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Decompressing harvest and preserving wine identity



FINAL REPORT to AUSTRALIAN GRAPE & WINE AUTHORITY

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Abstract

Climate change is already impacting the grape and wine sector in Australia. One of the measurable effects on viticulture is that hotter temperatures are causing earlier and compressed ripening of grapes. This places a strain on harvesting and winery infrastructure and changes berry chemistry and resulting wine quality. This project showed that delayed pruning is a practical, environmentally sound and economically viable tool to shift grape berry ripening. Experiments at two trial sites, including a commercial vineyard, showed that late pruning can delay grape ripening in Barossa Shiraz by up to two weeks, potentially spreading harvest with no deleterious effects on vine vigour, yield, grape quality or wine quality.

Executive Summary

It is well-acknowledged that climate change is impacting the grape and wine sector in Australia. Specific challenges due to warming include: (a) compressed harvests, (b) disruption of the balance between sugar, colour and flavour in ripening grapes, leading to high alcohol wines, and (c) potential loss of regional character due to warmer ripening conditions. Wineries lack the harvesting and crushing capacity to deal with a narrowing harvest window, leading to fruit becoming overripe and a reduction in quality. The expansion of processing facilities places more strain on a capital intensive industry. Viticultural practices are needed to deal with these challenges.

The aim of this project was to test delayed pruning as a tool to counteract warming effects. Delayed pruning seeks to spread maturity, hence decompressing harvest, and shift berry development into cooler conditions, hence preserving the balance between sugar, colour and flavour and regional wine styles. Delayed pruning is environmentally and economically superior to double pruning and chemical treatments.

Two trials were established with Shiraz in the Barossa Valley. First, using the open-top chambers constructed in previous industry-funded projects, we increased vineyard temperature and evaluated the interaction between delayed pruning and temperature in SARDI's experimental vineyard at Nuriootpa. Second, using large scale trials, we explored the feasibility of this practice in a commercial vineyard at Marananga. This trial further tested the carry-over effect of repeated late pruning. Three pruning dates were tested in both trials: winter control (current practice), budburst, and 2-3 leaves.

Delayed pruning was shown to satisfy four criteria. It shifted phenology and delayed grape maturity (by up to two weeks), was neutral or positive for yield, was neutral or positive for wine quality, was neutral for cost and fitted well with standard commercial vineyard practices. It is therefore a feasible practice to counteract the negative effects of global warming on viticulture and winemaking.

Background and Aims

Increased temperature, as a result of climate change, is thought to play a large part in the onset of earlier grape ripening, which is now well-documented. Grapes which ripen in the warmer months have altered chemistry, impacting on the quality of the resultant wine. In addition, grapes are ripening over a shorter timespan, with different varieties also tending to ripen together. The resulting harvest "compression" not only causes logistical issues, as not all wineries have the harvesting and crushing capacity to deal with it, but fruit often hangs on the vine beyond its optimal harvest date, leading to overripe characters and potential reduction in wine quality. Expansion of processing facilities places great strain on a capital-intensive industry. Therefore, viticultural practices are needed to deal with these challenges.

Barossa Shiraz and Coonawarra Cabernet Sauvignon are wine identities that underpin both the history and the future of the Australian wine industry. Increased warming challenges these identities by compressing harvest and disrupting the balance between sugar, flavour and colour in fruit. Previous studies have shown that the gap between harvest of Chardonnay and Cabernet Sauvignon at McLaren Vale has been compressed from 21 to nine days in the last 20 years. Sadras and Moran have also shown that warming disrupts the sugar/anthocyanin balance in Shiraz (AGWA project SAR 0901).

Vineyard practices are needed to counteract these warming effects. Three approaches are feasible: (i) chemicals e.g. auxins, (ii) double pruning or (iii) delayed pruning. The use of chemicals has several barriers to adoption including the cost of product registration, cost of use, and the potential impacts to the environment and public perception. Double pruning is more favourable, however involves high labour and input costs. Delayed pruning can be viewed as more environmentally and economically superior. It is seen in a risk management context, whereby rotation of pruning dates is necessary to spread harvest and to manage potential yield penalties and the depletion of vine carbohydrate reserves.

This part of the project has two objectives: (1) Evaluate the extent to which late pruning can be used to cancel the effects of warming on vine development and berry composition, and (2) Evaluate the feasibility for which delayed pruning can spread harvest time and improve the balance between sugar, flavour and colour in fruit and wine on commercial scale vineyards.

Methods

Nuriootpa trial

The trial was established in SARDI's experimental vineyard at Nuriootpa, in the Barossa Valley. Shiraz vines, clone 1654 were planted on Schwartzman rootstock in 1999 in a northwest-southeast orientation with vines spacing of 3m between rows and 2.25m within a row.

The question was how late pruning interacts with elevated temperature. We combined two thermal regimes (elevated temperature, ambient temperature control) and three pruning times: winter (control), budburst (E-L 4 in Coombe's scale), and 2-3 leaves (E-L 9 in Coombe's scale). Treatments were laid out in a split-plot design with three replicates; main plots were allocated to thermal regime and subplots were allocated to pruning time. Each combination of temperature by pruning time included six vines, and all sampling was done in the central four vines.

Marananga trial

The trial was established in a commercial vineyard in the Barossa Valley geographical indicator region of the Barossa zone (34.50ºS, 138.90ºE). Shiraz vines, clone 1654, were planted on own roots in 2006 in a north-south orientation with vines spacing of 3 m between rows and 1.8 m within a row. The main aim was to test the feasibility of late pruning in commercial vineyards, and particularly how it fits with normal vineyard practices. We also asked how vines respond to successive seasons of late pruning; this is important because late pruning might reduce plant vigour and carry-over effects need assessment. Table 1 outlines the treatments. The number of replicates was reduced to account for the increasing number of treatments with successive seasons (Table 1). Each replicate included 15 vines; nine vines were used to sample berries and measure yield. Treatments were separated by three buffer rows.

Measurements, wine making and analysis

We monitored phenology weekly by using the modified Eichhorn and Lorenz system proposed by Coombe (1995). Shortly before veraison, berry samples (100 per replicate) were taken to measure total soluble solids (TSS), pH and titratable acidity (TA). Yield and its components were measured by collecting all the fruit in the central vines of each replicate.

In both trials, wine was made in 2014 and 2015. We targeted harvest at approx. 15° Baume. However, seasonal conditions caused some deviations from this target. For example in 2015, grapes developed at about ~2 Baume per week instead of the usual 1.2 Baume and hence treatments were harvested at higher sugar concentrations, between 15.5 and 17° Baume, and the juice was diluted with distilled water to reach the target 15° Be.

Small batches of wines were made for each field replicate and treatments using about 25-30 kg of fruit per replicate (Nuriootpa) and 25-30 kg of fruit (Marananga). Bunches were crushed and destemmed and the fermentation was carried out in 75-l open top containers. Yeast was added at 20g/hectolitre (EC 118 Lalvin) and the cap was pushed in twice a day during fermentation. After a week, ferments were basket-pressed and wine was transferred into demijohns. Malolactic bacteria (Lavin 41) were inoculated once the wines completed primary fermentation and the residual sugar was below 2g/l (colorimeter method). The only exception was the winter pruning treatment in 2015 that had higher residual sugar. After malolactic fermentation finished (<100 mg/l accuvin colour strip test) the wine was racked off from gross lees and refrigerated at 2°C for 2 weeks prior to bottling. The wine was bottled in 375ml glass using a screw cap top (burgundy, antique green), packed in cartons and aged for 3 to 4 months prior sensory and chemical analysis (cellar temperature ~15 C°).

We measured total acidity, pH, volatile acidity, free and total sulphur (aspiration method) as described in Iland et al. (2004). Each measurement was done in duplicate. Wine colour was assessed by two methods; the tristimulus method CIELAB and modified Somers which also measures tannin and total polyphenols as explained in Mercurio et al. (2007). In addition the total soluble phenolic was measured using the high throughput Folin-Ciocalteu method described on Kwiatkowski (2014). Percentage of co-pigmentation, polymeratation (%) and delta colour (%) were measured using Gutiérrez (2003) protocol to account for the pigmented tannnin that is reported to contribute with the total colour of young red wines from about 40 to 70%.

A panel of twelve post-graduate students was trained to undertake descriptive analysis following the protocol described on Bastian et al. (2010). Each wine was analysed in triplicates and each attribute was scored from low to high intensity in a scale from zero (low) to 100 (high). The panel decided to score the attributes in the following order: colour, aroma,

taste, flavours, mouthfeel and aftertaste. There were a total of 37 attributes scored for each wine.

