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Shoot thinning of Semillon in a hot climate did not improve yield and berry and wine quality

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ABSTRACT

Aim: Shoot thinning is a common canopy management practice used to obtain a desired shoot density and to improve canopy microclimate. Since thinning is often carried out manually, the cost can be high. In this study the effect of severe shoot thinning (50 % of shoots removed) applied at EL 15 was investigated by comparing yield components, canopy size, berry and wine chemistry, and sensory attributes to a non-thinned control for the variety Semillon. The objective was to determine whether shoot thinning could change canopy architecture and lead to improved fruit and wine chemistry and sensory characteristics.

Methods and Results: The trial was carried out over four consecutive growing seasons (starting in 2014-15) in the Semillon block of the Coombe vineyard (Waite Campus, the University of Adelaide). Canopy architecture was monitored at key phenological stages in each season and yield components were assessed at harvest. The harvested fruit was used for chemical and sensory analysis of the berries. Wines were made and their chemistry and sensorial attributes assessed. Shoot thinning reduced the total leaf area in only two of the four seasons, but single shoot leaf area and cane weight were higher in shoot-thinned vines in all seasons. Shoot thinning did not reduce yield, despite a large reduction in bunch number, because of increased bunch weight. Shoot thinning did not change berry and wine chemistry. Similarly, little differences were observed in the sensory profile of berries and wines, and the assessors preferred the wines obtained from shoot thinned vines in the last season only.

Conclusions: In this study, shoot thinning increased the leaf area per shoot and the cane weight, but yield and grape and wine chemistry were unaffected. The vine balance indices leaf area/yield and yield/pruning weight were also unaffected by the treatment, despite its intensity (50 % of shoots removed).

Significance and impact of the study: The practice of shoot thinning when applied at EL stage 15 (8-9 leaves separated) was not effective as a technique to improve canopy microclimate and berry and wine chemistry for the white variety Semillon in a hot Australian climate. By not applying shoot thinning growers could potentially make significant savings without affecting yield or wine properties. Further research is needed to explore the effect and timing of shoot thinning on other varieties and in different environments.

KEYWORDS

canopy management, shoot thinning, leaf area, canopy porosity, Semillon, hot climate

INTRODUCTION

Practices implemented in the vineyard in order to achieve vine balance and an optimal canopy microclimate are known as canopy management (Smart, 1992). Vineyard profitability can be increased using canopy manipulations to improve canopy microclimate, grape quality, and efficiency of spray application. The undesirable effects of excessive shading of developing grapes are well documented and include decreased sugar, tartaric acid, colour, phenolic and flavour maturity (Gao and Cahoon, 1994; Morrison and Noble, 1990; Downey *et al.*, 2006; Ristic *et al.*, 2007), and increased potassium and malic acid concentrations, pH and botrytis incidence (Smart and Robinson, 1991). Shading has also been shown to reduce fruitfulness for future growing seasons (Dry, 2000), which in turn promotes a vegetative growth cycle in the vine (Smart *et al.*, 1986).

Count nodes left at winter pruning are not the only nodes that can grow shoots; shoots can also burst from latent and basal buds that were not considered during pruning (Pool *et al.*, 1978). Shoots from non-count nodes can contribute to a large proportion of non-fruit bearing canopy, providing excess leaf area and thus shade, without contributing to yield (Smart and Robinson, 1991).

Shoot thinning is often used to control shoot density by removing shoots at a stage when fruitful ones can be determined and retained (15–25 cm shoot length) (Bernizzoni *et al.*, 2011). This technique aims to improve canopy light interception, leaf exposure, and ventilation, as well as to reduce the number of carbohydrate sinks (developing shoots) with which other sinks (developing bunches) may compete (Smart, 1992). In highly regulated production areas, this technique is also used as an alternative to bunch thinning to achieve a target yield (Bernizzoni *et al.*, 2011). The effects of shoot thinning on canopy architecture and fruit composition can vary significantly depending on the timing of application. Reynolds *et al.* (2005) showed that shoot thinning post flowering improved canopy microclimate in terms of leaf and bunch exposure compared with pre-flowering treatments. The later the technique was applied, the lower the total soluble sugars, titratable acidity, TA, anthocyanins and phenolics of harvested berries (potential for delaying maturity). In a sensory analysis of final wines,

those subjected to earlier shoot thinning scored higher than the control and vines which were thinned later in the season.

Bernizzoni *et al.* (2011) applied shoot thinning on the Barbera variety when the shoots were 15–25 cm in length; the results showed a decrease in yield (because of less bunches/vine) and berry acidity, along with an increase in berry weights, bunch weights, total soluble solids, anthocyanins and phenolics. In another study, fruit parameters, such as pH and potassium, were found to increase with shoot thinning severity (14 compared with 44 shoots/vine) when the technique was carried out at EL 15–16 (Naor *et al.*, 2002). In conjunction with findings from Reynolds *et al.* (1994a), Reynolds *et al.* (1994b) and Reynolds *et al.* (1994c), the study concluded that wines decreased in quality with increased crop loads from higher winter pruning levels. Both Bernizzoni *et al.* (2011) and Reynolds *et al.* (2005) highlighted the scarcity of specific studies on shoot thinning.

