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Assessment of bunch thinning as a management technique for Semillon and Shiraz in a hot Australian climate

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ABSTRACT

Bunch thinning is a widespread management practice in vineyards and it has been reported to improve grape and wine quality depending on the timing and intensity of its application. This study assessed whether bunch thinning could affect vine performance, grape and wine chemistry and sensory attributes for Shiraz and Semillon in a hot Australian climate.

Own rooted Semillon and Shiraz vines planted in 1990 at the Waite Campus of the University of Adelaide were evaluated. For both varieties, bunch thinning was carried out by removing 50 % of bunches at veraison (EL35) for four and two seasons for Semillon and Shiraz, respectively. Vine performance, berry and wine chemistry and berry and wine sensory characteristics were assessed. Results showed a dramatic effect on yield but only minor effects on the other yield components. Berry and wine chemistry were also mostly unaffected by the treatment. Semillon wines from un-thinned vines were preferred, while for Shiraz, bunch thinning improved the wine acceptance by the sensory panel.

To support the decision on whether to bunch thin and justify its cost, a significant increase in fruit and wine quality should be expected; however, in this study, only mild effects were found. This study provides the wine industry with a better understanding of the effects of bunch thinning in a hot climate.

KEYWORDS: canopy management, vine balance, crop load, berry sensory, wine descriptive analysis, vine performance

INTRODUCTION

In recent years the wine sector has faced several challenges that have and will continue to affect the economic sustainability of growing grapes. Increased climate instability (Webb *et al*., 2012), a push towards more sustainable management practices (Daane *et al*., 2018) and a rise in the cost of inputs are all testing the resilience of the wine sector and the economic sustainability of grape growing. To maintain profitability, an improved understanding of the effectiveness of common vineyard practices is needed for different varieties and climatic conditions.

Canopy management is one of the main strategies applied in the vineyard to optimise canopy development, fruit ripening (Smart, 1985) and address wineries needs to maintain production and achieve a targeted wine style; however, these practices also represent a major production cost. Numerous techniques have been developed, applied, and studied to alter the canopy microclimate and favour ideal fruit ripening conditions (Smart, 1985; Vasconcelos and Castagnoli, 2000). Due to the complexity of grapevine physiology, the effect of these practices on grapevine performance can vary largely, and these manipulations can lead to different outcomes in yield parameters and berry composition depending on the variety and location (Palliotti *et al*., 2014).

Techniques such as leaf removal have been found to improve grape and wine chemistry through an increase in sunlight exposure and air circulation around bunches (Staff *et al*., 1997). The same technique, when applied late, has proven effective in delaying ripening without affecting grape chemistry for various varieties in Europe (Palliotti *et al*., 2013; Poni *et al*., 2013; Filippetti *et al*., 2015; Caccavello *et al*., 2017; Buesa *et al*., 2019), while only mild effects were achieved in a hot Australian climate (De Bei *et al*., 2019). Similarly, shoot thinning has often been reported to improve canopy light interception, leaf exposure and ventilation (Smart, 1992); however, it did not improve canopy microclimate and berry and wine chemistry when applied in hot Australian conditions (De Bei *et al*., 2020).
Bunch thinning is a management technique applied to adjust yield by regulating the partitioning between vegetative and reproductive growth (Nuzzo and Matthews, 2006) and reduce the crop load (Bravdo *et al*., 1985) to improve fruit maturity and quality (Preszler *et al*., 2013; Santesteban *et al*., 2011). It is more often carried out in vineyards targeted to produce premium wines (Silvestroni *et al*., 2016) as it is believed that overcropping could be detrimental to ripening and hence fruit and wine quality. The timing of bunch thinning varies from pre-flowering/flowering (thinning of inflorescence) to veraison, and it is often targeted to leaving one bunch per shoot (proximal bunch on the shoot) (Wolpert *et al*., 1983). Vegetative and reproductive growth are affected differently depending on the intensity and timing of application. Naor *et al*. (2002) have shown that early thinning can increase shoot growth due to the lack of competition from developing bunches. Other studies reported no influence of early thinning on vegetative growth (Smithyman *et al*., 1998). When applied at veraison, bunch thinning does not affect shoot growth and leaf area development (Reynolds *et al*., 1994; Valdés *et al*., 2009), but it has been reported to accelerate ripening (Nuzzo and Matthews, 2006; Preszler *et al*., 2013). The thinning intensity also impacts the results; Preszler *et al*. (2013) imposed reductions in bunch numbers as high as 66 % and as low as 4 % and showed that the effect on yield components correlated with the treatment intensity. Nuzzo and Matthews (2006) thinned to 25 %, 50 % and 75 % of the control and found that the intensity did not affect vegetative growth but affected sugar concentration. Santesteban *et al*. (2011), in a study conducted for four seasons in four Tempranillo vineyards, imposed a range of bunch thinning intensity that varied from 13 % to 76 % and concluded that the greater impact observed on grape quality was related to the water deficit rather than the thinning intensity.

Numerous studies have reported yield reductions in response to thinning at the phenological stages of flowering (Reynolds *et al*., 1994), pea-size (Sun *et al*., 2012; Keller *et al*., 2005) and veraison (Gil *et al*., 2013; Keller *et al*., 2005). However, the yield loss was not proportional to the thinning intensity due to compensation through increased berry and bunch weight (Reynolds *et al*., 2007; Sun *et al*., 2012; Gil *et al*., 2013). In terms of fruit and wine composition, studies showed that bunch thinning enhanced anthocyanins and phenolics (Guidoni *et al*., 2002; Keller *et al*., 2005; Nuzzo and Matthews, 2006), while results varied for pH and titratable acidity (Nuzzo and Matthews, 2006; Intrigliolo and Castel, 2011; Preszler *et al*., 2013). An advance in fruit maturity and increased sugar accumulation has been observed by various authors (Nuzzo and Matthews, 2006; Reynolds *et al*., 1994, Bowen *et al*., 2011).

The relationship between berry and wine properties is well documented and generally accepted in the wine industry (Le Moigne *et al*., 2008; Jackson and Lombard, 1993) however, studies on the effect of canopy manipulations on the sensory characteristics of wines are seldom and, even more so, are those on berry sensory assessments. Reynolds and Wardle (1989) found only minor differences in wine sensory characteristics when comparing a control to canopy manipulations such as leaf removal, bunch thinning and lateral shoot removal. Moreover, in their study, the control wines were described as being more balanced. In 1980, Freeman *et al.* (1980) did not find consistent effects in wine sensory scores due to yield manipulations, while Chapman *et al.* (2004) reported improvements in wine aromas in response to bunch thinning. Lohitnavy *et al.* (2010) were the first to demonstrate that the sensory characteristic of Semillon berries could be manipulated via canopy management practices. In a recent study by O'Brien *et al.* (2021), the importance of assessing both berry chemistry and sensory of canopy management trials is highlighted. In this latter study, differences were found between canopy manipulation treatments, but the sensory results were inconclusive.

This study aimed to evaluate the effect of bunch thinning on the performance of Semillon and Shiraz grown in a hot Australian climate. Yield components and grape and wine chemistry and sensory were assessed over two and four seasons for Shiraz and Semillon, respectively. It was hypothesised that bunch thinning would improve grape and wine quality for both varieties.

