil surface and that the site was of uniform soil texture of at least 2 m depth and elevated to minimise frost incidence.

During the winter before laying out the experiment the position of all vines within the area was mapped to ensure there were no missing vines in each plot. Vines appeared to be reasonably uniform.

The experiment was conducted over the 1991/92, 1992/93, 1993/94 and 1994/95 seasons; for convenience these are referred to as years 1, 2, 3 and 4 respectively. In years 1, 2 and 3, vines were spur-pruned to 60 two-bud spurs while for year 4, 50 two-bud spurs were retained at pruning. The vine canopies of all treatments were allowed to grow naturally in each season and no shoot removal or trimming was carried out.

1.2.2 Experimental design

Three treatments (two irrigated and an unirrigated), replicated nine times, were selected from the randomised block design. Each treatment plot was a rectangle comprising five vines in each of three adjacent rows. All data collection was from the middle vine of the three vines of the centre row of each plot. The other vines were barriers. The complete experimental area was 210 metres long and 60 metres wide. Each plot was irrigated with Plastro Tornado Ray-jet full circle under-canopy sprinklers (68 L per hour) placed mid-way between adjacent vines. Irrigation water was supplied to each plot via polythene irrigation pipe (19, 25 or 32 mm diameter depending on plot location) laid on the surface on either side of the vine trunk line and connected to a buried pipe manifold (each 50 mm diameter) at one end of the vine rows. Water meters measured the volume of water applied to all nine plots in each of the two treatments that were irrigated. Water application was controlled by a solar-powered irrigation controller and water supply pressure by a single pressure regulator.

1.2.3 Experimental treatments

The two irrigated treatments selected were (1) fully irrigated (IRR) — vines were irrigated between bud-burst and harvest at each stage when 30 mm soil water depletion occurred in 1.2 m soil depth, and (2) post veraison deficit (DEF) — the same scheduling as for (1) but no irrigation applied for approximately one month after veraison. The unirrigated treatment (DRY) received no irrigation during the growing period from budburst to harvest. The treatments were begun in spring 1991 and continued over four growing seasons until harvest 1995. In some seasons the duration of treatments was influenced by rainfall, especially during year 2. At the end of the stress period for DEF vines sufficient irrigation water was applied to refill the top 1.2 m soil to the pre-determined full point. Anthesis was defined as 50 percent cap-fall and veraison the first appearance of red colour in berries.

1.2.4 Experimental details for measurement of vine characteristics

The following measures were taken on the middle vine of each of the three vine replicate plots for each treatment. Measures of bunch exposure, leaf layer number and leaf area were taken

within the week prior to harvest. Yield and pruning weights were taken at harvest and at pruning, respectively. Leaf area to fruit weight ratio (LA/FW) and fruit weight to pruning weight ratio (FW/PW) were calculated from respective measures.

Bunch exposure and leaf layer number indices: A modified point quadrat technique, based on that of Smart and Robinson (1991), was used to determine percentage bunch exposure and leaf layer number. In this modified method for determining bunch exposure, the rod is positioned at a bunch at an angle of 45o and the number of leaves in front of each bunch recorded. Both sides of the canopy were assessed. At least 15 measures were taken per vine. The number of bunches with none or one leaf in front of it, was divided by the total number of measures to give percentage bunch exposure.

The modified measure of leaf layer number was determined by positioning the rod at a leaf and then moving the rod into the centre of the canopy while recording the number of leaves that the rod contacted. The rod was inserted at various positions along an imagined arc over the canopy — horizontally at the bottom of the arc, at 45o on both sides of the canopy and vertically at the top. The average number of leaf contacts per insertion was then calculated to give an index of leaf layer number. In year 4 bunch exposure was also determined by the use of a ceptometer. The ceptometer (Decagon Devices Inc., Cambridge, England) is a device with a probe lined with 80 light sensors which record the flux density of incoming radiation in the 400 to 700 nm wavelength band. The ceptometer was aligned horizontally in the direction of the vine row in the fruiting zone on both sides of the canopy. Light measures for ten insertions per vine were recorded and averaged.

Leaf area measure: Templates of leaf shapes representing the range of leaf sizes present in the canopies of the treatment vines were constructed by collecting leaves of different sizes and tracing each onto graph paper. The area of each leaf was then calculated. These leaf shapes were used to match and record the area of all intact leaves on at least 20 shoots of varying lengths. Addition of the area of all the leaves on each shoot gave a total leaf area per shoot. The shoot length for each shoot, on which leaf area was determined, was also recorded. A relationship was established between the length of the shoot and its leaf area. After pruning, the length of each shoot of each vine was measured and its leaf area calculated from the established relationship. Total leaf area per vine was calculated by addition of the leaf areas of individual shoots.

Photosynthetic activity measures: These were determined using a portable photosynthesis measuring system (Li-6200, Li-Cor, Lincoln, Nebraska, USA). The terminal part of the main lobe of a mature leaf was inserted into a 1.0 L chamber, which was positioned normal to the sun, and measures of photosynthetic activity recorded. Measurements were conducted during cloudless periods on exposed leaves with a flow rate of 500 to 600 mmol/s.

Yield per vine: At harvest the number of bunches per vine was counted as they were picked and the total weight of fruit per vine measured and recorded to the nearest 0.1 kg.
Pruning weight per vine: The weight of prunings removed from each test vine in each plot was recorded.

1.2.5 Fruit sampling and sample preparation

A random 100-berry sample was collected from the middle vine of each replicate at a maturity stage as close as possible to 24 ± 0.5 oBrix. Each sample was used for determination of

berry mass, total G-G, anthocyanin-glucose and red-free G-G and juice oBrix, pH and titratable acidity as described below.

Each 100-berry sample was divided randomly into two 50-berry samples. One 50-berry lot was placed in a labelled screw-top plastic container and frozen for later analysis of G-G by the modified G-G assay. The other 50-berry lot was weighed and then crushed. The juice from each sample was clarified by centrifugation at 1500 g for five minutes. Ten mL of supernatant were pipetted off to determine pH and titratable acidity. Juice pH was measured using a glass electrode and titratable acidity (g/L tartaric acid) by automatic end-point titration to pH 8.2 using 0.1 M sodium hydroxide (Iland et al. 2000) The pH meter was calibrated daily against pH 4.01 and pH 7.00 buffer standard solutions and the laboratory was maintained at about 20 oC air temperature. Total soluble solids concentration of the juice was measured using a constant temperature Atago (TM) Abbe refractometer standardised using 20 oC distilled water. Soluble solids concentration was expressed as oBrix at 20 oC (Iland et al. 2000).