The present study aimed to assess the effect of severe shoot thinning (50 % of total shoots removed) on the performance of Semillon grown in a hot Australian climate. Canopy architecture, yield components, vine balance indices, grape and wine chemistry and sensory attributes were assessed. By affecting canopy architecture, shoot thinning was expected to have a positive effect on the canopy microclimate, thus improving berry and wine chemistry and sensory attributes.

MATERIALS AND METHODS

1. Vineyard site

Three rows of the variety Semillon (clone 32) in the vineyard at the Waite Campus of the University of Adelaide, South Australia (34°58'3.47»S; 138°38'0.43»E) were used for the experiment. The trial was carried out over four seasons starting in 2014–15; season one (S1=2014–15), season two (S2=2015–16), season three (S3=2016–17) and season four (S4=2017–18). The vines were planted in 1990 on their own roots and trained to a bilateral spur-pruned cordon with the shoots vertically positioned and a spacing of 3 m between rows and 1.8 m between vines. At pruning, 20 two-node spurs/vine were left to obtain approximately 40 buds/vine. Vines were irrigated with 2 L/h in-line drippers and on average 0.5 ML/ha were used in S1, S2 and S4. In S3, irrigation was not applied because of high seasonal rainfall.

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

2. Trial design

The trial was set up on three adjacent rows in a fully randomised block design with each treatment repeated once along each row. Each block consisted of nine consecutive vines (three plots of three vines), and measurements were carried out on each middle vine of each plot for a total of nine vines per treatment.

Two treatments were assessed: a control (C) (no canopy interventions) and shoot thinning (ST). ST was carried out at EL stage 15 (Coombe, 1995) by removing exactly 50 % of the total shoots on the vines after counting. Double, short, malformed and unfruitful shoots were preferably removed. ST was carried out on October 18th, 14th, 21st and 16th in S1, S2, S3 and S4 respectively, which corresponded to GDD of 127, 143, 121 and 139 respectively.

3. Canopy architecture, yield components and grape composition

The VitiCanopy app was used to measure canopy size by taking an upward looking photo on each side of the middle vine in each panel for all treatments (De Bei *et al.*, 2016). The total leaf area per plant and per metre of cordon was then calculated according to the planimetric method described in De Bei *et al.* (2016). Measurements were carried out at the time of shoot thinning (EL 15), as well as around flowering (EL 21-23), berries at pea size (EL 31) and veraison (EL 34-35).

From EL 35, samples of 100 berries were collected weekly from each replicate to monitor maturity. Harvest was carried out at Total Soluble Solids (TSS) ranging between 21 and 23 °Brix (to align with commercial harvest levels). The 100 berry samples were used to measure berry weight, after which the juice was extracted to measure pH, titratable acidity (TA) (Mettler Toledo auto titrator, Greifensee, Switzerland) and TSS (digital refractometer BRX-242 Erma Inc. Tokyo, Japan).

At harvest, each middle vine was individually harvested by counting and weighing the bunches. To calculate yield components on a per metre basis, the cordon length of each middle vine was also measured. Bunch weight was calculated by dividing the total yield by the number of bunches. From the harvested fruit, samples of 50 berries were collected to be used for the measure of total phenolics according to Iland *et al.* (2004).

At pruning, the weight of all one-year-old wood was determined for each treatment replicate.

4. Berry sensory assessment

Berry sensory assessments (BSA) were conducted according to Olarte Mantilla *et al.* (2013) and as described in De Bei *et al.* (2019). Briefly, 300 berries were collected from each replicate in each season and kept at 4 °C until assessment. A panel of 10 to 12 assessors with previous BSA experience was first trained over two 2-hour sessions as described in Olarte Mantilla *et al.* (2013), and an agreement was reached on the attributes to be assessed. A number of 14 attributes were selected and divided into three categories: pulp (juiciness, acidity, citrus flavour, tropical flavour, grassy flavour, flavour intensity), skin (acidity, bitterness, astringency, grape flavour, grassy flavour) and seeds (colour, flavour, astringency). The formal assessments took place over three sessions, in which panellists were asked to taste either 12 or 15 three-berry samples. The assessors were given a 0-15 line scale to assess each attribute and a custom-designed App for mobile devices to collect the data. The App collated all the results for each assessor and sent them to a nominated email account.

BSA was carried out in the sensory facility of the University of Adelaide at the Waite Campus with the approval of the University of Adelaide ethics committee (H2017-054).