MATERIALS AND METHODS

1. Vineyard site and trial design

Measurements were carried out in a 1990 planting of Semillon (clone 32) and Shiraz (clone BVRC 12) on their own roots at the University of Adelaide (Waite Campus, South Australia, 34°58'3.47"S; 138°38'0.43"E) over a period of four growing seasons for Semillon, from 2014 to 2018 (season one (S1), 2014–15; season two (S2), 2015–16; season three (S3), 2016–17 and season four (S4), 2017–18), and two seasons for Shiraz, from 2016 to 2018 (S3 and S4). Both varieties were trained to a bilateral spur pruned cordon (two buds per spur) with vertically positioned shoots. Semillon vines were planted at a 3 × 1.8 m spacing (averaging 17 spurs/vine) and Shiraz to a 3 × 2.7 m spacing (averaging 22 spurs/vine). The blocks were irrigated with an average of 0.5 ML/ha.

A control (C), where no canopy interventions were carried out and a bunch thinning (BT) application performed at the onset of veraison, EL 33 (Coombe, 1995) (~10 °Brix) were compared. A fully randomised design was set up across three rows of Semillon, where each treatment was repeated once along each row in blocks of nine consecutive vines. Measurements were carried out on three vines per treatment per row. A different design was used for Shiraz, where own-rooted vines were selected on nine rows of a pre-existing rootstock trial. In each row, one vine per treatment was selected (n = 9). For the BT treatment, all bunches on the vines included in the trial were counted, on a per m basis, and exactly 50 % of them were removed in both varieties; distal, small and tangled ones were preferentially removed to emulate industry practice.

2. Climatic conditions at the site

The Kent Town weather station (station number 23090) of the Australian Bureau of Meteorology (http://www.bom.gov.au/) collected temperature and rainfall data. Hall and Jones (2010) have previously described the climate of the Adelaide Plains region, where this vineyard is located, as hot (minimum GDD = 2072, maximum GDD = 2209).

The mesoclimate at the vineyard site during the four growing seasons (October to April) has been previously described in De Bei *et al.* (2019) and De Bei *et al.* (2020). The growing degree days (GDD) (Gladstones, 2011) were 1811, 1899, 1770 and 1886 in S1, S2, S3 and S4, respectively, compared to a long-term average (LTA) of 1801. The LTA growing season rainfall was 198.4; during the four seasons of the trial, it varied from 137.8 mm (S1) to 354.2 mm (S3).

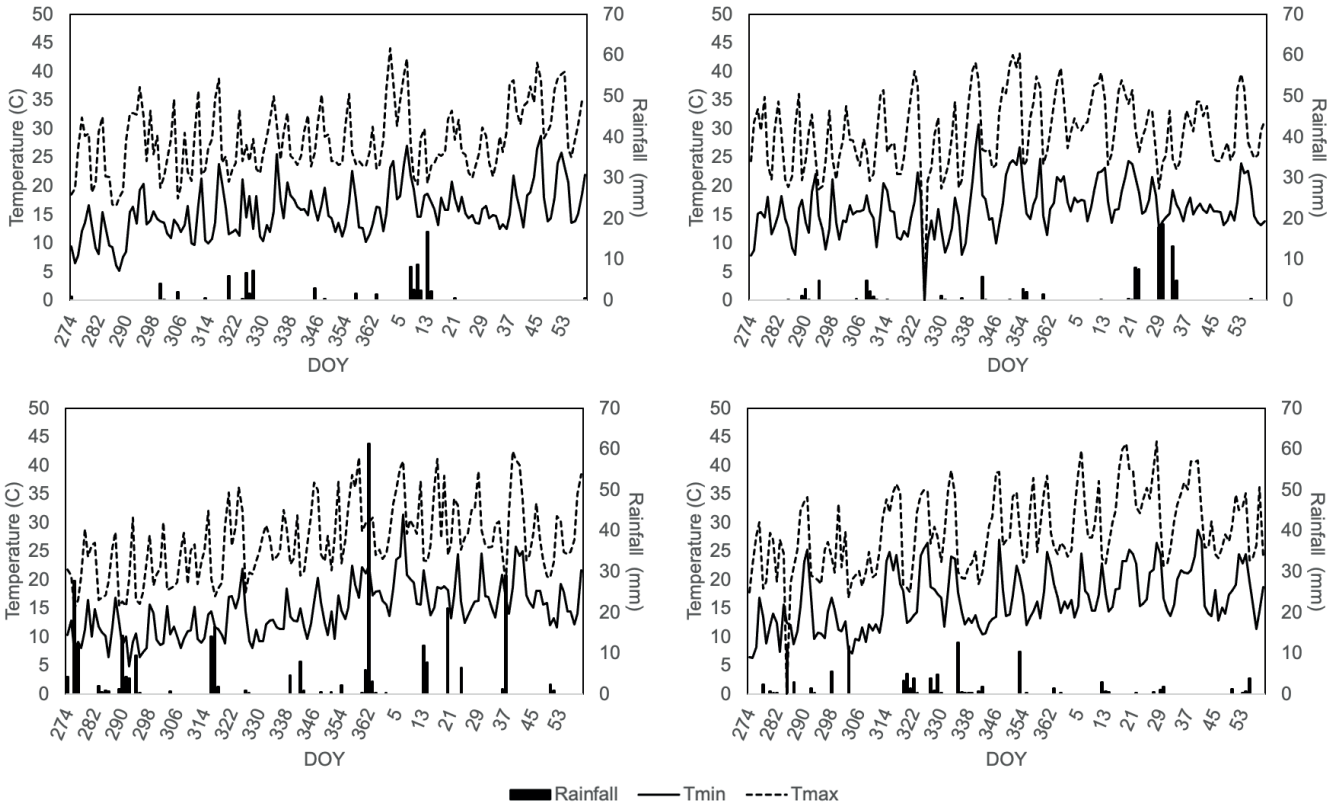


FIGURE 1. Daily minimum (Tmin), maximum (Tmax) and rainfall of the four growing seasons (Oct to Apr, DOY 274 to 59) of the trial.

Figure 1 depicts the minimum and maximum daily temperature and daily rainfall of the four growing seasons (October to April) of the trial. Season three was the wettest, with a peak of 61.2 mm of rain on the 28th Dec 2016; it was also the coldest of the four seasons.

3. Leaf area, yield components and grape composition

Leaf area was calculated according to the planimetric method described in De Bei *et al*. (2016) and from upward-looking photos analysed using the VitiCanopy app.

Berry weight, total soluble solids (TSS) (digital refractometer BRX-242 Erma Inc. Tokyo, Japan), total acidity (TA) and pH (Mettler Toledo auto titrator, Greifensee, Switzerland) were measured from EL 33 on a sample of 100 berries collected weekly from each replicate. The target TSS for harvest was ~23 °Brix in Semillon and ~26 °Brix in Shiraz (to align with commercial harvest levels); however, weather forecast and sanitary status of the grapes were also taken into account to determine harvest date.