1.2.6 Statistical analysis

The data are treated as arising from 27 individual vines, being nine replicates of three irrigation treatments in a random field assignment. Since each experimental unit (each vine) was measured on four occasions (each year) a repeated measures approach for analysis was carried out. This approach is similar to a split-plot design where the treatments are allocated at random to vines (whole-plots) and time (year) corresponds to the sub-plots. It was therefore necessary to test whether a correlation structure existed in the (vine.year) stratum and whether a correction factor applied to the degrees of freedom in this stratum was required. In order to test whether there was a significant correlation structure between the years, Box's test for symmetry was calculated. The correction factor is known as the Greenhouse-Geiser estimate, e (Crowder and Hand 1990). After correction, if necessary, the means for each measurement were compared by Analysis of Variance (AOV) to determine if there were differences between treatments within years or between treatments across years. Significant differences were determined at the $p<0.05$ level.

1.3 Results

1.3.1 Vine characteristics

There were significant irrigation treatment effects on bunch exposure across all years (Table 1.1). Bunch exposure index (measured as the percentage of bunches with none or only one leaf in front of the bunch) was significantly higher in DRY than DEF, which was significantly higher than that of IRR (Table 1.1).

Table 1.1 Comparison of bunch exposure index (%) for the IRR, DEF and DRY treatments across all years. Each number is the mean of the treatment response across all years. Means followed by different letters are significantly different ($p<0.05$).

Treatment	Bunch exposure index(%)
IRR	52.8a
DEF	60.2b
DRY	82.2c

Measures of light conditions within the canopy at the bunch zone were taken with a ceptometer in years 3 and 4. The ceptometer measures, expressed as absolute amounts (photosynthetic photon flux density (PPFD) units) and as a percentage of ambient PPFD were as

follows: year 3 — IRR 218 and 11%, DEF 350 and 18% and DRY 650 and 33% respectively; and year 4 — IRR 350 and 19%, DEF 574 and 31% and DRY 902 and 48%. Ceptometer measures were positively correlated with bunch exposure index (Figure 1.1).

Figure 1.1 The relationship between bunch exposure index by the modified point quadrat and of incident light determined by the use of a ceptometer positioned in the canopy at the bunch zone. Individual points represent measures on individual vine replicates for all treatments in years 3 and 4, taken either one or two weeks prior to harvest.

The practical advantage of such a relationship is, that if a ceptometer is not available, then a good estimation of light conditions within a canopy can be obtained by the modified point quadrat technique. This gives confidence to the bunch exposure data used in years 1 and 2 when the ceptometer was not available. It should be noted that the established relationship only applies to the types of canopies that contributed to the values, however similar relationships could be established for varying canopy types. In year 4, ceptometer measures were taken at fruit set, veraison and one week prior to harvest. At each stage the value for DRY was significantly higher ($p<0.05$) than that for DEF, which was significantly higher ($p<0.05$) than IRR (Figure 1.2).

Figure 1.2 Comparison of ceptometer measures for IRR (n), DEF (q) and DRY (q) vines at fruit set, veraison and harvest during year 4. Vertical lines indicate the standard error of the mean for each treatment.

Leaf layer numbers of IRR and DEF vines were not significantly different from each other but both were significantly higher ($p<0.05$) than that of DRY in all years (Figure 1.3).

Figure 1.3 Interaction plot for leaf layer number of the IRR (- l -), DEF (- D -) and DRY (- m -) treatments during the four years of the trial. Each point represents the mean of the nine replicates. Points followed by different letters are significantly different ($p<0.05$) within years.

In years 3 and 4, net photosynthesis (Pn) of leaves of the DRY vines were significantly lower compared to those of the DEF and IRR vines (Table 1.2).

Table 1.2 Net photosynthesis (Pn) for the IRR, DEF and DRY vines in years 3 and 4. Each number is the mean of three replicates. Measures were taken approximately one week prior to harvest. Means followed by different letters are significantly different ($p<0.05$).

Treatment	Pn	
	Year 3	Year 4
IRR	8.25a	8.67a
DEF	7.50a	9.36a
DRY	4.33b	5.41b

There was no significant difference in LA/FW between treatments in any year. However, there were significant differences between years (Table 1.3). Values were lowest in year 3 and highest in year 4.

Table 1.3 Comparison of leaf area to fruit weight (LA/FW) ratio for the IRR, DEF and DRY treatments across all years. Each number is the mean of the treatment response across all years. Means followed by different letters are significantly different ($p<0.05$).

Year	LA/FW ratio (cm2/g)
1	5.02a
2	5.82b
3	4.13c
4	6.69d

There was no significant difference in FW/PW between treatments in any year. However, there were significant differences between years (Table 1.4), values being lowest in year 1 and highest in year 3.

Table 1.4 Comparison of fruit weight to pruning weight (FW/PW) ratio for the IRR, DEF and DRY treatments across all years. Each number is the mean of the treatment response across all years. Means followed by different letters are significantly different ($p<0.05$).

Year	FW/PW ratio
1	9.03a
2	10.19a
3	16.08c
4	12.92b

Yield per vine of all three treatments was similar in the first two years, but thereafter it diverged. In year 3, the yield of IRR was significantly higher ($p<0.05$) than the other two treatments, while in year 4, the yield of DRY was significantly lower ($p<0.05$) than that of the other two treatments (Figure 1.4). Part of the reason for lower yields for DRY vines in year 4 was due to the fact that the mean mass per berry of this treatment was approximately 60% of that of the other treatments.

Figure 1.4 Interaction plot for yield per vine of the IRR (- l -), DEF (- D -) and DRY (- m -) treatments during the four years of the trial. Each point represents the mean of the nine replicates. Points followed by different letters are significantly different ($p<0.05$) within years.

In all years mass per berry of DRY was significantly lower ($p<0.05$) than that of the other two treatments (Figure 1.5). There was a major decline in mass per berry of DRY in year 4.

Figure 1.5 Interaction plot for berry mass of the IRR (- l -), DEF (- D -) and DRY (- m -) treatments during the four years of the trial. Each point represents the mean of the nine replicates. Points followed by different letters are significantly different ($p<0.05$) within years.

1.3.2 Criteria used for comparing berry compositional data

In this trial, an aim was to sample berries from each treatment replicate within a targeted juice oBrix range of 24 ± 0.5. Observation of the juice oBrix values in Figure 1.6 indicate that this aim was largely attained; across the four years of the trial, nine of the twelve means fell within 23.3 to 24.3 oBrix and eleven of the twelve means fell within 23.1 to 24.3 oBrix. To further evaluate differences between treatments, compositional data was also compared for pairs of treatments where juice oBrix of sampled berries were not significantly different ($p<0.05$) (see Table 1.5).

1.3.3 Comparison of berry composition

A summary of the comparison of berry composition is given below.