5. Winemaking

The harvested fruit from each replicate was pooled into vented crates (20 kg) to be used for winemaking. Three wines from each treatment were produced by maintaining the vineyard replicates. The fruit was cold soaked overnight at 2 °C and then crushed and de-stemmed using a combined crusher de-stemmer (Grifo Macchine Enologiche, Piadena, Italy). The

detailed winemaking procedure is described in De Bei *et al.* (2019).

All finished wines were bottled using 375 mL glass bottles, then crown sealed and stored until sensory and chemical analysis in a 22 °C controlled environment room.

6. Wine chemical analysis

Wine pH and TA were measured as described by Iland *et al.* (2004) using an autotitrator (Crison instruments Barcelona, Spain). Alcohol (v/v) content was measured with an AlcoLyzer Wine ME (Anton Paar, Graz, Austria). Total phenolics were determined spectrophotometrically according to Iland *et al.* (2004).

7. Wine sensory descriptive analysis

The sensory analysis of wine was carried out using descriptive analysis (DA) and a panel of 12 assessors in a similar way to the procedure used for berries and as described in De Bei *et al.* (2019). The assessors' training in this case included ranking exercises for acidity, astringency and bitterness and identification of unknown aroma standards. The 22 assessed attributes were divided into five categories: aroma (confectionery, citrus, tropical, grassy, intensity), taste (bitterness, acidity), flavour (bitter, acid, citrus, floral, stone fruit, confectionery, tropical, grassy), mouthfeel (body, astringency, alcohol) and aftertaste (fruit length, alcohol length, bitter length, likeability). Data were collected using the same custom-built App used to assess the berries.

8. Statistical analysis

The software XLSTAT (Version 2015.4.01. 20116 Addinsoft SARRL, Paris, France) was used for all statistical analyses.

Treatment comparisons within seasons were performed via t-test. ANOVA was performed to extract effects of treatment, season and their interaction (treatment x season) over the four years. Canopy architecture measures were analysed using repeated measures ANOVA and the means separated using Fisher's LSD. Berry and wine sensory results were analysed using the product and sensory panel performance analysis tool of the XLSTAT package. The significance level used to separate means was $p < 0.05$ for all data, apart from the berry and wine sensory means, for which a significance of $p < 0.1$ was considered.

RESULTS

1. Mesoclimate

The mesoclimate over the four growing seasons (October to April) has been described in detail in De Bei *et al.* (2019). Briefly, the growing degree days (GDD) calculated after Gladstones (2011) were lower than the long-term average (LTA) in S3 (Table 1). The highest GDD was recorded in S2. The total growing season (April to October) rainfall was lower than LTA in all seasons, except in S3 when it was 354 mm (Table 1).

2. Yield components

When all four seasons were combined, the number of shoots after application of the ST treatment was 42 % to 58 % lower than C (Table 2). For this parameter, not only was an obvious and expected treatment effect found, but the season also had a significant impact: C vines had similar shoot number in the first two seasons (22 on average), while in the third and fourth season C had 31.6 and 38.2 shoots respectively.

After ST (EL 15), removed leaf area was found to be 0.86, 0.62, 0.67 and 0.54 m² per m of

TABLE 1. Weather conditions of the four growing seasons (October to April) captured in this study.

	Mean January temperature (°C)	Growing season rainfall (mm)	Growing Degree Days (GDD) (°C)
S1	23.1	137.8	1811
S2	24.7	166.4	1899
S3	24.4	354.2	1770
S4	25.7	129.2	1886
LTA	23.3	198.4	1801

Growing Degree Days (GDD) are calculated after Gladstones (2011) with 19 °C cut-off. S1=season one= 2014-15; S2=season two=2015-16; S3=season three=2016-17; S4=season four=2017-18. LTA=long term average (1985-2013) (Australian Bureau of Meteorology (<http://www.bom.gov.au/>)).

TABLE 2. Effect of shoot thinning (ST) on yield components and leaf area of Semillon grown in the Coombe vineyard of the University of Adelaide, Waite Campus, Adelaide, Australia.