Table 1. Treatments in Marananga trial during four seasons starting in 2012-13. The core treatments were winter pruning (Wp) and two late pruning treatments at budburst (BB) and 2-3 leaves (2-3 L). 1st, 2nd, 3rd and 4th indicate plants that have been late pruned in a single season, or where late pruning was repeated in the same vines during 2, 3 and 4 seasons, respectively. In the fourth season, the 1st BB and 1st 2-3 L treatments were not established because the plants allocated to this treatment were inadvertently pruned in winter.

Season	Treatment	Number of treatments
1	Wp, **1st** BB, **1st** 2-3 L	3
2	Wp, **2nd** BB, **2nd** 2-3 L, 1st BB, 1st 2-3 L	5
3	Wp, **3rd** BB, **3rd** 2-3 L, 2nd BB, 2nd 2-3 L, 1st BB, 1st 2-3 L	7
4	Wp, **4th** BB, **4th** 2-3 L, 3rd BB, 3rd 2-3 L, 2nd BB, 2nd 2-3 L, 1st BB, 1st 2-3 L	9

Results and Discussion

Effect of pruning time on vine fruit ripening and harvest

Figures 1 and 2 show the weekly dynamics of sugars in berries in both trials. The largest separation of treatments was found in 2014-15, when the gap in target maturity (14-15 ^{o}Be) between winter and late pruned vines was up to two weeks in Nuriootpa, and 6 days in Marananga.

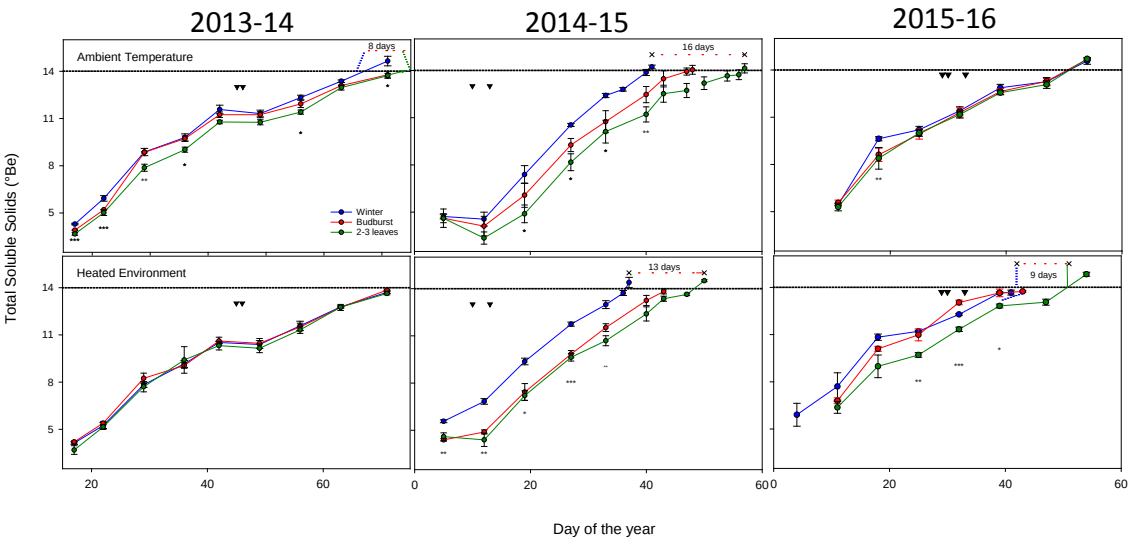


Figure 1. Dynamics of total soluble solids in Shiraz berries as affected by pruning date, thermal regime and season at Nuriootpa. Top row is ambient temperature and bottom row is heated. Values are mean ± standard error and asterisks indicate significant difference between treatments. Arrow heads indicate rainfall events over 5 mm. Dashed line indicates a putative maturity target.

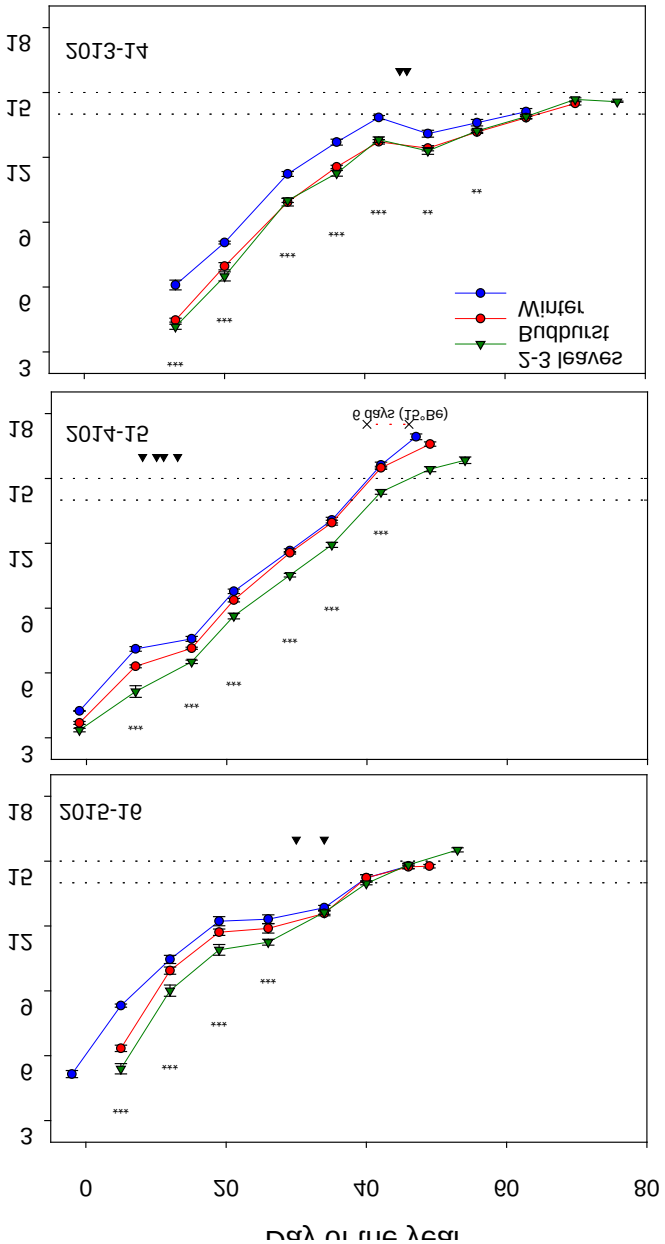


Figure 2. Dynamics of total soluble solids in Shiraz berries as affected by pruning date and season at Marananga. Values are mean ± standard error and asterisks indicate significant difference between treatments. Arrow heads indicate rainfall events over 5 mm. Dashed line indicates a maturity target band.

Effect of pruning time on yield

Preliminary trial

A pilot study in 2011-12 compared yield of winter pruned vines with late pruning between early September and mid-October. The aim was to determine how late we can delay pruning before significant yield reductions. We found that pruning beyond 2-3 leaves (mid-October) reduced yield substantially (Figure 3). This information was used to design the main trials, where late pruning treatments were established at budburst and 2-3 leaves.

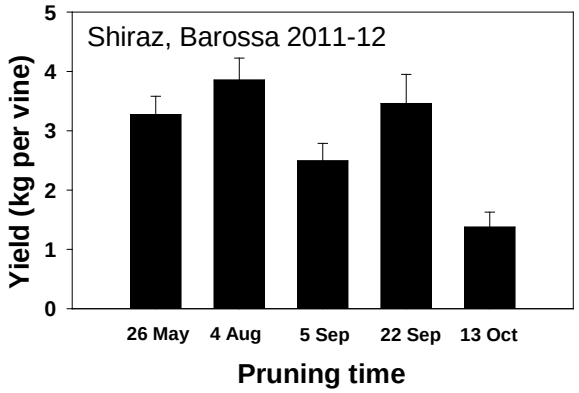


Figure 3. Pilot study with Shiraz at Marananga to establish the window for late pruning more likely to be neutral for yield. Error bars are one standard error.

Nuriootpa trial

Late pruning had no effect on yield in 2013-14, increased yield in 2014-15 and reduced yield in 2015-16 (Table 2). Elevated temperature increased yield in 2013-14 and had no effect in 2014-15. In 2015-16 elevated temperature reduced yield in winter and budburst pruned vines, but not in vines pruned at 2-3 leaves, as reflected in a significant interaction between temperature and pruning time.

Marananga trial

Pruning time had no effect on yield in three out of four seasons (Table 3). This was in part the result of compensation between yield components. For example in 2013-14, bunch number per plant was reduced from 63 in winter control to 45 in vines pruned at 2-3 leaves for two successive seasons, and this was compensated by larger berries. In 2014-15, some late-pruned vines, particularly pruned at 2-3 leaves, produced more bunches and out-yielded the winter pruned controls.