Grapes were harvested when the TSS reached a level of ~23 °Brix in Semillon and ~26 °Brix in Shiraz (to align with commercial harvest levels). Vines were harvested individually, and bunches were counted and weighted. A sample of 50 berries was collected from the harvested fruit to be used for the measurement of total phenolics according to Iland *et al*. (2004) and total tannins as described in Mercurio *et al.* (2007). Yeast assimilable nitrogen (YAN) and L-malic content were also measured from the must samples using Vintessential kits (Mornington Peninsula, Australia) for primary amino acid nitrogen (PAAN), ammonia nitrogen (AN) and L-malic acid by discrete analysis on a ChemWell® 2910 (Megazyme, Bray, Ireland). YAN was calculated as the sum of PAAN and AN. In winter, vines were pruned, and the pruning weight was recorded. Leaf area/m (LA), yield/m (Y) and pruning weight/m (P) were used to calculate the vine balance indices LA/Y and Y/P.

4. Winemaking

Wines were made from 20 kg of fruit from each treatment replicate. The vineyard replicates were maintained to produce three wines per treatment. The winemaking procedure is described in detail in De Bei *et al.* (2019). The finished wines were bottled into 375 mL crown sealed glass bottles and stored in a temperature-controlled environment (18 °C) until further analysis.

5. Wine chemical analysis

On the finished wines, pH and TA were measured with an autotitrator (Mettler Toledo auto titrator, Greifensee, Switzerland), and alcohol (v/v) content was measured using an Alcolyzer Wine ME (Anton Paar, Graz, Austria). The method proposed by Iland *et al.* (2004) was applied to the measurement of total phenolics, while total tannins concentration was measured according to Mercurio *et al.* (2007) via the methylcellulose precipitate (MCP) assay.

6. Sensory assessments

Sensory assessment of berries (BSA) and wines were carried out as previously described in De Bei *et al.* (2019) and De Bei *et al.* (2020) and according to the method proposed by Olarte Mantilla *et al*. (2013). For the BSA, from the harvested fruit, a total of 300 berries per variety and treatment replicate were kept at 4 °C until assessment, which was carried out within one week. Attributes of the pulp (P), skin (Sk) and seeds (S) were assessed. A number of 14 attributes were assessed for Semillon as follows: P-juiciness, P-acidity, P-citrus flavour, P-tropical flavour, P-grassy flavour, P-flavour intensity, Sk-acidity, Sk-bitterness, Sk-astringency, Sk-grape flavour, Sk-grassy flavour and S-colour, S-flavour and S-astringency. The attributes assessed for Shiraz were: P-sweetness, P-acidity, P-dark fruit, P-red fruit, P-dried fruit, P-green/grassy, P-juiciness, Sk-acidity, Sk-bitterness, Sk-astringency, Sk-grassy flavour, Sk-dark fruit flavour, Sk-red fruit flavour, S-flavour, S-bitterness and S-astringency.

Assessors (10–12 depending on the season) were trained for two 2-hour sessions before the three formal assessment sessions required to complete the BSA.

Similarly, wine sensory assessment was carried out using descriptive analysis (DA) as described in De Bei *et al*. (2019). Panellists were trained using ranking exercises for attributes such as acidity, astringency and bitterness. Assessors were also asked to identify unknown aroma standards as a training exercise. In total, 22 attributes were assessed in each of the formal sessions for Semillon and 20 for Shiraz. Attributes were divided into categories as follows: aroma (Semillon: confectionery, citrus, tropical, grassy, intensity; Shiraz: dark fruit, red fruit, jammy, pepper, green/grassy, aroma intensity), taste (bitterness, acidity and sweetness), flavour (Semillon: bitter, acid, citrus, floral, stone fruit, confectionery, tropical, grassy; Shiraz: dark fruit, red fruit, jammy, pepper, green/grassy and spice), mouthfeel (body, astringency, alcohol) and aftertaste (fruit length, alcohol length, bitter length, likeability).

Both BSA and wine DA were approved by the University of Adelaide ethics committee (H2017-054) and took place in a sensory facility of the University of Adelaide at the Waite Campus.

7. Statistical analysis

Treatment comparisons, seasonal effects and the interaction of the two (treatment x season) were analysed via two-way ANOVA; means were then separated using the Tukey's test. Sensory results were assessed using the XLSTAT® product and sensory panel performance analysis tool. XLSTAT® (Version 2015.4.01.20116 Addinsoft SARL, Paris, France) was used for all statistical analyses.

Means were separated at a significance level of $p < 0.05$ for all data but the berry and wine sensory for which a significance of $p < 0.1$ was considered (Olarte Mantilla *et al.*, 2013).

RESULTS

1. Vine performance

Bunch thinning, as intended, reduced the number of bunches per m compared to C in both varieties (Table 1). This had a strong effect on yield, which was lower in BT in all seasons and varieties (Table 1 and supplementary tables S1 and S2). For Semillon, the greatest difference was observed in S1, where BT yielded 47 % less than C, while in S2, the difference was 29 %, the lowest in the whole trial (Table S1). For Shiraz, the yield was 50 % and 40 % lower in BT in S3 and S4, respectively (Table S2). Bunch and berry weight were not affected by BT apart from Semillon in S3 when they were both heavier in BT (Tables S1 and S2). S3 is the main driver of the general difference observed in bunch weight in Semillon (Table 1).

Semillon showed a smaller leaf area in BT; however, no differences were then observed in the pruning weight measure. For Shiraz, no differences were observed both in leaf area and pruning weight (Table 2). The LA/Y of Semillon, for all seasons and treatments, varied between 1.2 and 3.4. Given the much lower yield observed in BT in all seasons, it is not surprising that the LA/Y was higher in BT. On the other hand, the Y/P showed a wider variation (ranging from 4.7 to 15) and no differences between treatments in Semillon. For Shiraz, the LA/Y was higher in BT while the Y/P was greater in C (Table 1). Strong seasonal influences emerged for most of the yield component results in Semillon, while for Shiraz, only the bunch weight and leaf area were influenced by the season.

2. Sugar accumulation and berry growth

For the variety Semillon, in the first two seasons of the trial, differences were measured at harvest when, in S1, TSS was higher in BT and, in S2, berry weight was greater in BT. In S3, TSS was greater in BT in each sampling date, which brought forward the C's harvest by six days to ensure similar final TSS in both treatments. From DOY 55 to DOY 61, the sugar accumulation in C was 0.62 Brix/day, if this rate was maintained, C should have been harvested at DOY 59 to achieve the same TSS as BT. In S4, no differences were measured in either the sugar accumulation and berry growth in the two treatments. Similarly to what was observed in the previous season, in S4, BT was harvested four days earlier than C.

In Shiraz in S3, BT showed a faster sugar accumulation while no differences in berry weight were observed. In S4, similar differences were observed in sugar accumulation; however, it was the C treatment that showed a faster ripening pattern. However, as in the previous season, no differences were observed in berry weight.

3. Berry and wine chemistry

For the variety Semillon, the only difference observed was in wine phenolic content, which was greater in C (Table 2). On a seasonal level, only modest differences in berry chemistry were observed: harvest TSS was higher in BT in S1; TA was lower in BT in S3 and higher in S4 (Table S3). Given the difference in TSS in S1, the difference in wine alcohol for the same season was expected.