Season (S)	Treatment (T)	Shoots (#/m)	LA at EL 35 (m ² /m)	LA/Shoot (m ²)	Yield (Y) (kg/m)	Bunches (#/m)	Bunch weight (g)	Berry weight (g)	Berry weight (kg/m)	Pruning weight (P) (kg/m)	Cane weight (g)	LA/Y (m ² /kg)	Y/P
S1	C	23.2 a	9.9 a	0.44 b	5.5	35.3 a	160.2	1.47	0.76 a	0.53	34.2 b	1.8	7.1
	ST	12.9 b	7.2 b	0.59 a	4.6	25.1 b	183.5	1.50	0.59 b	0.46	47.0 a	1.6	8.1
	p value	<0.001	<0.001	0.03	ns	0.002	ns	ns	0.02	ns	0.03	ns	ns
S2	C	20.9 a	7.7	0.39 b	5.9	39.6 a	146.9 b	1.27 b	0.53	0.53	26.4 b	1.29	11.7
	ST	12.2 b	7.2	0.59 a	5.1	21.6 b	239.4 a	1.52 a	0.46	0.46	38.2 a	1.4	11.6
	p value	<0.001	ns	<0.001	ns	<0.001	<0.001	ns	ns	ns	0.02	ns	ns
S3	C	31.6 a	11.3 a	0.41	7.3	35.3 a	217.3 b	1.73	1.03 a	0.83	34.4	1.7 a	7.5 b
	ST	13.4 b	6.9 b	0.53	6.6	19.8 b	335.3 a	1.83	0.62 b	0.79	46.5	1.1 b	12.3 a
	p value	<0.001	<0.001	ns	ns	0.002	<0.001	ns	0.005	ns	ns	0.007	0.002
S4	C	38.2 a	7.5	0.22 b	6.9	36.5 a	189.3 b	1.77	0.83	0.83	21.5 b	1.1	8.6
	ST	19.1 b	7.1	0.38 a	6.4	19.7 b	323.9 a	1.81	0.79	0.79	40.5 a	1.3	9.9
	p value	<0.001	ns	<0.001	ns	<0.001	<0.001	ns	ns	ns	0.008	ns	ns
Treatment	<0.001	<0.001	<0.001	ns	<0.001	<0.001	ns	ns	0.006	<0.001	<0.001	ns	0.03
Season	<0.001	<0.001	<0.001	0.003	ns	<0.001	<0.001	<0.001	0.001	0.001	ns	0.02	0.006
T x S	0.01	0.01	ns	ns	ns	0.002	ns	ns	ns	ns	ns	ns	ns

C=control, LA=leaf area, Y=yield, P=pruning weight. S1=season one= 2014-15; S2=season two= 2015-16; S3=season three= 2016-17; S4=season four= 2017-18. Means were separated by t-Test. The effect of the treatment and season, and their interaction, were analysed using analysis of variance. Means followed by different letters are significantly different. ns=not significant

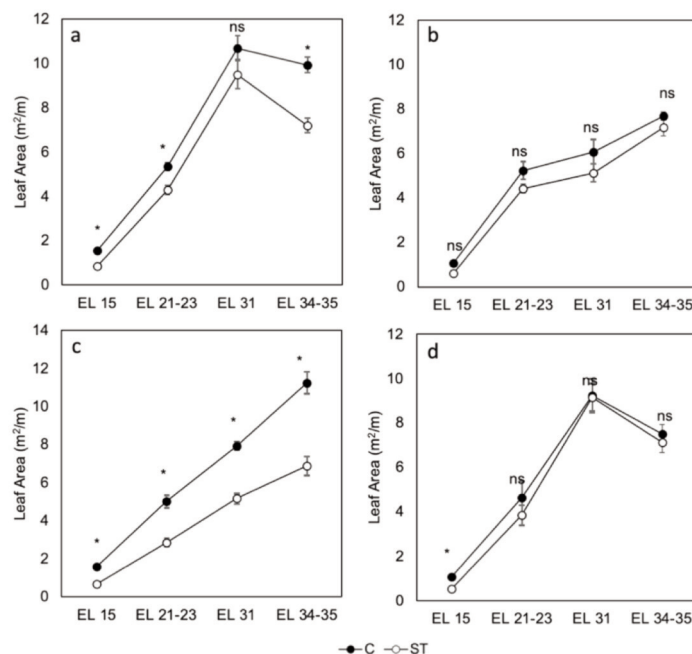


FIGURE 1. Total leaf area measured at four phenological stages (EL 15, 23, 32 and 37; Coombe, 1995) and in four seasons on Semillon vines grown in the Coombe vineyard of the University of Adelaide, Waite Campus, Adelaide, Australia.

a=S1=season one=2014-15; b=S2=season two=2015-16; c=S3=season three=2016-17; d=S4=season four=2017-18 C=control (black marker), ST=shoot thinning (white marker). Line bars indicate the standard error of the means. Means were separated by repeated measures ANOVA and Fisher’s LSD test. * indicate significance at $P < 0.05$. ns=not significant

cordon in S1, S2, S3 and S4 respectively. Over the four seasons, the final leaf area (EL 35) of the C varied from 7.7 to 11.2 m^2/m , with the highest measured in the wet S3 and the lowest in the hot and dry second season. Meanwhile, the leaf area of ST treated vines was very similar in the four seasons, only varying between 6.9 and 7.2 m^2/m . In this case a season effect was found, and the interaction treatment x season was also significant. When the leaf area/m was divided by the number of shoots/m, ST always showed a higher leaf area than C (not significant in S3) with a four-season average of 0.36 $m^2/shoot$ in C and 0.67 m^2 in ST.