Juice oBrix: The selected range in which the compositional data was evaluated was 23.1 to 24.3 juice oBrix, which excluded DRY in year 1. For the comparisons of pairs of treatments (Table 1.5), there was no significant difference ($p<0.05$) in juice oBrix for DEF and IRR in years 1 and 4, DRY and DEF in years 2 and 4, and DRY and IRR in years 2 and 3.

Juice pH: Juice pH was high in years 2 and 4, with DEF being significantly higher than the other two treatments in two of the four (years Years 3 and 4) (Figure 1.7). In year 4, DRY had significantly higher juice pH than the other two treatments (Figure 1.7). When compared as pairs not differing in juice oBrix, on both occasions (years 1 and 4), juice pH of DEF was significantly higher than IRR (Table 1.5a, Figure 1.7). There were no consistent differences between DRY and DEF or DRY and IRR (Figure 1.7).

Juice titratable acidity: Juice titratable acidity was high in years 1 and 3 (Figure 1.8). When compared as pairs not differing in juice oBrix, on both occasions (years 1 and 4), juice titratable acidity of DEF was significantly lower than IRR (Table 1.5e, Figure 1.8). There were no consistent differences between DRY and DEF or DRY and IRR (Table 1.5e, Figure 1.8).

Total G-G, anthocyanin-glucose and red-free G-G per berry (content): The shape of the graph of total G-G per berry was almost identical with that of anthocyanin-glucose (Figure 1.9a, b). Both show a tendency for higher levels in year 3 compared with the other years, and in years 2 and 4, DEF was higher than DRY and IRR and in year 1, DEF was higher than IRR (Figure 1.9a, b). When compared as pairs not differing in juice oBrix, on both occasions (years 1 and 4) and (years 2 and 4), total G-G and anthocyanin-glucose per berry of DEF were higher than IRR or DRY, respectively (Table 1.5b, c, Figures 1.9a, b). There were no consistent differences in total G-G and anthocyanin-glucose per berry between DRY and IRR (Table 1.5b, c, Figures 1.9a, b). There were no consistent differences between treatments for red-free G-G per berry (Table 1.5d, Figure 1.9c).

Berry total G-G, anthocyanin-glucose and red-free G-G per g berry mass (concentration): As with content per berry the shapes of the graphs of total G-G and anthocyanin-glucose concentration of berries were almost identical (Figure 1.9d, e). In all years, concentrations of DEF tended to be higher than those of IRR and in 3 of the 4 years DRY was higher than IRR (Figure 1.9d, e). The concentrations of red-free G-G were similar in years 1 and 2, but by year 3 showed differences (DRY > DEF > IRR) (Figure 1.9f). When compared as pairs of treatments not differing in juice oBrix, on both occasions (years 1 and 4), total G-G and anthocyanin-glucose concentration of DEF were higher than IRR (Table 1.5f, g, Figure 1.9d, e). On one occasion (year 2) DRY was higher than IRR. There was no consistent differences between treatments for red-free G-G concentration (Table 1.5h, Figure 1.9f).

Figure 1.6 Interaction plot for juice oBrix of the IRR (- l -), DEF (- D -) and DRY (- m -) treatments during the four years of the trial. Each point represents the mean of the nine replicates. Points followed by different letters are significantly different ($p<0.05$) within years.

Figure 1.7 Interaction plot for juice pH of the IRR (- l -), DEF (- D -) and DRY (- m -) treatments during the four years of the trial. Each point represents the mean of the nine replicates. Points followed by different letters are significantly different ($p<0.05$) within years.

Figure 1.8 Interaction plot for juice titratable acidity of the IRR (- l -), DEF (- D -) and DRY (- m -) treatments during the four years of the trial. Each point represents the mean of the nine replicates. Points followed by different letters are significantly different ($p<0.05$) within years.

Figure 1.9 Interaction plots for (a) total G-G per berry, (b) anthocyanin-glucose per berry, (c) red-free G-G per berry, (d) total G-G per g berry mass, (e) anthocyanin-glucose per g berry mass and (f) red-free G-G per g berry mass of the IRR (- l -), DEF (- D -) and DRY (- m -) treatments during the four years of the trial. Each point represents the mean of the nine replicates. Points followed by different letters are significantly different ($p<0.05$) within years.

Table 1.5 Significance of difference in eight variables (juice pH, juice titratable acidity, total G-G per berry, anthocyanin-glucose per berry, red-free G-G per berry, total G-G per g berry mass, anthocyanin-glucose per g berry mass and red-free G-G per g berry mass) within pairs of treatments selected with similar juice oBrix values. * indicates that the value is significantly higher ($p<0.05$) than the other value of the pair on the same row. No * means that the two values at not significantly different.

1.4 Discussion

1.4.1 Criteria for comparing compositional data

Sampling berries at a stage where the juice oBrix of berries of the different treatments are the same can be difficult, particularly for trials in hot climates where, over only a few days, effects of berry shrivel can lead to a concentration of total soluble solids and thus higher juice oBrix. In this trial, despite constant monitoring of juice oBrix of berries of the different treatments, some differences in juice oBrix of sampled berries did occur. Because of this, two approaches were used to compare the compositional data. The first approach compared data within a range of mean juice oBrix of 23.1 to 24.3, and to support this, a second approach compared data within years between pairs of treatments which did not differ significantly in juice oBrix. Overall, results from both approaches were similar.

1.4.2 Effects of no irrigation (DRY) for 4 years on vine growth and berry composition

The effect of no irrigation for four years on vines of the DRY treatment indicated a slow but steady re-adjustment of the vines to their new regime. In the last two years, canopies were open, and when compared with vines of the other treatments had a lower leaf layer number and more bunches exposed to ambient light (Table 1.1, Figure 1.3). Additionally, berry size and yield of the DRY treatment were generally lower than in the other treatments, particularly in year 4 (Figures 1.5, 1.4). In the last two years of the trial, DRY vines showed signs of water stress, and had lower values for net photosynthesis (Table 1.2) and had shorter shoots with wilting leaves (McCarthy 1997) compared to the other treatments.

In the selected range of juice oBrix, in the last two years, total G-G and anthocyanin-glucose per berry were significantly lower in berries of the DRY treatment compared to those of the other treatments, suggesting that vine stress was adversely affecting the accumulation of G-G components in berries of these vines (Figure 1.9a, b). Comparison of DEF and DRY as pairs supported this finding in year 4 (Table 1.5b, c). However the concentrating effect, due to smaller berry size of the DRY berries, resulted in total G-G and anthocyanin-glucose concentration of berries of the DRY treatment being either higher or similar to that of berries of the other treatments (Figure 1.9d, e). Other studies (Bravdo et al. 1985, Hepner et al. 1985, Matthews et al. 1990) have shown similar responses: — where cut-back of irrigation, normally pre-veraison, compared to continuous irrigation throughout the growing season, resulted in berries of the cut-back treatments being smaller and having higher concentration of berry colour and phenolics and/or wines of higher wine colour density and total phenolics.