TABLE 1. Effect of bunch thinning (BT) on yield components and leaf area of Semillon and Shiraz grown in the Coombe vineyard of the University of Adelaide, Waite Campus, Adelaide, Australia. The trial was carried out for four consecutive seasons (from 2014 to 2018) for the variety Semillon and two (from 2016 to 2018) for Shiraz.

		Control	BT	Season	Treatment × Season
Semillon	Bunches (#/m)	36.7 a	21.3 b	ns	ns
	Yield (kg/m)	6.4 a	4.1 b	0.003	ns
	Bunch weight (g)	177.5 b	196.7 a	0.0001	ns
	Berry weight (g)	1.7	1.6	0.001	ns
	Leaf area (m^2/m)	9.1 a	8.4 b	0.0001	ns
	Pruning weight (kg/m)	0.77	0.69	0.001	ns
	LA/Y (m^2/kg)	1.5 b	2.3 a	0.0001	ns
	Y/P	10.6	7.5	ns	ns
Shiraz	Bunches (#/m)	28.1 a	16.1 b	ns	ns
	Yield (kg/m)	4.4 a	2.5 b	ns	ns
	Bunch weight (g)	158.1	156.7	0.009	ns
	Berry weight (g)	1.6	1.5	0.03	ns
	Leaf area (m^2/m)	7.7	7.7	0.010	ns
	Pruning weight (kg/m)	1.5	1.3	ns	ns
	LA/Y (m^2/kg)	2.1 b	3.3 a	ns	ns
	Y/P	3.2 a	1.9 b	ns	ns

C = control, BT = Bunch Thinning, LA = leaf area, Y = yield, P = pruning weight.

Treatment and season effects and their interactions were analysed using a two-way ANOVA and Tukey's test. Means followed by different letters are different at $p < 0.05$. ns = not significant.

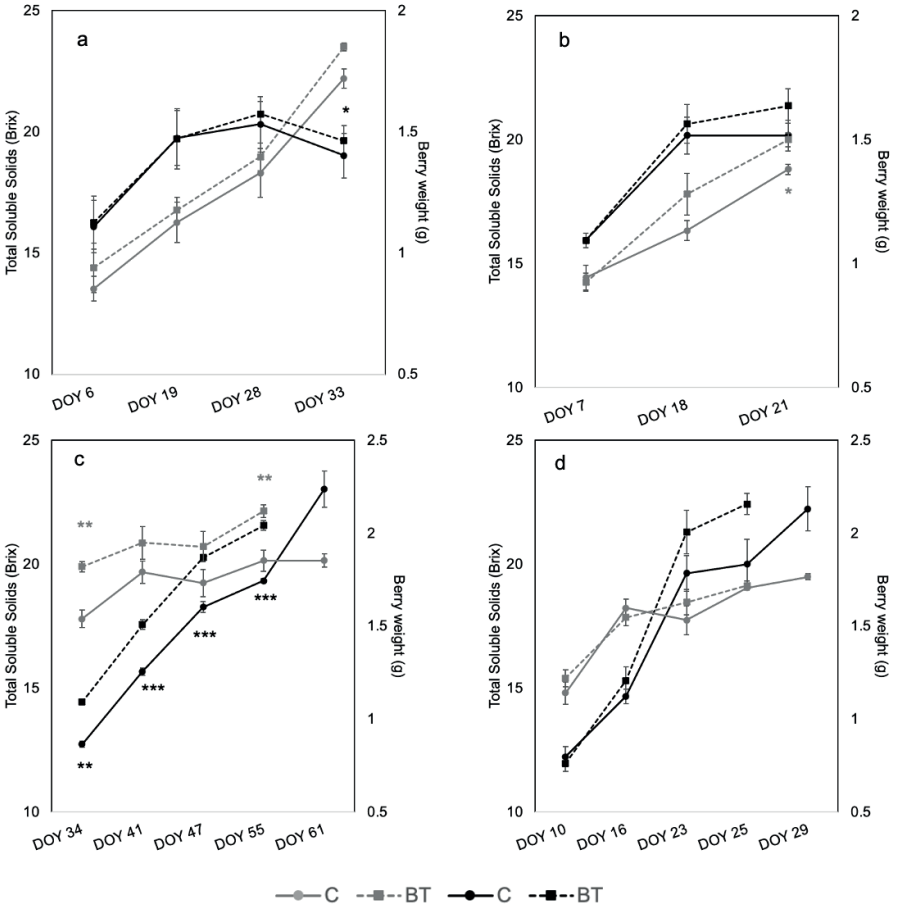


FIGURE 2. Changes in Total Soluble Solids (TSS) and berry weight during ripening of Semillon grown in the Coombe vineyard of the University of Adelaide, Waite Campus, Adelaide, Australia. The trial was carried out for four consecutive seasons: a: season one (S1), 2014–15; b: season two (S2), 2015–16; c: season three (S3), 2016–17; d: season four (S4), 2017–18.

Treatment effects were analysed using a one-way ANOVA and the means separated with Tukey's test. Means followed by different letters are different at $p < 0.05$. ns = not significant.

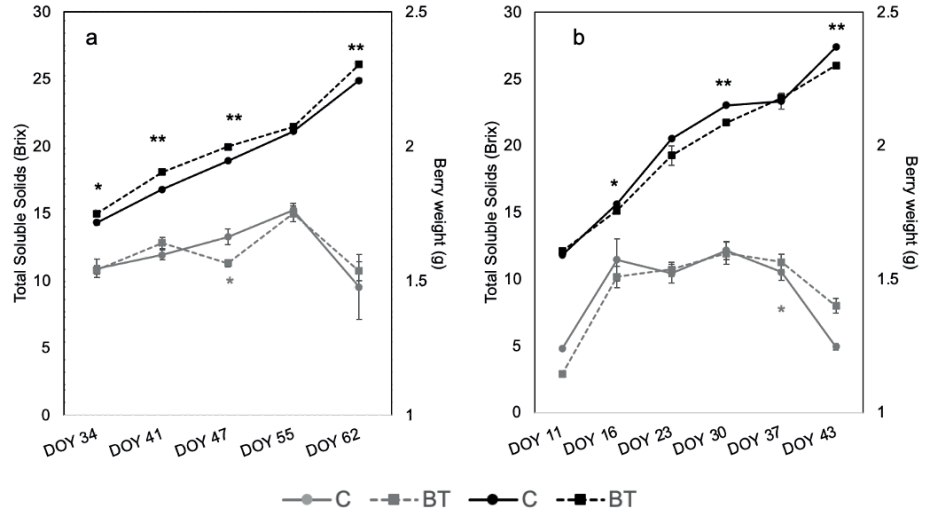


FIGURE 3. Changes in Total Soluble Solids (TSS) and berry weight during ripening of Shiraz grown in the Coombe vineyard of the University of Adelaide, Waite Campus, Adelaide, Australia. The trial was carried out for two consecutive seasons: a: season three (S3), 2016–17; b: season four (S4), 2017–18.

Treatment effects were analysed using a one-way ANOVA and the means separated with Tukey's test. Means followed by different letters are different at $p < 0.05$. ns = not significant.