While yield was never affected by the treatment, bunch number was always lower in ST. A seasonal effect on yield was found: the first two seasons showed lower yields than the last two. In terms of bunch weight, after the first season (when no differences were found) heavier bunches were always harvested from ST treated vines. Bunch weight was higher in ST by 63 % in S2 and S3, and by as much as 72 % in the last season. Berry weight was higher for ST in S2 only.

Pruning weight was different between treatments in only two of the four seasons (lower for ST); however, the weight of the single canes was much higher for ST in three of the four seasons.

The widely used vine balance indicators leaf area/yard (LA/Y) and yield/pruning weight (Y/P) were different only in S3 when ST showed lower LA/Y and higher Y/P compared to C.

3. Canopy architecture: leaf area and canopy porosity

Total leaf area (LA) was measured at four phenological stages (EL ~15, 23, 31 and 35) during the growing season (Figure 1). The within season LA development pattern of both treatments was very similar in all seasons. At EL 15, ST showed an obvious lower LA than C in all seasons, except in S2. At flowering (EL 21-23), the LA in the two treatments was different in only two of the four seasons (S1 and S3). In the first season, no differences were detected at EL 31, but a large decline was observed in ST at EL 35 (Figure 1a). LA in S2 was the same for both treatments at all phenological stages. Similarly, in S4 no differences were detected between

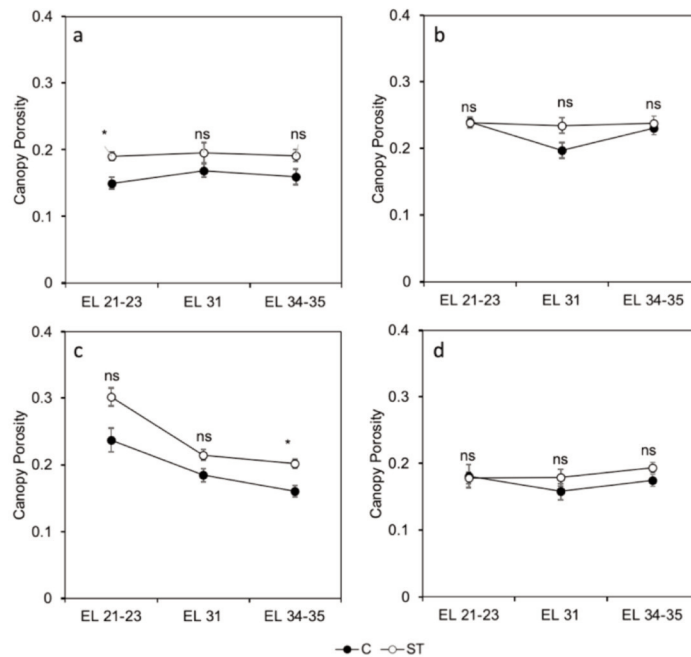


FIGURE 2. Canopy porosity measured at four phenological stages (EL 15, 23, 32 and 37; Coombe, 1995) and in four seasons on Semillon vines grown in the Coombe vineyard of the University of Adelaide, Waite Campus, Adelaide, Australia. a=S1=season one=2014-15; b=S2=season two=2015-16; c=S3=season three=2016-17; d=S4=season four=2017-18 C=control (black marker), ST=shoot thinning (white marker). Line bars indicate the standard error of the means. Means were separated by repeated measures ANOVA and Fisher's LSD test. * indicate significance at $P < 0.05$. ns=not significant

treatments, except at EL 15. S3 instead showed a much lower LA in ST for the whole season, despite canopy development being very similar in the two treatments.

Porosity measures showed very distinct patterns in the four seasons. ST showed a higher tendency for porosity (more open canopies) in S1 and S3; the difference, however, was only significant at EL 21-23 in S1 and at EL 34-35 in S3 (Figure 2). These results are somehow in agreement with the LA results. In S2 and S4, no differences in canopy porosity between treatments were observed.

4. Berry and wine chemistry

Treatments C and ST were always harvested on the same day in each season and, apart from in S3, there was no difference in TSS. In S3, due to heavy rainfall, the sanitary status of the grapes caused harvest date to be the same as C, despite ST showing a much lower TSS. A tendency for delayed ripening of ST was also observed in 2017-18. The pH of the must/juice never differed, while in the wines C showed a higher pH in S2. The acidity of the juice was again

different between treatments in only one of the four seasons; in S2, despite the identical TSS at harvest, the TA in C was lower than in ST. In the wines, no differences in TA were found in all four seasons.