Conclusion

The pooled data indicate that delaying pruning of Shiraz under Barossa conditions up to the 2-3 leaf stage is likely to be neutral for yield as a result of no yield responses, or yield reduction compensated by yield increase depending on seasonal conditions.

Table 2. Yield and its components in Shiraz vines in response to temperature and pruning time during three seasons at Nuriootpa. Three pruning times were compared: winter, budburst and 2-3 leaves. Values are means ± standard error; P are from analysis of variance indicating effect of temperature, pruning time and their interaction.

Season	Temp	Pruning time	Yield (kg vine^{-1})	Bunch No. (vine^{-1})	Bunch wt. (g bunch^{-1})	Berry No. (bunch^{-1})	Berry wt. (g berry^{-1})
2013-14	Control	Winter	3.6 ± 0.72	60 ± 10.6	60 ± 8.3	96± 11.7	0.73 ± 0.153
		Budburst	3.7 ± 0.31	56 ± 0.8	68 ± 5.3	73 ± 3.4	0.92 ± 0.043
		2-3 leaves	4.9 ± 1.05	67± 2.3	75± 12.8	83 ± 8 .6	0.89 ± 0.059
	Heated	Winter	6.8 ± 0.88	84 ± 6.4	83 ± 9.7	105 ± 2.7	0.79 ± 0.093
		Budburst	5.9 ± 1.47	73 ± 4.2	80 ± 15.0	105± 10.5	0.67 ± 0.114
		2-3 leaves	6.8 ± 0.77	82 ± 9.4	84 ± 6.6	105 ± 6.3	0.84 ± 0.024
		P-temp.	*0.016*	*0.009*	*0.184*	*0.002*	*0.206*
		P-pruning	*0.560*	*0.364*	*0.838*	*0.515*	*0.432*
		P-interaction	*0.910*	*0.862*	*0.968*	*0.065*	*0.206*
2014-15	Control	Winter	2.5 ± 0.37	42 ± 3.1	55 ± 6.4	54 ± 6.4	1.02 ± 0.013
		Budburst	4.4 ± 0.39	61 ± 2.2	72 ± 5.0	70 ± 2.6	1.01 ± 0.040
		2-3 leaves	2.7 ± 0.34	47 ± 4.9	60 ± 7.4	63 ± 4.6	0.93 ± 0.050
	Heated	Winter	3.3 ± 0.61	49 ± 7.0	63 ± 6.4	49 ± 4.5	1.29 ± 0.027
		Budburst	4.3 ± 0.53	61 ± 5.1	71 ± 6.1	67 ± 4.8	1.06 ± 0.063
		2-3 leaves	3.8 ± 0.44	56 ± 2.8	66 ± 6.0	63 ± 3.3	1.03 ± 0.057
		P-temp.	*0.134*	*0.135*	*0.415*	*0.441*	*<0.0001*
		P-pruning	*0.004*	*0.004*	*0.162*	*0.001*	*0.001*
		P-interaction	*0.386*	*0.540*	*0.7601*	*0.835*	*0.0427*
2015-16	Control	Winter	4.1 ± 0.18	79 ± 4.9	52 ± 3.0	82 ± 7.3	0.63 ± 0.027
		Budburst	2.7 ± 0.18	78 ± 5.0	36 ± 3.0	71 ± 5.0	0.50 ± 0.076
		2-3 leaves	2.3 ± 0.25	72 ± 4.4	31 ± 2.4	57 ± 1.3	0.56 ± 0.099
	Heated	Winter	3.0 ± 0.24	59 ± 3.7	52 ± 3.5	75 ± 9.2	0.70 ± 0.100
		Budburst	1.8 ± 0.13	63 ± 3.9	29 ± 1.7	48 ± 2.8	0.60 ± 0.062
		2-3 leaves	2.3 ± 0.21	53 ± 3.9	38 ± 4.1	60 ± 6.0	0.59 ± 0.099
		P-temp.	*0.0002*	*0.022*	*0.916*	*0.186*	*0.137*
		P-pruning	*<0.0001*	*0.216*	*0.039*	*0.014*	*0.329*
		P-interaction	*0.031*	*0.754*	*0.890*	*0.069*	*0.932*

Table 3 Yield and its components in Shiraz vines in response to pruning time during four seasons at Marananga. Three pruning times were compared: winter, budburst and 2-3 leaves. 1st, 2nd, 3rd and 4th indicate late-pruning treatments in a single season, two, three and four successive seasons, respectively. Values are means ± standard error; P values are from analysis of variance.

Season	Treatment	Yield (kg vine^{-1})	Bunch No. (vine^{-1})	Bunch wt. (g bunch^{-1})	Berry No. (bunch^{-1})	Berry wt. (g berry^{-1})
2012-13	winter	3.43 ± 0.222	48 ± 1.7	72.1 ± 3.86	86 ± 4.7	0.84 ± 0.032
	(1st) budburst	3.51 ± 0.221	51 ± 2.0	67.9 ± 5.16	79 ± 4.1	0.87 ± 0.072
	(1st) 2-3 leaves	2.76 ± 0.220	52 ± 1.5	54.2 ± 2.41	64 ± 3.6	0.85 ± 0.041
	P	*0.0743*	*0.1799*	*0.0137*	*0.0094*	*0.9278*
2013-14	winter	3.41 ± 0.419	63 ± 4.1	53.1 ± 3.55	63 ± 4.4	0.84 ± 0.025
	(2nd) budburst	3.45 ± 0.240	48 ± 1.4	70.4 ± 2.54	83 ± 4.9	0.86 ± 0.026
	(2nd) 2-3 leaves	2.94 ± 0.298	45 ± 1.7	63.7 ± 4.65	58 ± 3.4	1.10 ± 0.024
	(1st) budburst	3.79 ± 0.866	52 ± 6.4	71.1 ± 6.84	89 ± 8.8	0.80 ± 0.005
	(1st) 2-3 leaves	3.59 ± 0.371	55 ± 5.2	65.5 ± 3.31	71 ± 2.0	0.92 ± 0.020
	P	*0.7211*	*0.0144*	*0.0327*	*0.0009*	*<0.0001*
2014-15	winter	3.67 ± 0.198	46 ± 2.1	78.8 ± 1.42	77 ± 1.7	1.02 ± 0.01
	(3rd) budburst	3.74 ± 0.102	51 ± 0.6	72.9 ± 2.28	72 ± 2.1	1.01 ± 0.01
	(3rd) 2-3 leaves	4.87 ± 0.314	60 ± 2.1	80.6 ± 3.60	74 ± 2.9	1.09 ± 0.025
	(2nd) budburst	3.46 ± 0.246	49 ± 0.9	71.4 ± 4.04	68 ± 3.1	1.04 ± 0.038
	(2nd) 2-3 leaves	3.50 ± 0.291	52 ± 3.8	67.7 ± 1.45	65 ± 3.6	1.05 ± 0.032
	(1st) budburst	4.06 ± 0.445	51 ± 3.9	78.9 ± 5.52	74 ± 2.8	1.07 ± 0.054
	(1st) 2-3 leaves	4.67 ± 0.602	57 ± 2.5	80.7 ± 7.71	78 ± 4.4	1.03 ± 0.049
	P	*0.0135*	*0.0026*	*0.1632*	*0.0345*	*0.4549*
2015-16	winter	4.27 ± 0.266	83 ± 3.7	51.3 ± 1.72	141 ± 3.8	0.71 ± 0.02
	(4th) budburst	3.29 ± 0.265	71 ± 2.4	45.8 ± 2.59	138 ± 3.3	0.75 ± 0.02
	(4th) 2-3 leaves	3.65 ± 0.322	60 ± 1.9	60.7 ± 3.73	137 ± 2.9	0.78 ± 0.02
	(3rd) budburst	3.41 ± 0.582	72 ± 3.8	47.8 ± 7.02	118 ± 2.2	0.77 ± 0.03
	(3rd) 2-3 leaves	3.38 ± 0.253	59 ± 1.4	58.1 ± 3.93	121 ± 0.9	0.77 ± 0.03
	(2nd) budburst	4.19 ± 0.586	80 ± 5.1	52.0 ± 5.85	112 ± 2.4	0.80 ± 0.02
	(2nd) 2-3 leaves	3.36 ± 0.635	57 ± 3.2	58.6 ± 7.76	126 ± 4.1	0.76 ± 0.04
	P	*0.3983*	*<0.0001*	*0.1462*	*<0.0001*	*0.1581*

Effect of pruning time on wine

Nuriootpa trial

Tables 4 and 5 show sensory attributes of wines and Figure 5 combines sensory and chemical analysis.