In S4, however, despite no differences observed in TSS, the alcohol content of C wine was higher. Wine TA was different only in S3, where it was higher in C. pH was lower in C in both S1 and S3. Differences in phenolics were only observed in the wines of S3 when the measure was higher in C. In S4, no differences were observed in the malic acid content and yeast assimilable nitrogen (malic acid = 5.71 and 6.02 and YAN = 135 and 105 in C and BT, respectively); the phenolics were not measured.

In the two seasons when BT was trialled in Shiraz, on average, BT was harvested at a higher TSS (Table 3); however, at the seasonal level, this was only the case in one of the two seasons (Table S4). No differences were observed in TA, pH and total phenolics, while tannins and anthocyanins were higher in BT, both in berries and wines.

No differences were observed in the other wine chemistry measures taken (Table 3). A breakdown of the seasonal results is shown in Table S4 in the supplementary material.

4. Berry and wine sensory analysis

Differences in the sensory profile of the Semillon berries were found in all four seasons (Figure 1). The tropical flavour of the pulp was higher in S3 and lower in S1 and S4 for BT. The grassy flavour of the pulp was different in all seasons, and, apart from S2, berries were more green/grassy in BT. Similarly, in S1 and S3, the skin of C was also grassier. BT had the juiciest pulp in S1 and S3 but not in S4.

TABLE 2. Effect of bunch thinning (BT) on berry and wine chemistry of Semillon grown in the Coombe vineyard of the University of Adelaide, Waite Campus, Adelaide, Australia. The trial was carried out for four consecutive seasons (from 2014 to 2018).

		Control	BT	Season	Treatment × Season
Berry chemistry	Total Soluble Solids (Brix)	22.2	21.9	0.012	ns
	Titratable acidity (g/L)	8.7	8.9	0.0001	ns
	pH	3.2	3.2	0.0001	0.0001
	Total phenolics* (mg/g)	0.89	0.83	0.003	0.007
Wine chemistry	Alcohol (% v/v)	13.6	14	0.0001	ns
	Titratable acidity (g/L)	7.1	7.2	0.0001	ns
	pH	3.3	3.3	0.012	ns
	Total phenolics* (au)	7.7 a	6.7 b	0.0001	ns

*In season 4, total phenolics were not measured.

C = control, BT = Bunch Thinning

Treatment and season effects and their interactions were analysed using a two-way ANOVA and the means separated with Tukey's test. Means followed by different letters are different at $p < 0.05$. ns = not significant.

TABLE 3. Effect of bunch thinning (BT) on berry and wine chemistry of Shiraz grown in the Coombe vineyard of the University of Adelaide, Waite Campus, Adelaide, Australia.

		Control	BT	Season	Treatment × Season
Berry chemistry	Total Soluble Solids (Brix)	24.7 b	26.8 a	0.010	ns
	Titratable acidity (g/L)	5.8	5.6	ns	ns
	pH	3.6	3.7	0.042	ns
	Total phenolics* (mg/g)	1.04	1.18	ns	ns
	Tannins (mg/g)	0.46 b	0.52 a	ns	ns
	Anthocyanins (mg/g)	1.28 b	1.62 a	ns	ns
Wine chemistry	Alcohol (% v/v)	14.3	14.5	0.0001	ns
	Titratable acidity (g/L)	7.0	6.8	0.0001	ns
	pH	3.8	3.9	0.023	ns
	Total phenolics* (au)	33.6 b	42.3 a	0.001	ns
	Tannins (mg/L)	1.09 b	1.42 a	0.0001	ns
	Anthocyanins (mg/L)	371.7	427.2	0.0001	ns

C = control, BT = Bunch Thinning

Treatment and season effects and their interactions were analysed using a two-way ANOVA and the means separated with Tukey's test. Means followed by different letters are different at $p < 0.05$. ns = not significant.

The acidity of BT pulp was higher in S3 and S4, while the skin was less acidic in S3. BT skin was less bitter than C in three out of four seasons; similarly, the skins were less astringent in S2 and S3.

Only minor differences in the berry flavour profiles of Shiraz were found; in S3, BT berries were described as having more acidic skin and pulp, a juicier pulp and a more pronounced red fruit flavour compared to C (Figure 2). In S4, BT pulp was again described as juicier together with a more intense flavour of the pulp and more toasty flavoured seeds.

Differences between treatments were also observed in the Semillon wine descriptive analysis (Figures 3 and 4). Of the 22 attributes assessed by the panellists, in S1 and S2, only three were different between treatments (Figure 3a,b).

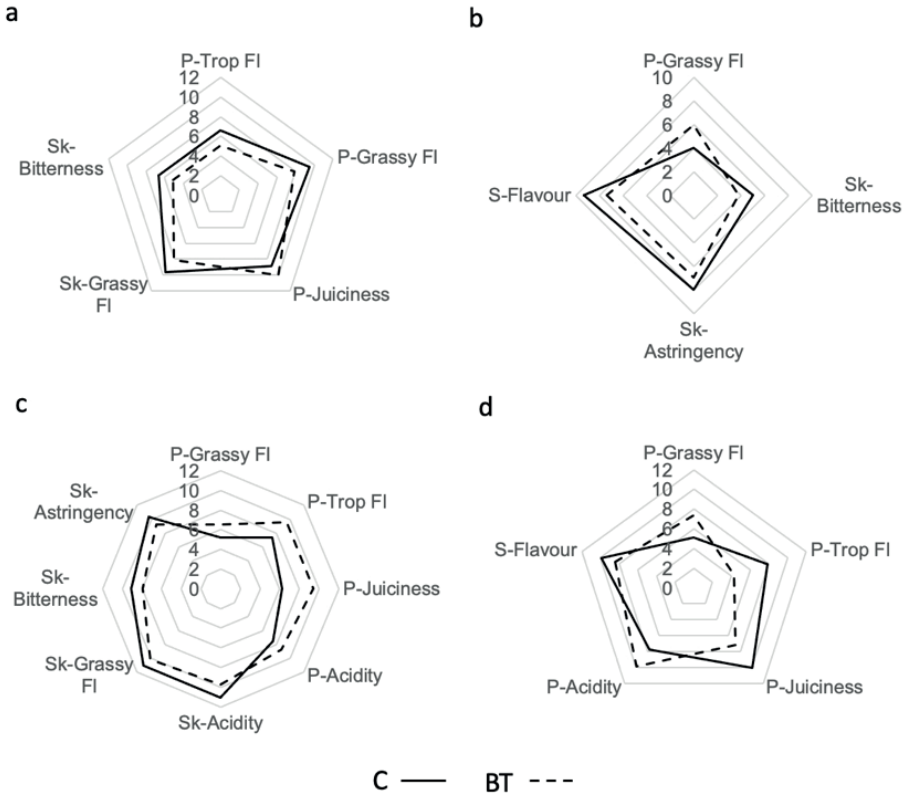


FIGURE 4. Radar plots of attributes found different at $p \leq 0.1$ in the berries of Control (C) (solid line) and bunch thinning (BT) (dashed line) treatments for Semillon grown in the Coombe vineyard of the University of Adelaide, Waite Campus, Adelaide, Australia.

a: season one (S1), 2014–15; b: season two (S2), 2015–16; c: season three (S3), 2016–17; d: season four (S4), 2017–18. P = Pulp, Sk = Skin, S = Seeds, Fl = Flavour.