Total phenolics and epicatechins were also measured in the berries, but no differences between treatments were detected. In the last year of the study, yeast assimilable nitrogen (YAN) was measured on the juice before fermentation; no differences in YAN were detected for C=135.5 and ST=116.0 ($p > 0.05$). Wine alcohol only differed in S3, reflecting the difference in harvest TSS. Total phenolics in the wines were only measured in the first three seasons. In S2 and S3, C and ST wines differed in a non-conclusive way: ST wines were higher in phenolics in 2015-16, while in 2016-17 they were lower. In the last season, malic acid was measured in the wines, but no differences ($p > 0.05$) were found.

5. Berry and wine sensory analysis

The expert panel assessed the fresh berries of both treatments in each season and different sensory profiles were evaluated. Juiciness of the

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

(S)	Treatment (T)	Total soluble solids (Brix)	pH	Titratable acidity (g/L)	Berry total phenolics (mg/g)	Berry Epicatechins (mg/g)	Alcohol	Wine pH	Wine titratable acidity	Wine total phenolics (au)
S1	C	22.2	3.05	10.08	0.90	5.22	14.5	3.12	7.6	7.0
	ST	22.6	3.10	10.20	1.02	5.44	14.1	3.13	7.8	7.3
	p-value	ns	ns	ns	ns	ns	ns	ns	ns	ns
S2	C	20.2	3.29	6.46 b	0.64	4.31	13.1	3.32	7.8	6.0
	ST	20.2	3.27	7.12 a	0.66	4.34	12.9	3.12	8.0	6.6
	p-value	ns	ns	0.01	ns	ns	ns	0.03	ns	ns
S3	C	23	3.12	8.52	0.66	1.78	13.8	2.91	7.9	10.3
	ST	20.2	3.13	8.95	0.63	1.71	12.0	2.88	8.3	8.5
	p-value	0.03	ns	ns	ns	ns	0.02	ns	ns	ns
S4	C	22.2	3.16	6.43	0.47	3.48	14.7	3.66	5.7	-
	ST	20.7	3.13	7.15	0.52	3.81	13.3	3.62	5.8	-
	p-value	ns	ns	ns	ns	ns	ns	ns	ns	ns
Treatment	ns	ns	ns	ns	ns	0.006	0.03	ns	ns	ns
Season	<0.001	0.05	<0.001	<0.001	<0.001	0.006	<0.001	<0.001	<0.001	<0.001
S x T	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

C=control, LA=leaf area, Y=yield, P=pruning weight. S1=season one=2014-15; S2=season two=2015-16; S3=season three= 016-17; S4=season four=2017-18. Means were separated by t-Test. The effects of the treatment and season, and their interaction, were analysed using analysis of variance. Means followed by different letters are significantly different. ns= not significant

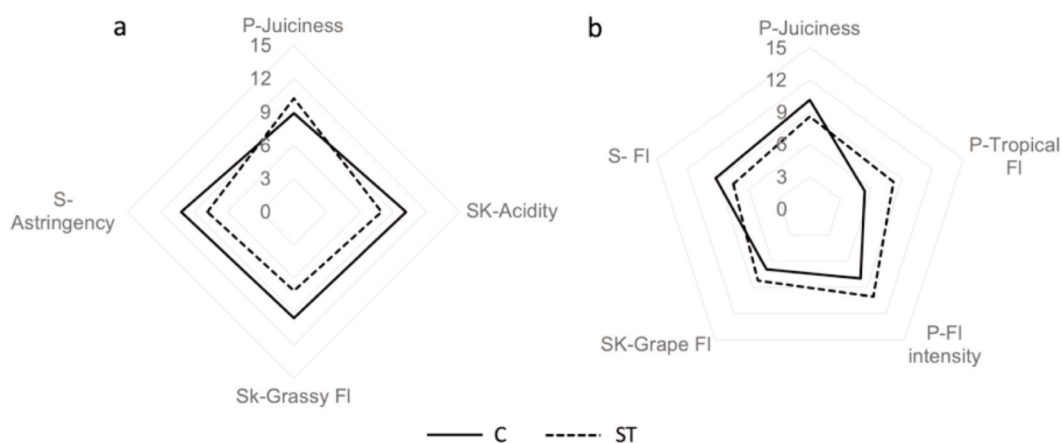


FIGURE 3. Radar plots of attributes found different at $p = 0.1$ in the berries of Control (C) (solid line) and shoot thinning (ST) (dashed line) treatments for Semillon grown in the Coombe vineyard of the University of Adelaide, Waite Campus, Adelaide, Australia.

a=S1=season one=2014-15; b=S2=season two=2015-16. P=Pulp, SK=Skin, S=Seeds, FI=flavour.

berries was different in each season [it was also the only discernible difference in the last season ($p < 0.1$)]; however, the pattern seemed unrelated to ST, which was described as having juicier berries in S1 and S3, while in the other two seasons C berries were found to be juicier. In S1, the skins of C berries were described as being more acidic than ST berries, with a more intense green/grassy flavour and seeds that were more astringent (Figure 3 a). Other descriptors were different between treatments in S2: ST showed a more tropical and intensively flavoured pulp, and the skin was described as having a more intense grape flavour; the flavour of C seeds was more on the toasted/nutty spectrum (Figure 3b). In S3, apart from the already mentioned difference in juiciness ($p < 0.1$), the green flavour of the pulp was also higher in ST ($p < 0.1$).