Lower levels of anthocyanin-glucose in DRY berries may be associated with high levels of berry exposure of this treatment, the exposure index being, on average, 82% compared to 60% for DEF and 53% for IRR (Table 1.1). Enzymes involved in the anthocyanin biosynthetic pathway show maximum activity within a temperature range of approximately 17 to 26 oC (Pirie 1977). The climate of the experimental site is such that berry temperatures can reach 35 oC (and above) on a number of days during the ripening period (Smart et al. 1977, Haselgrove et al. 2000). Such conditions would probably be unfavourable for anthocyanin production in berries and may even lead to anthocyanin breakdown in highly exposed berries.

In year 4, red-free G-G content and concentration of berries were significantly higher in berries of the DRY treatment compared to those of the IRR treatment (Figure 1.9c, f). In fact, concentration of red-free G-G of DRY in year 4 was by far the highest such value of all 12 reported over the four years of the trial. It is possible that this high value is due to higher levels of

quercetin-3-glucoside in berries of the DRY treatment since these berries were more exposed than those of the IRR treatment. Previous studies (Price 1994, Haselgrove et al. 2000) have reported that higher berry exposure can result in enhanced levels of quercetin-3-glucoside. Higher levels of quercetin-3-glucoside would increase measures of total G-G and red-free G-G. However, higher red-free G-G values may also be due to enhanced levels of glycosides of other phenolics and/or aroma and flavour compounds. This highlights the need for the composition of the fraction called red-free G-G to be partitioned further, since it must include glycosides of many volatile compounds that contribute to aroma and flavour; and an understanding of the metabolism of these is important in unravelling the complexities of flavour development in berries.

1.4.3 The effect of one month post veraison deficit (DEF) on vine growth and berry composition

Mass per berry of the IRR treatment tended to be higher than that of the DEF treatment across all years, however there was only a significant difference in year 3 (Figure 1.5). A similar trend was apparent for yield per vine (Figure 1.4). LA/FW or FW/PW ratios were similar for all three treatments. However, the ratios showed differences between years (Tables 1.3, 1.4). While both the numerator (LA), and the denominator (PW) of the ratios declined steadily over the four years (data not shown), the amount of FW per vine fluctuated considerably (Figure 1.4): FW was high in year 3, hence the low LA/FW ratio and high FW/PW ratio in year 3. The ratios of LA/FW and FW/PW provide an indication of vine balance; recommended values are 10 to 15 for LA/FW and 5 to 10 for FW/PW (Smart and Robinson 1991). LA/FW values of vines in this study are towards the lower end of the recommended range, the highest value being 6.7 cm2/g in year 4 (Table 1.3). Correspondingly, the ratio FW/PW was higher than the recommended value.

Restriction of water after veraison was sufficient to cause slightly more open canopies in DEF compared to IRR vines and bunch exposure of DEF vines was 60% compared to 53% for IRR vines (Table 1.1).

In the selected range of juice oBrix, total G-G and anthocyanin-glucose concentration of DEF berries were significantly higher than those of IRR berries in all four years (Figure 1.9d, e). Comparison of DEF and IRR as pairs (years 1 and 4, Table 1.5) showed similar results. Since mass per berry of these two treatments were similar in years 1, 2 and 4 (Figure 1.5), much of the difference in these years can be attributed to enhanced anabolism of these G-G components in berries of the DEF treatment. Differences in year 3 are also due to the concentrating effects of smaller berries of the DEF treatment.

Other irrigation studies (Matthews et al. 1990, Steer 1998) showed similar effects on berry composition. For Shiraz vines, when irrigation was restricted post veraison for approximately one month compared to continuous irrigation and where composition was compared at similar juice oBrix levels (Steer 1998), berries from vines of the restricted irrigation treatment had higher anthocyanin content and concentration. In the study of Matthews et al. (1990), at harvest, berries of vines where water was restricted after veraison had lower juice oBrix compared to those of vines which had been continuously irrigated during the growing season. Nevertheless, wines made from fruit of the post-veraison deficit treatment had either similar or higher colour density and total anthocyanin concentration compared to wines of the continuous irrigation treatment.

The pairs in which total G-G and anthocyanin-glucose concentration of DEF berries were higher than those of IRR (years 1 and 4, Table 1.5f, g) showed that the juice of DEF berries had lower titratable acidity and higher pH indicating that the 'must' of the DEF treatment, compared to the IRR treatment, would require a higher acid adjustment throughout the winemaking process to achieve a optimal acid balance.

Can differences in berry composition be explained by varying levels of bunch exposure? In all years bunches of the DEF vines were slightly more exposed to sunlight than those of IRR vines (Table 1.1). Although berries require light for anthocyanin synthesis, it appears that saturation may occur at low light intensities. Dokoozlian and Kliewer (1995) found that for Pinot Noir berries maximum colour (anthocyanin) accumulation occurred at less than 333 to 400 PPFD (approx 18% ambient). Similar studies with Merlot (Mabrouk and Sinoquet 1998) showed that the concentration of anthocyanins in berries was near maximum when light intensity was in the order of 10% of ambient (ambient not reported) and, for Cabernet Sauvignon (Kellar and Hrazdina 1998) in the range of 240 and 280 PPFD (approx 20% ambient). Light conditions at the bunch zone of the IRR vines were 218 PPFD (11% ambient) in year 3 and 350 PPFD (19% ambient) in year 4. Light conditions at the bunch zone of the DEF vines were 350 PPFD (18% ambient) in year 3 and 574 PPFD (31% ambient) in year 4. Under these light conditions, it is unlikely that there is any limitation to anthocyanin synthesis in berries of either IRR or DEF vines. However, if there is any limiting effects, these will be greater in the IRR treatment compared to the DEF treatment, since bunches of IRR vines were more shaded than those of DEF vines.

It remains to be seen whether the improvement in berry composition caused by restricting irrigation after veraison can be explained by the cumulative effects of small differences in canopy openness and berry size, or whether other mechanisms controlling berry composition are involved.