In 2014, temperature, time of pruning and its interaction affected 16 out of 35 sensory attributes. Elevated temperature decreased the colour, hue and the opacity of wines. Pruning and its interaction with temperature increased the colour (hue and opacity) for budburst in both ambient and heated environments. Wines made from ambient temperature vines showed aromas with more intense chocolate, savoury and dried fruit while wine made from heated vines showed more intense floral. Similarly to the aromas profile, the palate showed more intense flavours of dried fruit and savoury in wines from ambient temperature vines. The mouthfeel showed more intense body, tannin quantity and quality in ambient temperature. An interaction between temperature and pruning time highlighted the increase in wine's body for the 2-3 leaves pruning time under elevated temperature.

In 2015, temperature, pruning and its interaction affected 10 out of 30 sensory attributes. Pruning increased the colour opacity, red fruit and floral aromas, and the red fruit and meaty palate but decreased the meaty aroma. Temperature decreased the colour opacity, the meaty palate and the aftertaste.

Principal component analysis was used to explore the associations between wine chemical and sensorial traits that responded to temperature and pruning time. PC1 and PC2 accounted for the 80 % of the variance in 2014 and 84% in 2015 (Figure 6). In both vintages, the temperature and the three pruning times showed consistent differentiation of wines.

In 2014, PC1 was best explained by the effect of temperature on the wine berry fruit and floral aroma, bitter taste (sensory profile), and total anthocyanin, total pigment and total phenolic (chemical). Whereas PC2 captured the variation between pruning dates and their effect on the intensity of colour opacity and hue, savoury and dried fruit aromas, dried fruit

palate, body, tannin quantity and quality, non-fruit aftertaste (sensory), and colour density, tannin, % pigmented tannin, total phenolic and % degree ionization of anthocyanin (chemical).

In 2015, PC1 and PC2 was best explained by the effect of temperature and an its interaction with pruning time whereby the heated wine from vines pruned at 2-3 leaves shifted towards ambient temperature for wine colour intensity (opacity), red fruit and floral aromas, pepper and meaty palate, aftertaste (sensory), and total anthocyanin, colour density, total phenolic (Folin Cicalteau), tannins, chemical age 1 and 2, % pigmented tannin, % polymerization (chemical).

Overall, in the two vintages, pruning improved the wine colour density measured in laboratory, and this was consistent with sensory analysis. Temperature consistently reduced both the colour density and the total anthocyanin. Furthermore, in 2015 late pruning at 2-3 leaves offset the negative effect of high temperature on colour density, tannin and total anthocyanin content.

Table 4 Wine sensory analysis from wines made from vine grown at two temperatures (control and heated) combined with three pruning times at Nuriootpa in 2014. Values are average ± standard error in a 0-100 scale, and significance is shown as * (P<0.05), ** (P<0.01) and *** (P<0.001) from analysis of variance for T = temperature, P = pruning and TxP = interaction.

Sense	Trait		Control			Heated		Significance		
		Winter	Budburst	2-3 leaves	Winter	Budburst	2-3 leaves	T	P	TxP
Colour	Hue	87.6 ± 2.39	93.3 ± 1.37	86.4 ± 2.53	69.2 ± 3.20	74.5 ± 2.94	69.7 ± 3.25	***	**	ns
	Opacity	94.0 ± 1.62	93.0 ± 1.80	83.9 ± 3.00	54.5 ± 4.08	65.1 ± 3.71	58.0 ± 3.94	***	***	***
Aroma	Berry Fruit	53.1 ± 4.02	52.3 ± 3.82	53.5 ± 3.37	58.0 ± 3.62	54.1 ± 3.38	54.1 ± 3.38	ns	ns	ns
	Dried Fruit	43.6 ± 3.98	43.9 ± 3.83	45.9 ± 4.02	38.1 ± 3.41	41.8 ± 3.53	40.4 ± 3.76	**	ns	ns
	Ripe Fruit	45.2 ± 4.68	43.4 ± 4.19	42.9 ± 3.83	44.4 ± 3.74	44.4 ± 3.60	44.4 ± 4.05	ns	ns	ns
	Black Olive	33.4 ± 3.50	31.9 ± 3.57	32.1 ± 3.39	27.7 ± 3.33	31.0 ± 2.99	28.4 ± 3.25	**	ns	ns
	Cola	12.6 ± 2.72	13.8 ± 2.73	14.4 ± 2.72	16.1 ± 3.11	13.5 ± 2.86	15.9 ± 2.96	ns	ns	ns
	Pepper	32.5 ± 3.35	34.5 ± 3.38	31.8 ± 3.28	31.0 ± 3.18	31.9 ± 3.01	31.8 ± 3.44	ns	ns	ns
	Licorice	15.8 ± 2.14	16.6 ± 1.86	16.8 ± 1.97	16.3 ± 1.88	16.6 ± 1.86	15.6 ± 1.57	ns	ns	ns
	Savoury	20.8 ± 4.10	20.9 ± 4.14	18.1 ± 3.74	16.4 ± 3.38	18.5 ± 3.58	15.7 ± 3.25	***	**	ns
	Floral	11.2 ± 1.90	11.8 ± 1.88	12.5 ± 2.04	15.7 ± 2.42	14.8 ± 2.49	13.1 ± 2.02	**	ns	ns
	Veg Green	9.9 ± 2.39	10.5 ± 2.41	10.9 ± 2.53	10.9 ± 2.36	10.0 ± 2.38	10.5 ± 2.46	ns	ns	ns
	Mint	11.7 ± 2.54	11.9 ± 2.46	12.2 ± 2.52	11.4 ± 2.38	12.3 ± 2.47	11.0 ± 2.46	ns	ns	ns
	Chocolate	13.0 ± 2.42	12.4 ± 2.22	13.0 ± 2.34	12.8 ± 2.18	13.1 ± 2.40	11.5 ± 2.13	ns	ns	ns
	Earthy	13.1 ± 2.40	11.1 ± 2.05	10.6 ± 2.18	12.0 ± 2.16	12.1 ± 2.24	12.1 ± 2.39	ns	ns	ns
	Leather	12.9 ± 3.08	12.7 ± 2.80	13.0 ± 2.89	12.6 ± 2.71	12.9 ± 2.75	13.7 ± 2.80	ns	ns	ns
	Faulty	6.1 ± 2.89	3.2 ± 1.18	2.6 ± 0.70	1.5 ± 0.48	3.2 ± 1.03	2.3 ± 0.66	ns	ns	ns
Taste	Acid	57.8 ± 3.28	55.8 ± 3.31	55.4 ± 3.06	54.2 ± 2.95	57.2 ± 2.85	54.0 ± 3.05	ns	ns	ns
	Sweet	20.6 ± 3.98	20.3 ± 4.10	21.1 ± 4.39	21.3 ± 4.58	19.3 ± 3.93	20.2 ± 3.96	ns	ns	ns
	Bitter	28.2 ± 4.85	25.3 ± 4.36	25.9 ± 4.16	25.4 ± 4.24	23.4 ± 4.10	25.8 ± 4.77	*	*	ns
Palate	Berry Fruit	48.1 ± 4.11	49.9 ± 3.88	50.1 ± 3.88	51.9 ± 3.42	51.5 ± 3.48	50.9 ± 3.39	ns	ns	ns
	Dried Fruit	43.9 ± 4.25	41.0 ± 3.51	40.3 ± 3.51	38.0 ± 3.57	38.0 ± 3.45	36.5 ± 3.51	***	ns	ns
	Ripe Fruit	40.7 ± 4.29	39.4 ± 4.25	39.4 ± 3.98	41.7 ± 3.91	40.4 ± 3.72	38.8 ± 3.76	ns	ns	ns
	Black Olives	28.5 ± 3.32	29.2 ± 3.53	25.5 ± 3.07	25.0 ± 3.05	26.7 ± 3.00	25.8 ± 3.23	*	ns	ns
	Spice	36.0 ± 4.11	36.8 ± 4.28	35.6 ± 4.15	35.9 ± 4.07	34.6 ± 3.68	35.4 ± 4.14	ns	ns	ns
	Savoury	19.0 ± 4.10	18.5 ± 3.80	16.5 ± 3.44	16.3 ± 3.41	17.5 ± 3.50	16.8 ± 3.36	*	ns	ns
	Veg Green	11.0 ± 2.59	12.8 ± 2.47	10.7 ± 2.42	12.1 ± 2.43	11.4 ± 2.42	11.8 ± 2.45	ns	ns	*
	Mint	9.8 ± 2.49	10.2 ± 2.51	9.3 ± 2.49	9.9 ± 2.52	9.2 ± 2.52	9.8 ± 2.46	ns	ns	ns
	Chocolate	11.5 ± 2.55	10.7 ± 2.29	11.0 ± 2.33	10.4 ± 2.23	10.4 ± 2.29	9.4 ± 2.13	*	ns	ns
Mouthfeel	Body	61.9 ± 3.97	61.4 ± 4.12	57.8 ± 4.14	51.7 ± 4.17	54.3 ± 4.31	56.6 ± 3.88	***	ns	*
	Tan Qty	57.5 ± 3.31	54.8 ± 3.32	51.5 ± 3.32	48.2 ± 3.07	48.9 ± 3.46	47.3 ± 3.14	***	ns	ns
	Tan Qly	52.6 ± 3.37	51.7 ± 3.64	47.4 ± 3.54	43.9 ± 3.37	44.8 ± 3.56	45.1 ± 3.50	***	ns	ns
After taste	Fruit	45.9 ± 4.96	45.6 ± 4.55	44.6 ± 4.55	44.3 ± 4.29	46.0 ± 3.97	43.8 ± 4.45	ns	ns	ns
	Alcohol	70.0 ± 4.18	70.9 ± 3.68	69.9 ± 4.29	67.9 ± 4.30	68.6 ± 4.31	69.0 ± 4.35	ns	ns	ns
	Non Fruit	77.0 ± 2.52	75.7 ± 2.39	74.7 ± 2.58	72.5 ± 3.05	70.3 ± 3.12	72.3 ± 3.14	**	ns	ns