The wines showed more distinct differences during their sensory assessment compared to the berries. Ten out of 21 assessed attributes were different between ST and C in S1 (Figure 4a). The aroma and the palate (flavour) of ST was described as being more confectionary than C. In terms of flavour, C was more bitter, acidic and citrusy, while ST was described as tropical. C wines were also more astringent than ST. C had a lingering bitterness and was perceived as being more alcoholic, while ST showed a more intense fruit length. In S2, only four of the assessed attributes were different and all higher for ST (Figure 4b): grassy aroma, floral flavour, body and alcohol length. In contrast to the previous season, the C wines from the rainy S3 were

generally more aromatic and in particular more tropical than ST (Figure 4c). The tropical character was found as a flavour too, and was again higher in C, together with an intense stone fruit flavour. C also had more body and alcohol length, while ST was more astringent. In the last season, the confectionary character was different as in S1; however, this time C wines were preferred (Figure 4d). C also showed more body, astringency, alcohol length and bitterness. Likeability was assessed in all four seasons, but it differed only in the last two, and the assessors preferred C in S3 and ST in S4.

DISCUSSION

Shoot thinning is a common canopy management strategy for removing shoots (when unfruitful, short, abnormal) to obtain a desired number per vine or per metre of canopy (Bravetti *et al.*, 2012; Silvestroni *et al.*, 2016) and achieve vine balance (Reynolds *et al.*, 2005). The technique can also be used to attain a desired yield (Bernizzoni *et al.*, 2011; Morris *et al.*, 2004) as an alternative to bunch thinning. Intriери and Poni (1995) have reported that manual shoot thinning requires between 50 and 60 h/ha. Julian *et al.* (2008) reported a cost of \$405 per acre in Oregon; in South Australia a cost of about \$700 Australian Dollars/ha has been estimated (DJs Growers, personal communication, 2016).

Despite shoot thinning being a widespread technique (Silvestroni *et al.*, 2016; Reynolds *et al.*, 2005), few studies on the subject exist and

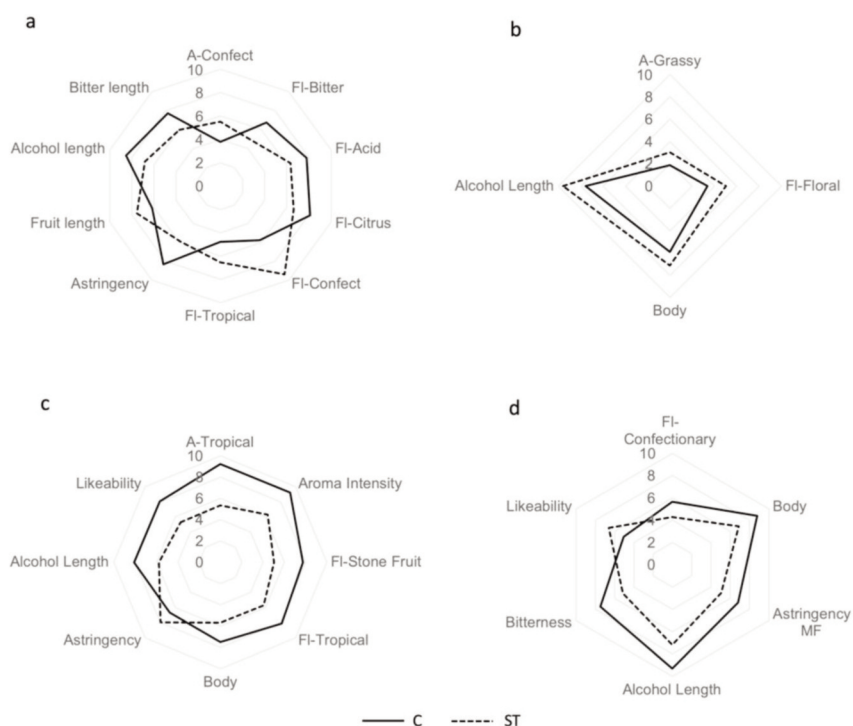


FIGURE 4. Radar plots of attributes found different at $p < 0.1$ in the wines of control (C) (solid line) and shoot thinning (ST) (dashed line) treatments applied to Semillon grown in the Coombe vineyard, Waite Campus, Adelaide.

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

they are mostly from Europe or the USA. To the best of our knowledge, in the past decade, only one published study - complementary to this one - has been carried out in Australia on Shiraz and Semillon in Adelaide (Wang *et al.*, 2019).