1.5 Conclusions

a. Measurement of G-G components of berries was useful in evaluating the effects of irrigation scheduling on berry composition. The measures of total G-G and anthocyanin-glucose were more consistent in showing differences between treatments than the measure of red-free G-G, and are therefore regarded as being the more useful G-G measures to interpret the data.

b. The responses in berry composition due to the different treatments varied between years, therefore it was not possible to indicate a treatment which would consistently perform better than any of the other two. However, based on comparisons made within a narrow juice oBrix range and on pairs of treatments where juice oBrix was not significantly different in any one year, total G-G and anthocyanin-glucose concentration of berries of the unirrigated and post-veraison deficit treatments were generally higher than those of the fully-irrigated treatment. Unlike, the unirrigated treatment, which had severe effects on vine growth and yield in the last two years of the trial, the post-veraison deficit caused only small reductions in vine growth and yield but brought about beneficial changes in berry composition.

Section 2 — Relationships between the concentration of different classes of G-G in grapes and chemical and sensory properties of wines and the effect of irrigation scheduling on wine flavour intensity

2.1 Introduction

Can measures of grape and wine composition be used to predict chemical and sensory properties of wines? For black grapes, measurement of grape colour would seem to be a suitable indicator of potential wine colour, but while a number of reports allude to this, there appears to be only a few that provide data to support such a connection (Iland 1987, Holgate 2001). Results of sensory studies with hydrolysates of grape glycosides indicate that measures of total and red-free G-G of grapes are related to aroma and flavour characteristics of wines (Abbott 1991, Abbott et al. 1990a, b, 1991, 1993, Francis et al. 1992, 1998a).

For red wines, aspects of wine colour have been shown to be linked with organoleptic assessment of wine quality; for a set of Shiraz and Cabernet Sauvignon wines the measures of wine colour density, percentage ionisation of anthocyanins and ionised anthocyanin concentration of wines were significantly and positively correlated with wine score (Somers and Evans 1974).

In this part of the project the fruit from the eight irrigation plots (see Section 1.1) were used to make small lot wines. These experiments were used to —

a) test the relationships between the G-G measures of berries and wine composition and wine flavour intensity and
b) determine which of the eight irrigation treatments resulted in wines with the most intense flavour.

2.2 Materials and methods

At a ripeness stage of approximately 24 oBrix the two outside vines of each replicate plot were harvested and for each treatment, bunches from all replicates were combined and then divided randomly into three 20 kg lots for small-lot winemaking. For this experiment all eight irrigation treatments were harvested, giving in total 24 small-lot winemaking samples, ie eight treatments by three replicates of each. The trial was conducted for the 1994 and 1995 seasons. The winemaking was carried out according to the standard procedure used at Adelaide University small-lot winemaking facility. Berry samples were taken randomly from each replicate batch of grapes prior to crushing. Berry composition (juice oBrix and total G-G, anthocyanin-glucose (colour) and red-free G-G concentration of berries were determined as described previously. Wine colour measures were determined by the methods of Somers and Evans (1977) and a modified wine colour density measure, which takes into account any effects of pH and sulfur dioxide. For both the 1994 and the 1995 wines, analyses were conducted approximately 19 months after completion of fermentation, to coincide with the sensory evaluation studies.

Sensory assessment was carried out on two sets of eight wines. Selection of the wines for each set was based on obtaining wines originating from grapes with a wide range of concentration of G-G components but within as narrow a juice oBrix range as possible. Set 1 (23.4 to 25.7 oBrix) contained a replicate of each of the wines made from the eight irrigation treatments from the 1994 season. Set 2 (24.3 to 25.1 oBrix) contained wines from the 1995 season, but excluded wines from the unirrigated treatment because the juice oBrix of the original fruit was greater than 26 oBrix. Another replicate of the fully irrigated treatment was used to give

eight wines in total for Set 2. Wines were evaluated at approximately 19 months of age. An incomplete block design was employed. The sensory assessments were performed by a number of experienced tasters, recruited from staff of Adelaide University, Department of Horticulture, Viticulture and Oenology and The Australian Wine Research Institute. Thirty panelists were involved. The wines were assessed under colour-masking lights so that the potentially biasing influence of differences in wine colour was eliminated. For each set of wines, each panelist received four of the eight wines and was asked to rank them on flavour intensity. The testing was repeated the following week using the same panelists. The ranks of all the tasters were averaged to obtain the value for wine flavour intensity rank that was used in the correlation studies. Differences in aroma and wine flavour intensity of wines from the different irrigation treatments were determined by analysis of variance.

2.3 Results

2.3.1 Relationships between berry composition and wine composition measures

For the 1994 wines, total G-G, anthocyanin-glucose and red-free G-G concentration of berries were positively correlated with total G-G concentration of wine and with colour density and modified wine colour density and for the 1995 wines, total G-G, anthocyanin-glucose and red-free G-G concentration of berries were positively correlated with colour density and modified wine colour density (Tables 2.1a, b). Depending on the particular relationship, the significance of the regression analysis varied from $p<0.1$ to $p<0.001$.

2.3.2 Relationships between berry composition and assessment of wine flavour intensity

For the sensory studies lower total rank values indicate a higher perception of wine flavour intensity. In preparing the graphs of relationships between berry and wine components and wine flavour intensity rank, the rank values on the y-axis are inverted so that the highest sensory perception (the lowest rank value) is at the top of the axis (Figures 2.1a, b, 2.2a, b).

For the 1994 wines, the assessment of wine flavour intensity, (ie inverse wine flavour intensity rank) was positively correlated with anthocyanin-glucose concentration of berries ($p<0.1$) (Table 2.1a, Figure 2.1a) and for the 1995 wines, with juice oBrix ($p<0.05$), total G-G ($p<0.05$), anthocyanin-glucose ($p<0.05$) and red-free G-G ($p<0.05$) concentration of berries (Table 2.1b, Figure 2.1b).

2.3.3 Relationships between wine composition and assessment of wine flavour intensity

For one of the sets of wines, assessments of wine flavour intensity (inverse wine flavour intensity rank or wine flavour intensity score) were positively correlated with total G-G concentration of wine and for both sets of wines with the measures of wine colour density and modified wine colour density (Tables 2.1, Figures 2.2a, b). No significant relationships were found between the total anthocyanin concentration of wines and wine flavour intensity rank or wine flavour intensity score (Tables 2.1, Figures 2.2a, b).

2.3.4 The effect of the different irrigation schedules on wine flavour intensity

The wine aroma intensity of the Trt 3 wine was significantly higher than that of the Trt 8 and 5 wines, while that of Trt 7, 4 and 2 wines were significantly higher than that of Trt 5 wines, but not to the wines of the other treatments (Table 2.2). The wine flavour intensity of the Trt 7 and 4 wines were significantly higher than that of the Trt 6, 8 and 5 wines, but not higher than Trt 2, 3 and 1 wines (Table 2.3). A feature evident in this data is that the aroma and flavour intensities were related to the oBrix of the juice from which the wines were made. The score for

Trt 2 wines is higher than expected in relationship to its lower oBrix value. In 1995, the sensory evaluation was conducted on wines made from grapes within as small a range of oBrix as possible.This excluded the Trt 8 wines as in this year they were above 26 oBrix when harvested for small-lot winemaking. The wine aroma intensity of Trt 2 wine was significantly higher than wines from Trt 3 and one of the Trt 1 wines; there were no significant differences between Trts 2, 6, 4, 5, 7 and one of the Trt 1 wines nor between treatments 6, 4, 5, 7, one of the Trt 1 and Trt 3 wines (Table 2.4). The wine flavour intensity of one of the Trt 1 wines was significantly lower than five of the other wines; there were no significant differences between all the other wines (Table 2.5).