Table 5 Wine sensory analysis from wines made from vine grown at two temperatures (control and heated) combined with three pruning times at Nuriootpa in 2015. Values are average ± standard error in a 0-100 scale, and significance is shown as * (P<0.05), ** (P<0.01) and *** (P<0.001) from analysis of variance for T = temperature, P = pruning and TxP = interaction.

Sense	Trait	Control			Heated			Significance		
		Winter	Budburst	2-3 leaves	Winter	Budburst	2-3 leaves	T	P	TxP
Colour	Opacity	64.9 ± 1.47	70.4 ± 1.21	69.1 ± 1.37	62.2 ± 1.85	58.8 ± 1.87	67.9 ± 1.39	***	***	***
Aroma	Red fruit	47.3 ± 1.91	47.8 ± 1.88	51.1 ± 2.19	46.5 ± 2.26	46.9 ± 2.07	50.4 ± 1.90	ns	**	ns
	Dark fruit	54.7 ± 1.91	55.8 ± 1.90	56.3 ± 2.13	53.6 ± 1.57	55.0 ± 1.79	55.8 ± 1.59	ns	ns	ns
	Dried fruit	46.7 ± 2.07	45.1 ± 1.91	45.9 ± 2.20	48.0 ± 2.26	50.8 ± 1.87	46.2 ± 2.08	*	ns	ns
	Cooked fruit	42.9 ± 2.48	44.0 ± 2.47	44.8 ± 2.47	43.9 ± 2.62	43.7 ± 2.56	43.1 ± 2.67	ns	ns	ns
	Black olive	36.7 ± 1.80	37.6 ± 1.92	35.5 ± 1.73	38.6 ± 1.98	36.8 ± 2.19	35.5 ± 1.96	ns	ns	ns
	Floral	27.7 ± 2.11	29.6 ± 2.06	32.0 ± 2.42	28.6 ± 2.12	28.1 ± 2.15	30.3 ± 2.13	ns	*	ns
	Vegetal Green	23.2 ± 1.89	21.7 ± 1.73	22.3 ± 1.85	23.0 ± 1.90	22.4 ± 2.03	21.9 ± 1.72	ns	ns	ns
	Pepper	29.1 ± 1.65	30.5 ± 1.71	28.9 ± 1.43	27.3 ± 1.35	27.8 ± 1.39	29.9 ± 1.69	ns	ns	ns
	Minty	31.7 ± 2.39	30.4 ± 2.71	34.0 ± 3.32	31.5 ± 2.33	29.8 ± 2.70	33.6 ± 2.96	ns	ns	ns
	Spice	36.1 ± 1.93	35.7 ± 1.69	35.8 ± 1.55	33.2 ± 1.97	36.6 ± 1.71	34.4 ± 1.85	ns	ns	ns
	Confectionery	22.4 ± 1.68	23.0 ± 1.45	24.9 ± 1.74	24.5 ± 1.73	23.2 ± 1.54	24.9 ± 1.62	ns	ns	ns
	Meaty	25.9 ± 1.93	24.5 ± 1.67	21.9 ± 1.46	26.4 ± 1.90	25.4 ± 2.04	23.2 ± 1.71	ns	**	ns
	Licourice	29.1 ± 1.66	26.9 ± 1.47	25.7 ± 1.27	26.6 ± 1.49	28.5 ± 1.84	27.7 ± 1.63	ns	ns	ns
Palate	Red fruit	46.5 ± 2.13	51.1 ± 1.79	50.8 ± 1.86	48.9 ± 2.08	46.8 ± 1.77	50.9 ± 1.86	ns	**	**
	Dark fruit	53.4 ± 2.15	53.7 ± 1.58	54.1 ± 2.00	52.1 ± 1.73	53.9 ± 1.50	53.1 ± 1.90	ns	ns	ns
	Cooked fruit	47.1 ± 2.42	47.6 ± 2.54	49.1 ± 2.69	45.6 ± 2.68	45.9 ± 2.25	47.6 ± 2.88	ns	ns	ns
	Black olive	39.8 ± 1.85	38.8 ± 1.39	41.6 ± 1.27	38.9 ± 1.63	42.6 ± 1.52	39.5 ± 1.55	ns	ns	ns
	Vegetal	24.8 ± 1.33	23.6 ± 1.24	23.6 ± 1.47	25.2 ± 0.92	25.4 ± 1.17	25.6 ± 1.10	ns	ns	ns
	Pepper	31.4 ± 0.93	33.4 ± 1.29	32.8 ± 1.27	27.3 ± 1.40	29.6 ± 1.12	29.5 ± 1.10	***	ns	ns
	Spice	38.4 ± 1.23	38.7 ± 1.58	37.8 ± 2.03	33.7 ± 1.55	35.9 ± 1.29	37.6 ± 1.75	ns	ns	ns
	Meaty	20.9 ± 0.94	27.2 ± 1.41	31.4 ± 1.47	20.5 ± 0.80	21.2 ± 0.88	21.6 ± 1.03	***	***	***
Taste	Acidity	55.6 ± 1.31	50.3 ± 1.12	48.5 ± 1.05	53.9 ± 1.60	55.1 ± 1.21	52.3 ± 1.87	ns	*	ns
	Bitterness	38.8 ± 1.56	35.5 ± 1.76	35.3 ± 1.55	40.3 ± 1.89	38.6 ± 1.58	38.9 ± 2.26	ns	ns	ns
	Salty	29.3 ± 1.64	30.5 ± 1.59	31.5 ± 1.62	31.0 ± 1.80	30.4 ± 1.49	31.0 ± 1.65	ns	ns	ns
	Sweetness	47.7 ± 1.82	45.5 ± 1.73	42.4 ± 1.93	45.5 ± 2.36	44.5 ± 1.48	45.6 ± 1.79	ns	ns	ns
Mouthfeel	Body	43.8 ± 1.76	44.9 ± 1.61	45.2 ± 1.26	44.7 ± 1.77	46.1 ± 1.70	40.4 ± 1.55	ns	ns	ns
	Alcohol heat	49.8 ± 1.57	50.9 ± 1.16	49.1 ± 1.39	50.3 ± 1.57	49.4 ± 1.58	50.3 ± 1.62	ns	ns	ns
	Astringency	51.5 ± 2.12	54.4 ± 2.00	47.3 ± 1.74	49.2 ± 2.19	47.8 ± 2.29	50.2 ± 2.67	ns	ns	ns
After taste	Aftertaste	55.5 ± 1.77	55.5 ± 1.67	52.2 ± 1.50	50.8 ± 1.06	51.0 ± 1.52	51.9 ± 1.48	*	ns	ns

Marananga trial

Table 6 shows sensory, Figure 4 chemical attributes of wines and Figure 6 the combined analysis. In 2014, time of pruning affected 9 out of 35 sensory attributes. Late pruning favoured a more intense colour described as opacity and it was strongly correlated to more intense body, mouthfeel and chocolate aroma. The 2-3 leaves pruning wine showed more intense aroma of dark fruit, and more flavour of red fruit while budburst pruning wine showed more floral aroma, and dark and ripe fruit flavours. Overall, winter pruning wines showed less fruit aroma, colour intensity and fruit flavours and body when compared with later pruning ones.

In 2015, time of pruning affected 13 out of 42 sensory attributes. The panellists decided not to score for wine colour intensity due the high intense and consistent purple showed across all pruning treatments. Wines made from late pruning showed more intense aromas of savoury and miscellaneous. Winter pruning wines tasted sweeter, and less bitter, acidic and salty than late pruning wines. In the palate the former wines had more intense red fruit, fruit sweetness, vanilla and confectionary flavours.