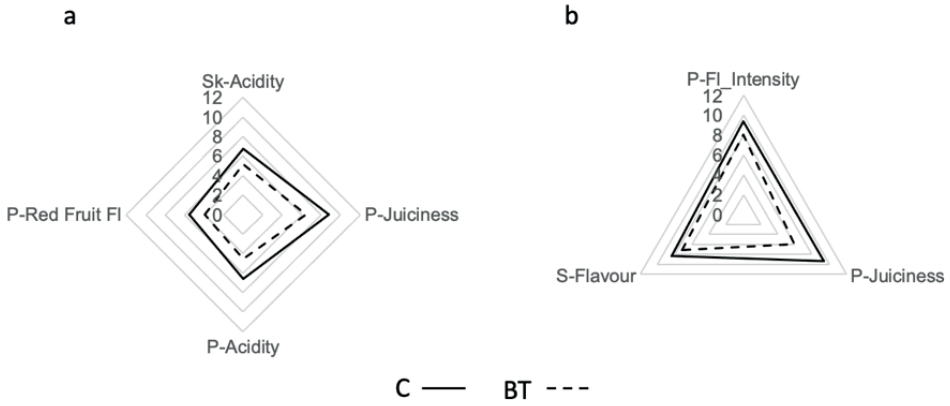


FIGURE 5. Radar plots of attributes found different at $p \leq 0.1$ in the berries of Control (C) (solid line) and bunch thinning (BT) (dashed line) treatments for Shiraz grown in the Coombe vineyard of the University of Adelaide, Waite Campus, Adelaide, Australia.

a: season three (S3), 2016–17; b: season four (S4), 2017–18. P = Pulp, Sk = Skin, S = Seeds, Fl = flavour.

In particular, in S1, BT wines demonstrated a greater overall bitterness and a lingering bitter finish compared to C. Moreover, C wines were more citrusy in flavour. Completely different attributes differentiated BT and C wines in S2; BT wines had a grassier aroma, more floral in flavour and presented a fuller body compared to C. In S3, all but one of the differentiating attributes were scored higher in C (citrus and tropical aroma, aroma intensity, stone fruit and tropical flavour and body) (Figure 3c). C was also the preferred wine (higher likeability score). The only attribute that was higher in BT in S3 was the bitter flavour.

In the last season, eight of the 22 attributes assessed were different (Figure 3d). BT wines were scored as aromatically grassier and more acidic in flavour.

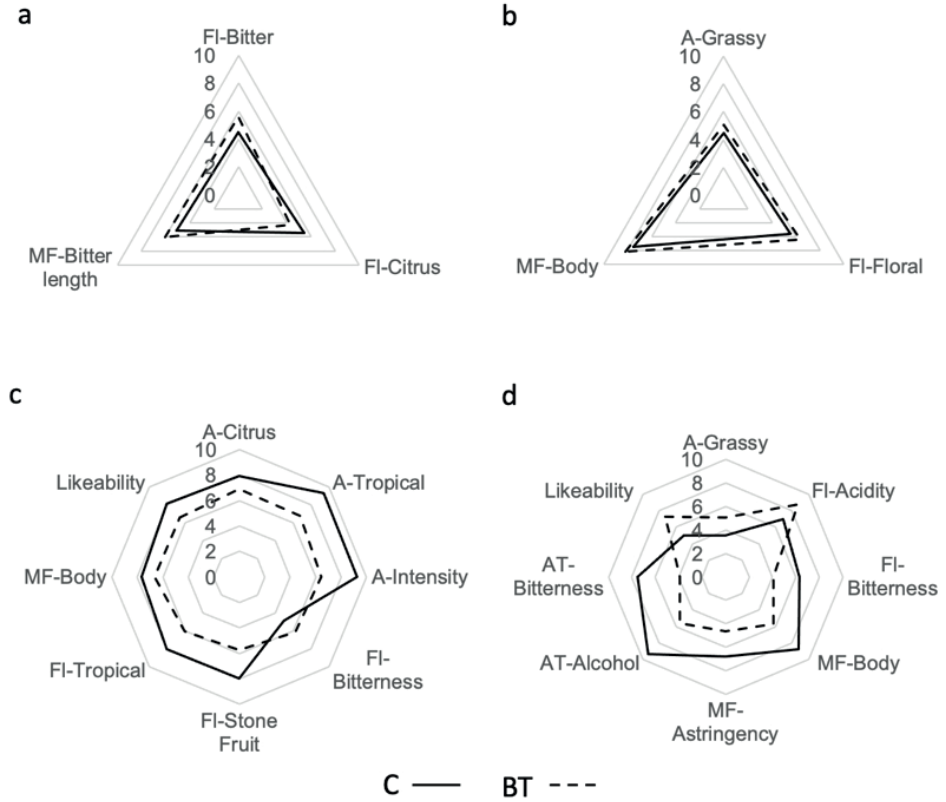


FIGURE 6. Radar plots of attributes found different at $p \leq 0.1$ in the wines of control (C) (solid line) and bunch thinning (BT) (dashed line) treatments applied to Semillon grown in the Coombe vineyard, Waite Campus, Adelaide.

a: season one (S1), 2014–15; b: season two (S2), 2015–16; c: season three (S3), 2016–17; d: season four (S4), 2017–18.
A = Aroma, Fl = flavour, MF = mouthfeel.

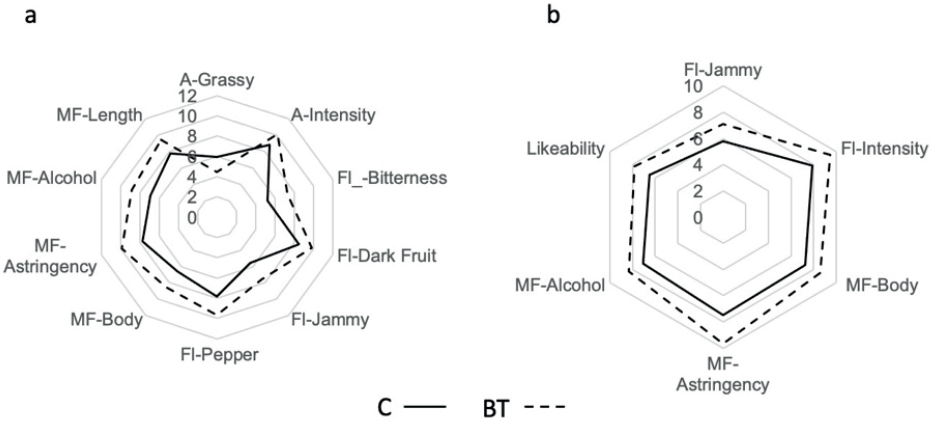


FIGURE 7. Radar plots of attributes found different at $p \leq 0.1$ in the wines of control (C) (solid line) and bunch thinning (BT) (dashed line) treatments applied to Shiraz grown in the Coombe vineyard, Waite Campus, Adelaide.