Table 2.1 Correlation matrices (juice oBrix; BTG-G (total G-G per g berry mass); BA-glu (anthocyanin-glucose per g berry mass); Br-f G-G (red-free G-G per g berry mass); WTGG (wine total G-G (mM)); WCD (wine colour density, abs units); MWCD (modified wine colour density, abs units); WTA (wine total anthocyanin concentration, mg/L) and IWFR (inverse wine flavour intensity rank, ie wine flavour intensity)) for (a) the 1994 and (b) the 1995 irrigation trial wines (section 5.2.1).Values shown are r (the correlation coefficient for the respective regression analysis).+, *, ** and *** indicate significance at the $p<0.1$, 0.05, 0.01 and 0.001 respectively.

	oBrix	BTG-G	BA-glu	Br-f G-G	WTGG	WCD	MWCD	WTA	IWFR
(a) 1994 irrigation	trial	wines							
oBrix	-	-	-	-	-	-	-	-	-
BTG-G	0.944***	-	-	-	-	-	-	-	-
BA-glu	0.852**	0.938***	-	-	-	-	-	-	-
Br-f G-G	0.877**	0.881**	0.662+	-	-	-	-	-	-
WTGG	0.851**	0.899***	0.932***	0.667*	-	-	-	-	-
WCD	0.814**	0.869*	0.853**	0.713*	0.969***	-	-	-	-
MWCD	0.860**	0.910***	0.878**	0.767*	0.976***	0.992***	-	-	-
WTA	0.545	0.670*	0.512	0.749*	0.516	0.574	0.634+	-	-
IWFR	0.542	0.537	0.583+	0.366	0.808**	0.822**	0.780**	0.143	-
(b) 1995 irrigation	trial	wines							
oBrix	-	-	-	-	-	-	-	-	-
BTG-G	0.788*	-	-	-	-	-	-	-	-
BA-glu	0.728*	0.958***	-	-	-	-	-	-	-
Br-f G-G	0.747*	0.921***	0.780*	-	-	-	-	-	-
WTGG	0.517	0.536	0.468	0.515	-	-	-	-	-
WCD	0.660+	0.800**	0.836**	0.652+	0.768*	-	-	-	-
MWCD	0.618+	0.714*	0.700*	0.638+	0.891**	0.954***	-	-	-
WTA	0.527	0.258	0.144	0.367	0.668*	0.470	0.667+	-	-
IWFR	0.669*	0.713*	0.707*	0.675*	0.761*	0.854**	0.861**	0.476	-

Figure 2.1 The relationship between juice oBrix, berry total G-G concentration, berry anthocyanin-glucose concentration, berry red-free G-G concentration and wine flavour intensity rank or wine flavour intensity score for sets of Shiraz berries and wines from (a) the irrigation trial in 1994 and (b) the irrigation trial in 1995. Note the y-axis has been inverted in (a) and (b) so that the lowest wine flavour intensity rank, (ie the highest wine flavour intensity) is at the top of the scale. r is the correlation coefficient for the respective linear regression analysis. +, *, ** and *** indicate significance at the $p<0.1$, 0.05, 0.01 and 0.001 respectively.

Figure 2.2 The relationship between wine total G-G concentration, wine colour density, modified wine colour density, wine total anthocyanin concentration and wine flavour intensity rank or wine flavour intensity score for sets of Shiraz berries and wines from (a) the irrigation experiment in 1994 and (b) the irrigation experiment in 1995. Note the y-axis has been inverted in (a) and (b) so that the lowest wine flavour intensity rank, (ie the highest wine flavour intensity) is at the top of the scale. r is the correlation coefficient for the respective linear regression analysis. +, *, ** and *** indicate significance at the $p<0.1$, 0.05, 0.01 and 0.001 respectively.

Table 2.2 Wine aroma rank totals and juice oBrix corresponding to wines and juices of the different irrigation treatments for the 1994 season. A lower value for the rank total indicates a higher aroma intensity. Numbers followed by different letters are significantly different ($p<0.05$).

Treat	3	7	4	2	6	1	8	8	5	5
Wine aroma rank total	47a	53ab	54ab	54ab	59abc	62abc	63bc	68bc	70c	70c
juice oBrix	25.7	25.6	24.9	23.4	23.8	24.0	24.3	24.4	23.6	24.0

Table 2.3 Wine flavour rank totals and juice oBrix corresponding to wines and juices of the different irrigation treatments for the 1994 season. A lower value for the rank total indicates a higher flavour intensity. Numbers followed by different letters are significantly different ($p<0.05$).

Treat	4	7	2	3	1	8	5	6	8	5
Wine flavour rank total	46a	47a	50ab	54abc	60abcd	63bcd	67cd	69cd	69cd	75d
juice oBrix	24.9	25.6	23.4	25.7	24.0	24.3	24.0	23.8	24.4	23.6

Table 2.4 Wine aroma rank totals and juice oBrix corresponding to wines and juices of the different irrigation treatments for the 1995 season. A lower value for the rank total indicates a higher aroma intensity. Numbers followed by different letters are significantly different ($p<0.05$).

Treatment	2	6	4	5	7	1	3	1
Wine aroma rank total	89a	95ab	97ab	104ab	107abc	108abc	114bc	126c
juice oBrix	24.5	25.1	24.9	24.8	25.1	24.3	24.8	24.3

Table 2.5 Wine flavour rank totals and juice oBrix corresponding to wines and juices of the different irrigation treatments for the 1995 season. A lower value for the rank total indicates a higher flavour intensity. Numbers followed by different letters are significantly different ($p<0.05$).

Treatment	2	7	6	4	3	5	1	1
Wine flavour rank total	97a	98a	98a	99a	102a	109ac	109ac	128bc
juice oBrix	24.5	25.1	25.1	24.9	24.8	24.8	24.3	24.3

2.4 Discussion

2.4.1 Relationships between total G-G and anthocyanin-glucose of berries

The range of berry total G-G values (2.3 to 4.4 mmol per g berry mass) fell within the range reported for a set of Shiraz grapes from a national survey (0.5 to 6.1 mmol per g berry mass) (Francis et al. 1998b). The proportion of total G-G attributable to anthocyanin-glucose (77%) (data not shown) was similar to values reported previously — 76% for samples reported in the national survey and 86% (1994 season) and 72% (1995 season) for samples from McCarthy (1997). These figures indicate that in Shiraz grapes, and presumably in most black grape varieties, anthocyanins make up the major part of the total pool of G-G.