Alcohol content was 16.2% ± 0.2 across all treatments in 2014 and the vintage had a significant effect in 8 out of 9 colour and co-pigmentation traits; the exception was tannins. Pruning time affected 5 out of 9 traits, and the interaction between vintage and pruning time was significant for 6 traits. Anthocyanins, total polyphenols, colour density, total pigments, SO_2 resistant pigments, co-pigmentation, % polymerisation and delta colour were all higher in 2015. This is partially related to untimely, large rain events in 2014 compared to the drier conditions for 2015. Late pruning increased the wine's anthocyanin and the difference between winter and late pruning (about 120 mg/l) was more marked for 2015 (significant interaction). The late pruning treatments increased tannin and total polyphenol; however the difference in tannins was higher in 2014 than in 2015. As result of these effects, the colour density and total pigments increased in the late pruning treatments. Hue and chemical age were lower in 2015, and these were also affected differentially by pruning time in the two vintages.

Principal component analysis was used to explore the associations between wine chemical and sensorial traits that responded to pruning time. PC1 and PC2 accounted for 85 % of the variance in 2014 and 76% in 2015. In both vintages, the three pruning dates showed consistent differentiation of wines. In 2014, PC1 was best explained by the palate-fruit, wine colour, mouthfeel body in the sensory profile, and total anthocyanin in the chemical analysis. PC2 represents the variation between % polymerisation and % degree of ionization of anthocyanin. In 2015, PC1 was best explained by the mouthfeel tannin quality, mint and pepper palate (sensory) and the total anthocyanin, colour density, tannins, total phenolic, SO_2 resistant pigments, hue, chemical age (chemical); PC2 was best explained by the confectionary, red fruit and vanilla palate, and the glucose-fructose as residual sugars.

Table 6 Wine sensory analysis from two vintages at Marananga trial. NA indicates traits that the panel decided not to assess. Values are average ± standard error in a 0-100 scale, and P values are from analysis of variance

Sense	Trait	Vintage 2014				Vintage 2015			
		Winter	Budburst	2-3 leaves	P-value	Winter	Budburst	2-3 leaves	P-value
Colour	Opacity	91.3 ± 0.85	93.9 ± 0.73	91.8 ± 0.82	**0.0011**	NA	NA	NA	NA
Aroma	Red fruit	54.0 ± 2.91	55.0 ± 2.94	56.7 ± 2.89	0.156	41.7 ± 1.81	42.4 ± 1.72	43.5 ± 1.75	0.6658
	Dark fruit	55.6 ± 2.74	58.9 ± 2.69	60.1 ± 2.87	**0.0015**	47.5 ± 1.78	46.8 ± 1.85	45.7± 1.84	0.4477
	Overripe fruit	45.9 ± 3.14	46.0 ± 3.12	46.1 ± 3.22	0.9811	40.6 ± 1.83	39.7 ± 1.97	41.2 ± 2.03	0.3614
	Black olive	34.8 ± 3.04	33.1 ± 2.77	35.8 ± 2.90	0.0682	14.3 ± 1.01	13.9 ± 1.06	15.3 ± 1.06	0.4529
	Floral	23.8 ± 2.01	27.6 ± 2.33	27.5 ± 2.24	**0.0119**	16.0 ± 1.15	17.1 ± 1.16	15.8 ± 1.11	0.3708
	Vegetal Green	22.8 ± 2.11	23.1 ± 2.23	21.9 ± 2.13	0.4989	13.6 ± 1.10	11.8 ± 1.00	13.4 ± 1.09	0.183
	Mint/menthol	30.1 ± 1.76	30.4 ± 1.92	28.2 ± 1.97	0.1569	15.0 ± 1.02	14.9 ± 1.06	15.6 ± 1.15	0.8115
	Pepper	29.9 ± 2.20	29.6 ± 2.53	29.3 ± 2.25	0.8865	14.9 ± 1.14	15.2 ± 1.12	16.4 ± 1.28	0.3079
	Spice	35.1 ± 2.35	34.4 ± 2.54	33.6 ± 2.33	0.4597	18.9 ± 1.20	19.1 ± 1.15	18.1 ± 1.19	0.5897
	Chocolate	32.7 ± 2.68	36.1 ± 2.87	33.0 ± 2.57	**0.0102**	10.5 ± 0.76	12.9 ± 0.86	11.9 ± 0.83	0.0515
	Confectionery	31.1 ± 3.04	33.1 ± 3.10	33.3 ± 3.18	0.2117	15.3 ± 1.24	17.2 ± 1.37	17.1± 1.29	0.333
	Earthy	20.7 ± 2.02	19.6 ± 1.76	19.6 ± 1.58	0.5407	14.2 ± 1.17	14.5 ± 1.20	13.7 ± 1.11	0.8706
	Savoury	27.4 ± 2.16	25.5 ± 2.08	27.1 ± 2.08	0.3734	15.5 ± 1.12	14.6 ± 1.03	17.1 ± 1.14	**0.0111**
	Soya Sauce	25.0 ± 1.85	22.4 ± 1.76	26.4 ± 1.98	**0.0464**	NA	NA	NA	NA
	Leather	22.4 ± 2.16	22.4 ± 2.16	20.4 ± 1.62	0.0943	10.1 ± 0.77	11.6 ± 0.83	11.4 ± 0.83	0.1261
	Miscellaneous	NA	NA	NA	NA	12.1 ± 1.37	12.5 ± 1.50	14.2 ± 1.79	**0.0229**
Taste	Acid	49.0 ± 2.19	49.2 ± 2.16	48.9 ± 2.19	0.9557	49.9 ± 1.35	54.7 ± 1.25	55.0 ± 1.37	**0.0006**
	Sweet	22.9 ± 2.46	22.1 ± 2.37	21.1 ± 2.12	0.3237	26.9 ± 1.63	17.9 ± 1.42	17.9 ± 1.44	**<.0001**
	Salty	NA	NA	NA	NA	8.1 ± 0.81	10.3 ± 1.15	9.8 ± 1.09	**0.0377**
	Bitter	18.9 ± 2.14	19.2 ± 1.86	20.6 ± 2.20	0.3607	11.0 ± 0.93	12.9 ± 1.08	13.3 ± 1.07	**0.0228**
Palate	Red fruit	49.7 ± 2.97	52.2 ± 2.82	53.1 ± 2.91	**0.0453**	43.0 ± 1.96	40.7 ± 1.88	38.6 ± 1.91	**0.0085**
	Dark fruit	53.3 ± 3.05	57.7 ± 3.11	59.0 ± 3.23	**<.0001**	44.9 ± 1.90	45.2 ± 1.90	42.6 ± 1.83	0.1899
	Ripe fruit	37.4 ± 3.24	40.8 ± 3.19	40.8 ± 2.97	**0.002**	39.1 ± 1.91	39.6 ± 1.89	38.6 ± 1.98	0.9935
	Fruit sweetness	NA	NA	NA	NA	39.4 ± 1.83	32.5 ± 1.91	30.4 ± 1.84	**<.0001**
	Vegetal green	26.3 ± 2.33	27.4 ± 2.42	27.1 ± 2.32	0.5766	11.0 ± 0.84	11.6 ± 0.87	14.7 ± 1.07	**0.0014**
	Mint/menthol	29.3 ± 2.07	31.7 ± 2.29	30.9 ± 2.33	0.1099	12.3 ± 0.96	13.6 ± 0.97	15.0 ± 1.11	**0.0401**
	Pepper	31.1 ± 2.53	31.9 ± 2.72	31.8 ± 297	0.7412	16.1 ± 1.17	18.6 ± 1.18	19.4 ± 1.22	**0.0058**
	Spice	34.1 ± 2.46	35.3 ± 2.61	33.8 ± 2.61	0.4179	19.4 ± 1.19	18.6 ± 1.08	20.0 ± 1.16	0.5067
	Savoury	27.9 ± 2.40	26.1 ± 2.36	27.0 ± 2.47	0.4739	13.1 ± 1.08	12.7 ± 1.03	14.4 ± 1.05	0.1871
	Vanilla	NA	NA	NA	NA	18.2 ± 0.98	15.2 ± 0.84	13.7 ± 0.90	**<.0001**
	Confectionery	NA	NA	NA	NA	18.1 ± 1.56	15.5 ± 1.36	14.8 ± 1.39	**0.025**
Mouthfeel	Wine Body	53.5 ± 1.36	57.8 ± 1.47	56.3 ± 1.78	**0.0072**	48.2 ± 1.19	49.3 ± 1.21	48.6 ± 1.18	0.7842
	Tannin quantity	53.7 ± 1.16	55.7 ± 1.26	54.0 ± 1.26	0.2869	47.4 ± 1.47	49.9 ± 1.56	50.1 ± 1.37	0.1172
	Tannin quality	56.4 ± 1.46	58.3 ± 1.42	58.7 ± 1.34	0.2742	41.0 ± 1.63	45.2 ± 1.62	45.7 ± 1.53	**0.0068**
After taste	Fruit flavour	50.2 ± 2.84	51.1 ± 2.62	48.7 ± 2.56	0.0941	53.8 ± 2.07	48.0 ± 2.19	46.5 ± 2.15	**<.0001**
	Alcohol	61.2 ± 2.21	62.5 ± 1.91	60.9 ± 2.05	0.3545	46.5 ± 1.79	50.2 ± 1.79	50.4 ± 1.76	**0.0137**
	Non Fruit	60.1 ± 2.15	61.3 ± 2.24	61.6 ± 2.14	0.4256	41.3 ± 2.51	44.6 ± 2.51	47.2 ± 2.62	**<.0001**