A = S3 = season three = 2016–17 ; b = S4 = season four = 2017–18.
A = Aroma, Fl = flavour, MF = mouthfeel.

On the other hand, C wines were more bitter both in flavour and aftertaste; the aftertaste was also scored as more alcoholic. The mouthfeel was more astringent in C, which also was scored as having more body. In this last season, BT wines were preferred.

As many as 11 attributes differed between C and BT Shiraz wine in S3 (Figure 4a). Specifically, BT wines were scored higher in all parameters but the grassy aroma. Six of the 11 attributes found to differ in S3 were also different in S4, and they were all higher in BT (Figure 4b). In this season, BT wines were also preferred to the C wines (higher likeability score).

DISCUSSION

Whether to bunch thin is of particular importance for high cropping varieties, in vigorous sites and it is required more often for red varieties than whites. The trial site in this study could be considered vigorous (leaf area/m as high as 11.5 and 8.4 m^2 for Semillon and Shiraz, respectively) and the variety Semillon, in particular, is high yielding (maximum of 7.3 kg/m during the trial). Keller *et al*. (2005) and Nuzzo and Matthews (2006) stressed that bunch thinning might improve fruit quality only in the case of overcropping (low LA/Y). However, often bunch thinning is carried out independently of LA/Y, which might lead to an absence of the expected changes in grape composition (Herrera *et al*., 2015).

1. Effects of bunch thinning on yield components

BT was carried out to remove 50 % of bunches/m; compared to C, the reduction in bunch number varied between 32 % and 51 % in the four seasons for Semillon, while in Shiraz, 43 % of the bunches were removed in both seasons. This greatly impacted yield, which was always lower in BT. For Semillon in S1 and S2, the percentage of yield loss was proportional to the difference in bunch number between treatments. In S3 and S4, a 51 % and 40 % reduction in bunch number by BT reduced yield by 38% and 31%, respectively. This was due to an increase in bunch weight observed in S3 and, to a lesser extent, in S4 (not significant). Greater berry weight in S3 in BT contributed to greater bunch weight. Increased berry weight is common when BT is performed early, after fruitset (Naor *et al*., 2002), but it is rarely reported for thinning carried out at veraison (Santesteban *et al*., 2011; Wang *et al.,* 2019). In Shiraz, the yield was reduced by almost 50 % in S3 and 38 % in S4; however, no differences were observed in bunch and berry weight. Bubola *et al*. (2017) and Howell (2001) also observed a proportional effect between bunches removed and yield reduction. Smith and Centinari (2019) observed the opposite effect in their trial on Gruner Veltliner, where a 30 % reduction in bunch number reduced yield by 40 % despite greater bunch weight.

Increased bunch weight is a common effect observed after repeatedly bunch thinning the same block; Preszler *et al*. (2013) observed no differences upon removal of ~50 % of bunches for two seasons on Riesling; however, in the third season, bunch weight in BT was 40 % higher than C. In this trial, despite running for up to four seasons, this effect was only observed in Semillon in S3 when BT bunches were about 50 g heavier than those in C. This was also the wettest season of the trial; the growing season rainfall was 354 mm (156 mm higher than the LTA), and it is likely that the much lower bunch number (and higher LA/Y) of BT at the same canopy size induced a more favourable water status for those vines that could have contributed to increased bunch weight. This is, however, not supported by the scarce literature on the topic; Valdés *et al*. (2009) did not find a link between bunch thinning and plant water status. Santesteban *et al*. (2011) have investigated the role of water status on the effect of thinning, concluding that thinning could result in higher grape quality under water deficit; however, in their four-year trial, bunch weight was different between C and BT in only one instance, and it was lower in BT.

A surprisingly lower leaf area was measured for Semillon in BT in two of the four seasons; however, no differences were then observed in pruning weight to indicate that leaf area is not a proxy of pruning weight and vice versa, as also shown by Keller *et al*. (2005). These differences could be unrelated to the thinning treatment but due to the spatial and seasonal variability of the vineyard. Bubola *et al*. (2017) also observed a lower LA in BT vines while Smith and Centinari (2019) did not measure any differences; BT was carried out at around veraison for both studies. Keller *et al*. (2005) also reported that BT did not influence vegetative growth when applied at veraison in the varieties Cabernet-Sauvignon, Chenin Blanc and Riesling.

2. Crop load and LA/Y

A crop load between 5 and 10 is considered ideal for producing quality grapes (Bravdo *et al*., 1985; Terry and Kurtural, 2011). Higher values have been associated with reduced grape quality and delayed ripening (Jackson and Lombard, 1993). Similarly, it is widely accepted that a LA/Y between 0.8 and 1.2 m^2/kg is required to fully ripen the fruit (Kliewer and Dokoozlian, 2005); the same authors also suggested that a pruning weight of 1 kg/m should be considered optimal. Despite their wide range of values, especially for the Y/P, these indices have been extensively adopted as indicators of vine balance and linked to high-quality fruit with little consideration given to the mesoclimate, variety and production target. In this study, the Y/P of Semillon varied between 7.1 and 15 in C and between 4.7 and 10.3 in BT. According to Bravdo *et al*. (1985), bunch thinned vines could be considered more balanced than C vines as Y/P fell within the range that is considered optimal (5-10) for quality grape production. On the contrary, C vines could be considered out of balance in two of the four seasons (S2 and S3) with Y/P values as high as 15 (Bravdo *et al*., 1985; Terry and Kurtural, 2011). However, in these two seasons, the crop load was high for both treatments and not different despite the significant yield reduction of BT. Much lower values and a narrower range were measured in Shiraz, where the Y/P was about 3 in C and 2 in BT in both seasons. According to previous literature reports (Bravdo *et al*., 1985; Terry and Kurtural, 2011), these values indicate vines that

are out of balance and the measured pruning weights ranging from 1.3 to 1.5 kg/m support this hypothesis (Kliewer and Dokoozlian, 2005).

In Semillon, no correlation was found between Y/P and LA/Y, with the LA/Y falling within the ideal 0.8–1.2 range only in two seasons for C and never for BT. These numbers indicate that the vines had sufficient or even excessive leaf area to ripen the fruit even in the C (LA/Y ranging from 1.2 to 1.9) or that even the C vines could be under-cropped despite yields as high as 6.9 kg/m in S4. Values below 0.8 have been reported to delay ripening (Kliewer and Bledsoe, 1986), while values higher than 1.2 might accelerate it; however, none of these effects have been found in this study. In a recent study, De Bei *et al.* (2019) suggested that the manipulation of LA/Y was not critical for ripening Semillon in a hot climate and did not result in differences in grape composition. The findings from this study support this and imply that optimal LA/Y might depend on the variety, season and location. Moreover, given the lack of differences in fruit composition (discussed below), it could be inferred that both the LA/Y and the Y/P for the Semillon variety in a hot climate are not good balance indicators and are not correlated to the measured fruit chemistry. This agrees with Santesteban *et al*. (2010), who showed that the LA/Y only slightly influences berry composition.