2.4.2 Relationships between grape composition and wine composition

In most cases the total G-G and anthocyanin-glucose concentration of berries were strongly positively correlated with wine total G-G concentration and the measures of wine colour density and modified wine colour density of wines (Table 2.1).

The pigment composition of a wine changes as the wine ages; progressively there is a shift from monomeric to polymeric forms and this leads to changes in wine colour density (Somers 1998). Therefore, it is important that any comparisons of relationships between berry composition and measures of wine colour density are carried out at similar wine age.

Correlations between red-free G-G concentration of berries and wine composition were poorer (r values varied between 0.045 and 0.767) than those for total G-G and anthocyanin-glucose (r values varied between 0.551 and 0.932). This finding indicates that berry red-free G-G measures are not as satisfactory as berry total G-G and anthocyanin-glucose measures in predicting aspects of wine composition.

2.4.3 Relationships between berry composition and assessment of wine flavour intensity

Total G-G and anthocyanin-glucose

Total G-G concentration of berries was positively correlated with the assessment of wine flavour intensity in one of the two sets of wines (Figure 2.1), while anthocyanin-glucose concentration of berries was positively correlated with the assessment of wine flavour intensity in both sets of wines (Figure 2.1). The data indicate that both total G-G and anthocyanin-glucose concentration of berries act equally as predictors of wine flavour intensity; this is not unexpected since anthocyanin-glucose is a major component of the total G-G and hence is likely to show similar relationships to that of total G-G. The relationships reported here, and in Francis et al. (1999), demonstrate direct links between the concentration of G-G components of berries and wine flavour intensity. Other studies (Abbott 1991, Abbott et al. 1990a, 1993, Francis et al. 1992, 1998) have shown that glycosidic hydrolysates of grape juice or skins had sensory characters similar to those of wines of that variety and that measures of glycoside concentration were related to intensity of flavour characters or wine quality ratings. For example, Abbott's studies (quoted above) showed that the concentration of total G-G in hydrolysis products of Shiraz grapes from low- and high-rated vineyards matched the quality rating of resultant wines.

It is important to appreciate that any observed relationships are valid only for the range of berry G-G values investigated. The range of total G-G was 2.9 to 3.8 mmol per g berry mass (1994 data) and 2.4 to 3.6 mmol per g berry mass (1995 data). Since these studies only examined relationships for Shiraz grapes and wines, separate relationships should also be determined for each variety.

Relationships between berry G-G composition and wine sensory properties may not, in all cases, be linear. For the two sets of wines, curvilinear relationships were tested, but generally these did not show an increased r value when compared to the r values of corresponding linear relationships. However, this does not negate that in other studies relationships may be either linear or curvilinear.

It is possible that high concentrations of total G-G and anthocyanin-glucose in berries are associated with overripe flavours, which when carried over into the wine may detract rather than add to wine style and quality definition; higher perception of flavour intensity may not then necessarily relate to improved wine quality. For the styles of red wines typically produced from this site, higher levels of perceived wine aroma and flavour would generally be seen as an improvement in overall wine quality; and thus it does not seem unreasonable to conclude that, in this case, wines made from grapes with higher values of glycosides would be of higher flavour intensity and of higher wine quality.

Red-free G-G

Red-free G-G concentration of berries was positively correlated with assessment of wine flavour intensity in only one set of wines (those of the 1995 irrigation study). Hence, it appears that red-free G-G measures are not as satisfactory as total G-G and anthocyanin-glucose measures in predicting wine sensory properties.

2.4.4 Relationships between wine composition and assessment of wine flavour intensity

For the two sets of wines, total G-G concentration, wine colour density and modified wine colour density measures of wines were all strongly positively correlated with assessment of wine flavour intensity (Figure 2.2). All acted equally in predicting wine flavour intensity. The potential

use of wine colour density measures as predictors of wine sensory properties warrants further research.

In this study, wine flavour intensity was strongly positively correlated with wine total G-G concentration but not with wine total anthocyanin concentration (Figure 2.2). The determination of total anthocyanin concentration of wines measures the spectrophotometric response of two sets of chromophores, namely free anthocyanins and red polymeric pigments; the calculation uses a correction factor to allow for differences in the response of the different chromophores. Previously Bakker and Timberlake (1986) have questioned the value of the measure of total anthocyanin concentration in wine, arguing that the correction factors given by Somers and Evans (1977) are not applicable to all wines. The determination of total G-G concentration of wine is not prone to any of the above assumptions, since the glucose moiety rather than the chromophore is measured.

2.4.5 The effect of the different irrigation schedules on wine flavour intensity

In the sensory evaluation studies where G-G measures were taken on berries from each of the eight irrigation treatments prior to small-lot winemaking and where sensory assessment of wine flavour intensity was conducted on wines made from the separate lots of fruit, measures of berry total G-G and colour both acted as good predictors of wine flavour intensity. An increase in these components in berries (on a concentration basis) was associated with a higher perception of wine flavour intensity. Berry total G-G and colour measures were more satisfactory in predicting wine composition and wine sensory properties than berry red-free G-G measures. It is important to appreciate that any conclusions are only valid for this viticultural region and for the range of values investigated, eg for values of berry colour from 1.4 to 1.6 mg/g berry weight in 1994 and 0.9 to 1.3 mg/g berry weight in 1995. Further studies are required to test relationships for other viticultural regions and years and for other varieties.

As there were no consistent significant differences in the perception of wine flavour in wines of the eight different irrigation treatments over the two years of sensory assessment, it was not possible to identify which irrigation treatment would produce grapes leading to wines with the highest flavour intensity. Also, differences in maturity of the fruit at harvest have confounded the interpretation of the sensory results. Often higher scoring wines were associated with higher oBrix fruit. However, comparing wines made from grapes with a narrow range of maturities (23.4 to 25.7 oBrix in 1994 and 24.3 to 25.1oBrix in 1995). The results indicated that wines from the fully irrigated treatment were always in the lower group of berry G-G and wine flavour intensity values and in one year were significantly lower than six of the other treatments. Wines from the vines with water deficits during the post-anthesis, post-veraison and veraison to harvest treatments were always in the higher group of berry G-G and wine flavour intensity.