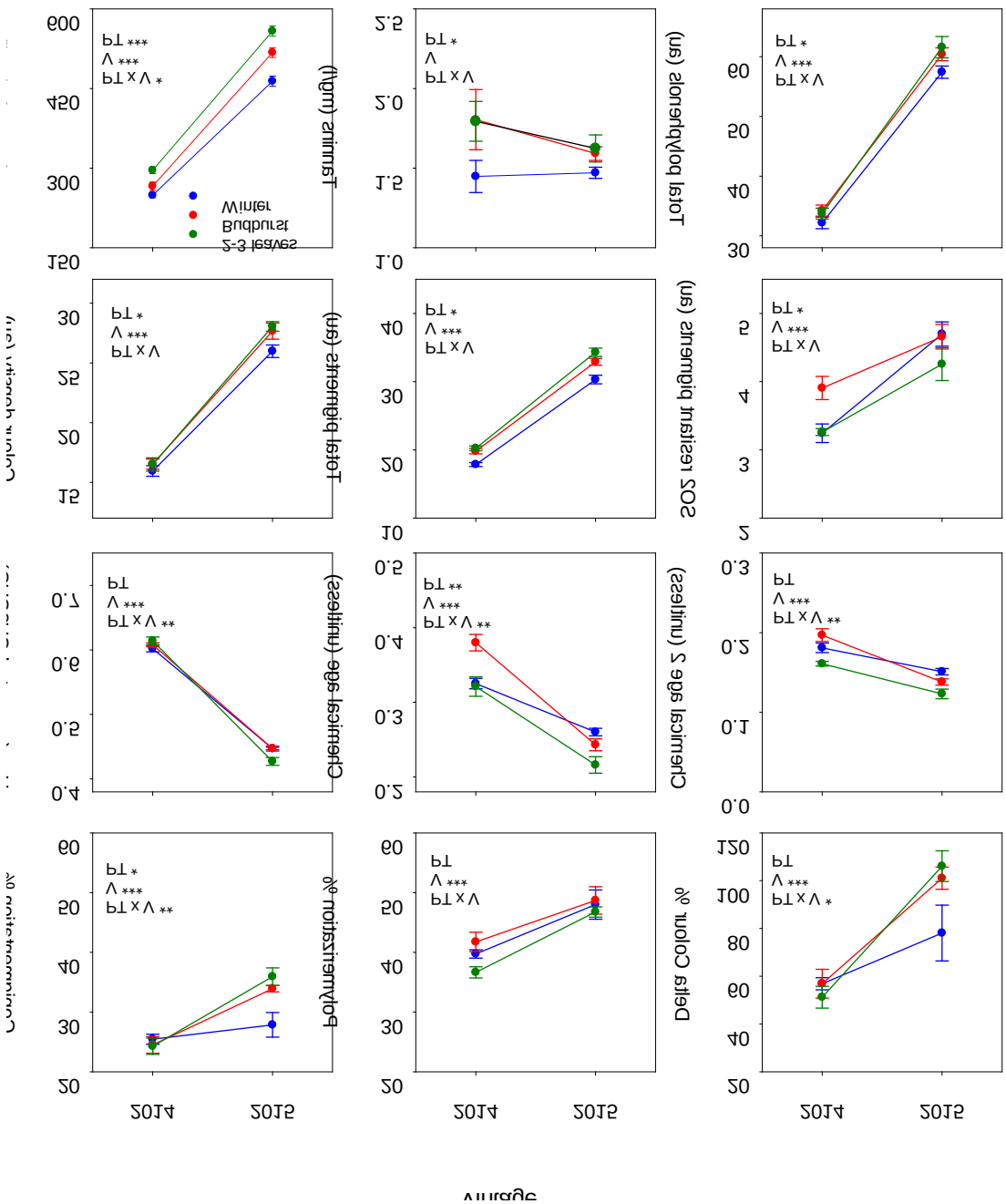


Figure 4. Wine chemical profiles in Marananga trial as affected by pruning time (PT), vintage (V) and their interaction (PT x V). Asterisks indicate * P < 0.05, ** P < 0.01, and *** P < 0.001. Error bars are two standard errors.

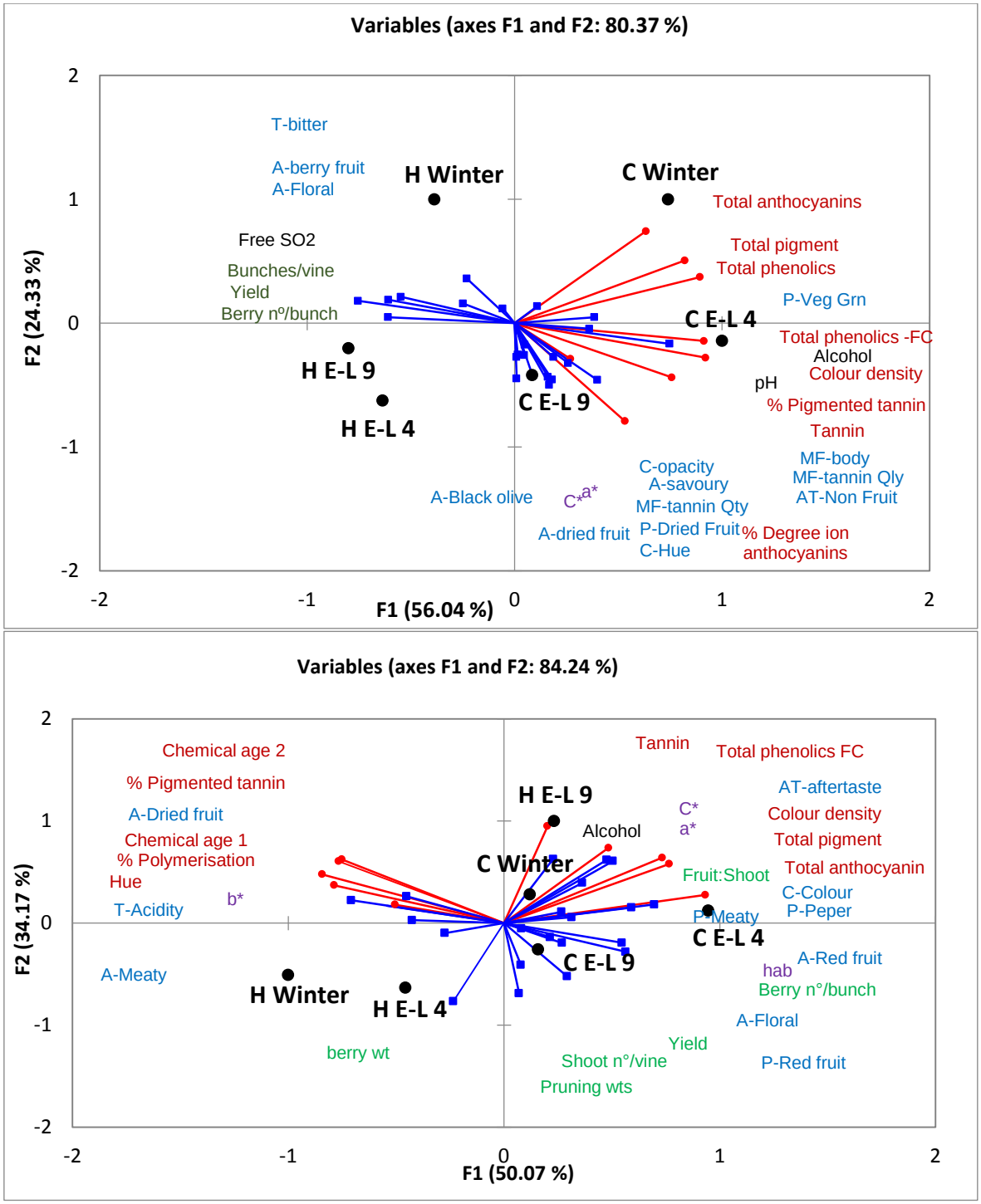


Figure 6 Principal component analysis of chemical (red) and sensory (blue) attributes of wines in Marananga trial for 2014 (top) and 2015 (bottom) vintages. Time of pruning is winter (Win), budburst (E-L4) and 2-3 leaves (E-L 9).