For Shiraz, the LA/Y was much higher than Semillon, with values of ~2 for C and ~3 for BT, well above the ideal range. Moreover, a negative correlation was found between LA/Y and Y/P ($R^2 = 0.6$). These values, as discussed above for the Y/P, can be associated with vigorous vines with excessive leaf area that could potentially support a bigger yield than the one obtained from these vines in the two seasons of the trial. Not surprisingly, BT in this situation increased the LA/Y to values completely outside of the ideal range.

3. Berry and wine chemistry

Bunch thinning produced only minor differences in TSS in one season and TA in the last two seasons of the Semillon trial. This is in line with Šuklje *et al*. (2013), who found no difference in berry chemistry after bunch thinning Sauvignon Blanc. Lohitnavy *et al*. (2010) found differences in pH but not in TA in response to applying BT (30 % bunches removed) to Semillon for one season. Keller *et al*. (2005) also reported only minor differences in fruit composition in response to crop adjustment for the white varieties Riesling and Chenin Blanc. Moreover, the same authors stated the lack of clear relationships between crop levels and TSS and TA. As in this study, Keller *et al*. (2005) also found that the three cultivars they studied were able to ripen all crop levels without differences between treatments, and they identified that the effect of bunch thinning was variety-dependent and less important for white varieties where deep colouration is not sought after.

The higher acidity and lower wine pH measured in C in S3 could be a result of the higher crop load, which has previously been reported to increase TA (Bravdo *et al*., 1985); however, in S4, a lower acidity was measured in C despite the higher yield and crop load. This supports the conclusion from Keller *et al*. (2005) that seasonal conditions are likely to influence fruit and wine composition more than bunch thinning.

Some of the differences observed in the fruit chemistry translated into the wines as higher alcohol and pH in BT in S1 while in S4, despite no differences in TSS at harvest, the wines obtained from C were more alcoholic. The wet S3 season yielded the greatest differences in wine chemistry between the treatments, and, unexpectedly, C produced a wine with higher TA, total phenolics and tannins and lower pH.

In Shiraz too, only minor differences were detected in berry chemistry with higher TSS in BT in the second season, suggesting an accelerated ripening (Keller *et al*., 2004; Nuzzo and Matthews, 2006; Reynolds *et al*., 2007; Preszler *et al*., 2013) and higher tannins, while in season one, BT berries were higher in anthocyanins in line with findings from other studies on red varieties (Keller *et al*., 2005; Nuzzo and Matthews, 2006). These differences did not translate to the wine. Wine anthocyanins were not different despite a tendency to higher concentrations in BT. Only tannins in the second season were significantly higher in BT.

4. Berry and wine sensory

The effect of viticultural practices on the sensory properties of the resulting wines has been reported by various authors (Bravdo *et al*., 1985; Reynolds and Wardle 1997; Diago *et al*., 2010; Gamero *et al*., 2014) while berry sensory characteristics are often less investigated. However, it is accepted that the berry properties are the drivers of wine quality (Le Moigne *et al*., 2008; Jackson and Lombard, 1993).

Very limited information on the effect of BT on berry sensory properties can be found in the literature, with the main study by Lohitnavy *et al*. (2010) reporting no differences between C and BT treatments on Semillon vines (30 % of bunches were removed) when berries were subjected to descriptive analysis (23 attributes were assessed). However, the study was only carried out for one season. In the current study, a higher proportion of bunches were removed for four consecutive seasons. Assessors found differences in the berries between the two treatments from the first season. The tropical flavour of the pulp, which can be considered a positive attribute for Semillon, was higher in C in two (S1 and S4) of the three seasons when differences were observed. The grassy flavour, more associated with negative attributes, was higher in BT in three of the four seasons. Reynolds *et al*. (2007) and Chapman *et al*. (2004) also found a link between lower crop and increased herbaceous and vegetable notes for Chardonnay Musque and Cabernet-Sauvignon; however, these studies only focused on wine sensory.

Semillon wines vary in style; however, it is accepted that fresh fruit characters, citrus and tropical are common descriptors for this variety (Blackman and Saliba, 2009). These characters, when they were found to differentiate the wines, were higher in the C. In this study, BT failed to maximise the expression of the varietal characters as described by Blackman and Saliba (2009), with the untreated C showing better scores.

More studies exist on the effect of BT on the sensory profile of red wines. Gamero *et al*. (2014) found that the BT of Tempranillo produced more balanced and structured wines. Similarly, in this study, Shiraz wines from BT vines were generally described as more intense in aroma and flavour, jammy and with a greater body. In the second season, the panel preferred BT wines to the C ones. Shiraz vines in this trial, as already discussed, could be considered out of balance (high LA/Y and low Y/P), and the BT treatment pushed the LA/Y and Y/P even further away from what is considered the balanced range; however, it can be claimed that it did have a positive effect on the wine quality. This questions the suitability of the LA/Y and Y/P, especially the recommended range, as vine balance/vine performance indicators.

Santesteban *et al.* (2011) also found that bunch thinning led to inconclusive results with gains in quality in some vineyards and seasons but not in others. This study confirms that fruit composition and wine quality are dependent on the fruit environment (Reynolds *et al*., 1994) and less linked to vine balance indices, especially in a hot climate, as previously observed (De Bei *et al.*, 2019; De Bei *et al.*, 2020).

CONCLUSION

Bunch thinning carried out at veraison by removing as much as 50 % of the bunches had little effect on the performance of the Semillon variety in a hot Australian climate, and indeed, wine produced from the untreated control were preferred. The effect on Shiraz was more notable, especially in the final wine, to confirm that the practice should be considered in managing red varieties rather than white. To support the decision on whether to bunch thin and justify its cost, a significant increase in fruit quality has to be achieved. Keller *et al*. (2005) discussed how the practice is often dictated by wineries, based on the belief that higher yield would result in poor quality wines even though evidence of this relationship is limited and most often based on data from cool climate viticulture. To reiterate this, yields in European countries are regulated by law so that often, techniques such as bunch thinning are non-negotiable to remain within the allowed yield per hectare rather than being driven by a quality target. In the early 1990s, Jackson and Lombard (1993) advocated for the need to investigate the optimum yield for each cultivar in each region and training system to produce quality wine and remain profitable. This study contributes to that goal and has demonstrated that bunch thinning of Semillon in a hot climate did not alter measurable chemistry parameters despite considerable (especially from an economic point of view) differences in yield. Moreover, despite the differences in sensory attributes of the grapes and wines produced from control and bunch thinned vines, it was difficult to extract a clear pattern; often, the more productive control vines resulted in wines that were judged more favourably by a panel of assessors in their ability to express better the expected varietal characters of Semillon grapes. For Shiraz, no gains in berry chemistry were observed; however, a better performance of the BT wines during the sensory analysis was observed.

Bunch thinning, by reducing yield, is also likely to promote a faster ripening of the grapes (observed in some seasons of this study both in Semillon and Shiraz). With recent vintages showing a trend of early harvests and significant compression of the ripening window (Jones *et al*., 2005; Palliotti *et al*., 2014), bunch thinning is likely to exacerbate this issue.

Further research on other high yielding varieties (particularly reds) and in commercial vineyards, where bunch thinning is unlikely to remove 50 % of the fruit, is required to understand better the effect of this management technique in hot climates.

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