2.5 Conclusions

a. Anthocyanins make up the major part of the total G-G of Shiraz grapes.

b. For both sensory studies, berry total G-G concentration, berry anthocyanin-glucose concentration, wine total G-G concentration and wine colour density measures acted as predictors of wine flavour intensity. Total G-G and anthocyanin-glucose measures were more satisfactory in predicting wine composition and wine sensory properties than red-free G-G measures.

c. The fully irrigated treatment resulted in vines producing grapes of lower concentration of total G-G and anthocyanin-glucose (colour) and wines of lower flavour intensity than vines where deficit irrigation schedules had been applied.

2.6 References

Abbott, N.A. (1991) A study of Shiraz grape berry composition in relation to the quality of table wine. PhD Thesis. The University of Adelaide, Adelaide, Australia.

Abbott, N.A., Coombe, B.G., Sefton, M.A. and Williams, P.J. (1990a) The secondary metabolites of Shiraz grapes as an index of table wine quality. In: Proceedings 7th Australian Wine Industry Technical Conference, Adelaide, South Australia, Australia. Eds. P.J. Williams, D. Davidson and T.H. Lee (Winetitles: Adelaide, Australia) pp. 117-120.

Abbott, N.A., Coombe, B.G. and Williams, P.J. (1990b) The flavour of Shiraz as characterised by chemical and sensory analysis. Australian and New Zealand Wine Industry Journal 5, 315-319.

Abbott, N.A., Coombe, B.G. and Williams, P.J. (1991) The contribution of hydrolyzed flavour precursors to quality differences in Shiraz juice and wines: An investigation by sensory descriptive analysis. American Journal of Enology and Viticulture 42, 167-174.

Abbott, N.A., Williams, P.J. and Coombe, B.G. (1993) Measure of potential wine quality by analysis of grape glycosides. In: Proceedings 8th Australian Wine Industry Technical Conference, Melbourne, Australia. Eds. C.S. Stockley, R.S. Johnstone, P.A. Leske and T.H. Lee (Winetitles: Adelaide, Australia) pp. 72-75.

Bravdo, B., Hepner, Y., Loinger, C., Cohen, S. and Tabacman, H. (1985) Effect of irrigation and crop level on growth, yield and wine quality of Cabernet Sauvignon. American Journal of Enology and Viticulture 36, 132-139.

Crowder, M.J. and Hand, D.J. (1990) 'Analysis of repeated measures'. (Chapman and Hall, London).

Francis, I.L., Sefton, M.A. and Williams, P.J. (1992) Sensory descriptive analysis of hydrolysed precursor fractions from Semillon, Chardonnay and Sauvignon Blanc grapes juices. Journal of Science and Food Agriculture. 59, 511-520.

Francis, I.L., Kassara, S., Noble, A.C. and Williams, P.J. (1998a) The contribution of glycoside precursors to Cabernet Sauvignon and Merlot aroma. Sensory and compositional studies. In: 'Chemistry of wine flavour. ACS Symposium series 714'. Eds. A.L. Waterhouse and S.E. Ebeler (American Chemical Society, Washington D.C.) pp. 13-30.

Francis, I.L., Armstrong, H., Cynkar, W.U., Kwiatkowski, M., Iland, P.G. and Williams, P.J. (1998b) A national vineyard fruit composition survey — evaluating the G-G assay. The Australian Grapegrower & Winemaker Annual Technical Issue pp. 51-57.

Francis, I.L., Iland, P.G., Cynkar, W.U., Kwiatkowski, M., Williams, P.J., Armstrong, H., Botting, D.G., Gawel, R. and Ryan, C. (1999) Assessing wine quality with the G-G Assay. In: Proceedings 10th Australian Wine Industry Technical Conference, Sydney, Australia. Eds. R.J. Blair, A.N. Sas, P.F. Hayes and P. B. Høj. (Winetitles: Adelaide) pp. 104-108.

Haselgrove, L., Botting, D., Heeswijck, R., Høj, P.B., Dry, P.R., Ford, C. and Iland, P.G. (2000) Canopy microclimate and berry composition: The effect of bunch exposure on the phenolic composition of Vitis vinifera L cv. Shiraz grape berries. Australian Journal of Grape and Wine Research 6, 141-149.

Hepner, Y., Bravdo, B., Loinger, C., Cohen, S. and Tabacman, H. (1985) Effect of drip irrigation schedules on growth, yield, must composition and wine quality of Cabernet Sauvignon. American Journal of Enology and Viticulture 36, 77-85.

Iland, P.G., Ewart, A., Sitters, J., Markides, A. and Bruer, N. (2000) 'Techniques for chemical analysis and quality monitoring during winemaking'. Patrick Iland Wine Promotions: Adelaide, Australia.

Matthews, M.A., Ishii, R., Anderson, M.M. and O'Mahony, M. (1990) Journal of Science and Food Agriculture 51, 321-335.

McCarthy, M.G. (1997) Effect of timing of water deficit on fruit development and composition of Vitis Vinifera cv. Shiraz. PhD Thesis, The University of Adelaide, Adelaide, Australia.

Pirie, A.J.G. (1977) Phenolics accumulation in red wine grapes (Vitis vinifera L.). PhD Thesis. University of Sydney, Sydney, Australia.

Price, S.F. (1994) Sun exposure and flavonols in grapes. PhD Thesis. Oregon State University, Oregon USA.

Smart, R.E. Dry, P.R. and Bruer, D.R.G. (1977) Field temperatures of grape berries and implications for fruit composition. In: Proceedings O.I.V. Symposium of the 'Quality of the Vintage', Capetown, South Africa. pp. 227-231.

Smart, R.E. and Robinson, M.D. (1991) 'Sunlight into wine: a handbook for winegrape canopy management' (Winetitles: Adelaide, Australia).

Somers, T.C. and Evans, M.E. (1974) Wine quality: Correlations with colour density and anthocyanin equilibria in a group of young red wines. Journal of Science, Food and Agriculture 25, 1369-1379.

Somers, T.C. and Evans, M.E. (1977) Spectral evaluation of young red wines: anthocyanin equilibria, total phenolic, free and molecular SO2, 'Chemical age'. Journal of Science, Food and Agriculture 28, 279-287.

Somers, T.C. and Vérette, E. (1988). Phenolic composition of natural wine types. In: 'Modern Methods of Plant Analysis, New Series Vol 6, Wine Analysis', Eds. H. F. Linskens and J. F. Jackson (Springer-Verlag: Berlin, Heidelberg, New York, London, Paris, Tokyo) pp. 219-257.

Steer, R. (1998) The effect of irrigation strategy on growth, yield and fruit composition of Shiraz vines in the McLaren Vale region. Honours project for Bachelor of Agriculture Science (Viticulture) Thesis. The University of Adelaide, Adelaide, Australia.