Conclusions and Recommendations

Warming has two major impacts on the wine industry: advanced and compressed harvest, and unbalanced wines. This project has sought to investigate whether delayed pruning can be used as a practical, inexpensive and environmentally-friendly practice to decompress harvest and restore wine balance.

To be a viable option in commercial vineyards, delayed pruning has to:

(1) shift phenology and delay maturity,
(2) be neutral or positive for yield,
(3) be neutral or positive for wine quality,
(4) be cost-neutral and fit current vineyard practices.

Combined, three (Nuriootpa trial) and four (Marananga trial) seasons returned seven cases where the criteria 1, 2 and 4 were tested. Wines were made in two seasons at each site, hence there were four cases to test criterion 3.

Criterion 1

Late pruning shifted phenology. Early events such as flowering were clearly separated in winter and late-pruned vines, and treatments tended to converge at later stages. Spread of maturity between winter and late pruning was up to two weeks. Untimely rainfall arresting sugar accumulation in berries cancelled the effect of pruning time in 2013-14. It is concluded that late pruning has potential to shift phenology and maturity, but the actual result is strongly influenced by seasonal conditions, and possibly other factors such as fruit/canopy ratio.

Criterion 2

In most cases, late pruning had no effect on yield in comparison with standard winter pruning. Occasionally, late pruning increased yield and occasionally it reduced yield, but these differences cancelled each other over time. Pooled across the whole dataset, the yield of late-pruned vines was 97% of the yield of winter pruned vines. The overall conclusion from the combination of sites, seasons and experimental set-up is that late pruning of Shiraz under Barossa conditions is, in the long term, neutral for yield.

Criterion 3

Wines were made in two vintages, 2014 and 2015, for both trials. Adverse effects of late pruning on wine quality were not obvious. Late-pruned vines produced consistently distinct wines in comparison to winter-pruned vines. In particular, wine from late-pruned vines developed more intense colour detected with both analytical and sensory methods. Notably, in 2015-16, late-pruning at Nuriootpa reverted the effects of warming on grape and wine characteristics.

Criterion 4

Late pruning was tested on a commercial vineyard, and was shown to fit well with standard practices. As the method involves only a change in the timing of pruning, it is cost-neutral. A commercial vineyard in Marananga established late pruning in 8 ha, and maintained this practice during four vintages; in 2015-16, an additional 4.8 ha were late–pruned. In addition late pruning has been implemented in other commercial vineyards in Barossa (20 ha), Langhorne Creek (20 ha), NE Victoria (10 ha) and Fleurieu region (8 ha). There is also interest in cooler regions, where 2ha Chardonnay was late-pruned in Adelaide Hills in the 2015 vintage.

Late pruning seems a practice with potential for Shiraz in Barossa Valley. Late pruning delays harvest maturity primarily by delaying the onset of sugar accumulation in berries, with further delays associated with lower rates. The actual spread of harvest that can be achieved in relation to winter-pruned vines depends on seasonal conditions; some factors such as untimely rainfall could cancel the maturity gap between late and winter pruned vines. Logistically, late pruning fits well with overall vineyard practices. Some minor adjustments might be needed. For example, it may be required to fine tune early fungicide sprays and timing of first and last irrigation. To achieve its goal of spreading maturity, late pruning has to be used on a rotational basis. This means combining conventional winter pruning and delayed pruning in proportions that have to be defined for the goals and conditions of particular vineyards. Whereas repeated late pruning over 2-4 seasons had no apparent carry over effect on vigorous vines, we suggest it is safer to avoid late pruning the

same vines over successive vintages. Late pruning can be feasible beyond Barossa Shiraz, but direct experimental tests are recommended for other sites and varieties.

Feedback from industry was positive throughout this project, with late pruning has already being adopted in commercial vineyards. A commercial vineyard in Marananga established late pruning in 8 ha, and maintained this practice during four vintages; in 2015-16, an additional 4.8 ha were late–pruned. In addition, late pruning has been implemented in other commercial vineyards in Barossa (20 ha), Langhorne Creek (20 ha), NE Victoria (10 ha) and the Fleurieu region (8 ha). There is also interest in cooler regions, where 2 ha Chardonnay was late-pruned in Adelaide Hills in the 2015 vintage.

Appendix 1: Communication

Results of the project were presented in two industry wine-tasting workshops, two updates at Treasury Wine Estates, eight industry articles and seven conference papers. The adoption of late pruning in commercial vineyards, as detailed above, highlights both the interest and potential of this practice, and our engagement and effective communication with industry.

Wine tasting workshops

2014 Workshop. It was held at Wolf Blass, Nuriootpa, on the 14th of November 2014; attendance: 12 growers and winemakers. The tasting consisted of five pair-wise comparisons to highlight the effects of pruning date, temperature and their combination in the Nuriootpa trial, and one pair-wise comparison from winter and late-pruned wines from the Marananga trial. The results of the workshop were further communicated to industry in an article published in The Australian & New Zealand Grapegrower and Winemaker (see next section).



Henschke winemaker Paul Hampton, left, with vineyard manager Travis Coombe at tasting workshop at Wolf Blass Winery at Nuriootpa.

2015 Workshop. It was held at Old Redemption Cellar Peter Lehmann Winery, on the 8th of October 2015; attendance: 30 growers and winemakers. The workshop included a brief presentation of the project and trials, and tasting consisted of x pair-wise comparisons to highlight the effects of pruning date, temperature and their combination in the Nuriootpa trial, and one pair-wise comparison from winter and late-pruned wines from the

Marananga trial using the guidelines in Appendix 2. The results of the workshop were further communicated to industry in an article published in The Australian & New Zealand Grapegrower and Winemaker (see next section).

Industry publications

1. Moran MA, Sadras VO, Petrie PR 2016 Sensory attributes of Barossa Shiraz 2015 in response to warming and pruning date. *Australian and New Zealand Grapegrower and Winemaker* April issue.
2. Petrie PR, Moran MA, Sadras VO (2015) Pruning after bud break to spread grape maturity. *Riverina Wine Grapes Newsletter*.
3. Sadras VO, Moran MA, Petrie PR 2015 Delayed pruning shifted Shiraz maturity by two weeks in 2015. Australian and New Zealand Grapegrower and Winemaker 617, 66-67.
4. Sadras VO, Moran MA, Petrie PR (2015) Pruning trials move into second round. *AGWA R&D eNews* http://research.agwa.net.au/pruning-trials-move-into-second-round/ March 2015
5. Sadras VO Second round of pruning trials 2015. *Australian New Zealand Grapegrower and Winemaker* 615, 53
6. Moran MA, Sadras VO, Petrie PR, Bastian S, Johnson T, Kwiatkowski M 2015 Pruning time and temperature influence on wine attributes. *Australian and New Zealand Grapegrower and Winemaker* 614:38-40
7. Sadras VO, Petrie PR, Moran MA 2014 Yield of Shiraz in response to warming and late pruning. *Australian New Zealand Wine Industry Journal* 605:38-39
8. Sadras VO, Petrie PR, Moran MA, Bastian S, Taylor D 2013 Decompressing harvest and preserving wine style in warming climates. *Australian New Zealand Wine Industry Journal* 594:47

Conference papers

Xiao Z, Sadras VO, Rogiers SY, Tyerman S 2016 Is Oxygen Deficiency the Cause of Cell Death in Grape Berries? *X International Symposium on Grapevine Physiology and Biotechnology*. Verona, 13-18th June 2016.

Xiao Z, Tyerman S, Sadras VO, Rogiers S 2015. The physiological cause of cell death in grape berries, *Crush 2015*, 20 November 2015 Adelaide, Australia.

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Appendix 3: Staff

Martin Moran was responsible for the field trials, wine making and data analyses. Paul Petrie contributed to the design and development of the project. Sue Bastian, Denis Taylor, Trent Johnson, Mariola Kwiatkowski, Joanna Gambetta, students from the sensory panel of Adelaide University and AWRI provided input in wine chemical and sensory analyses. Tim Malone and Jana Shepherd kindly supported our trial in Treasury Wine Estates vineyard at Marananga. SARDI's Nuriootpa staff maintained the experimental vineyard. Jacquie Selles, Gaston Sepulveda, Sandra Olarte-Mantilla and Marcos Bonada helped with field and laboratory work.