Shoot thinning can be carried out mechanically (Geller and Kurtural, 2013; Kurtural *et al.*, 2013; Brillante *et al.*, 2017), with little control over the type and number of shoots removed. More often studies have reported on manual shoot thinning with the number of shoots being adjusted to 12 to 20 per vine (Naor *et al.*, 2002; Bravetti *et al.*, 2012; Silvestroni *et al.*, 2019; Silvestroni *et al.*, 2016) to obtain a per metre shoot density of 8 to 15, depending on the vine spacing of the trial site. The choice of shoot density is likely based on the numerous studies demonstrating that a density of 15 to 25 shoots per metre of cordon can improve canopy microclimate (Reynolds *et al.*, 1994a; Reynolds *et al.*, 1994c; Smart, 1988). In the present study, instead of adjusting the number of shoots to a defined amount per metre, exactly 50 % of the total number was removed; this has not been trialled in previous studies.

In a comprehensive study, Reynolds *et al.* (2005) compared the results of shoot thinning conducted at five phenological stages: from three expanded leaves to the stage of cell division (corresponding to EL 9 to 31 (Coombe, 1995)). In other studies by Silvestroni *et al.* (2019, 2016) and Bravetti *et al.* (2012), shoot thinning was done at the phenological stages of pre-flowering/flowering. In our study, shoot thinning was carried out at EL 15, when shoots were between 15-30 cm in length and never more than 40 cm (Morris *et al.*, 2004), thus aligning with timing of the operation in commercial vineyards in Australia.

1. Leaf area and canopy porosity

According to Smart (1988), shoot densities of 15 to 25 shoots/m improve canopy microclimate and allow the desired grape composition to be attained. In the present study, the shoot density varied from 21 to 38 shoots/m in the C (average of 28.5) and from 12 to 19 shoots/m in ST (average=14.5). The variability in shoot number between seasons was likely due to the influence of the high rainfall observed in S3, which caused

a higher than usual number of non-count shoots to burst. The removed leaf area varied from 0.54 to 0.86 m²/m of cordon. Leaf area could not be measured after veraison, due to the installation of bird nets in the whole vineyard. However, given the short veraison-to-harvest period (from 14 to 28 days in the four years) (De Bei *et al.*, 2019) and the fact that irrigation ceased at veraison, it is assumed that leaf area at veraison would have been very similar to the one at harvest.

The four seasons differed climatically, with S2 being extreme in terms of heat and low rainfall (especially in winter) and S3 in terms of low temperature and high rainfall. These two seasons also had the earliest (DOY21) and latest (DOY61) harvests respectively (De Bei *et al.*, 2019).

The within season canopy development pattern in the two treatments and the four seasons was very similar. S1 and S4 (the two “average seasons”) showed a very comparable leaf area pattern with a steep increase until EL 31 and a reduction thereafter, attributable to a routine canopy trimming operation. In general, in the early phenological stages and until flowering, ST showed lower leaf area, apart from in S4. By EL 31, however, the ST canopies reached and followed the growth of C in three of the four seasons. S3 was characterised by heavy rainfalls and during this season the C vines reached their highest leaf area of the whole trial. ST, however, despite following the growth pattern observed in the C, never reached a similar leaf area; furthermore, the leaf area measured for ST at veraison did not differ from previous seasons at the same phenological stage. In a two-season trial, Bernizzoni *et al.* (2011) reported no differences in final total main and lateral leaf area per vine upon a 40-50 % reduction in shoot number (as in S2 and S4 in this study). Miller *et al.* (1996) saw no difference in final leaf area in Concord pruned from 20 to 160 nodes per vine; similarly, Myers *et al.* (2008) did not find differences in leaf area with shoot densities of 12, 20 and 28 shoots/vine.

Despite the leaf area per plant not being different in two of the four seasons, the single shoot leaf area was higher in ST (not significant in S3). Bernizzoni *et al.* (2011) observed that, upon reductions of 40 and 50 % of shoots over two seasons through shoot thinning, the total leaf area was not different, but the single shoot leaf area increased by 43 and 50 % respectively.

Moreover, they found that the increased leaf area was mostly due to larger leaf blades (+57 % compared to C). Similarly, Myers *et al.* (2008) compared densities of 12, 20 and 28 shoots/vine and found no differences in total leaf area per plant; however, the leaf area per shoot increased as the shoot density decreased.

Canopy porosity is a measure of canopy openness; the higher the value, the more open a canopy is. Canopy porosity is therefore linked to canopy microclimate (De Bei *et al.*, 2016; Fuentes *et al.*, 2014). In S1 and S3, the shoot-thinned vines were characterised by a tendency for higher porosity throughout the season (significant only at EL 21-23 in S1 and EL 34-35 in S3). In the other two seasons, there were no differences in porosity between the treatments. Reynolds *et al.* (2005) also observed similar canopy behaviour (i.e., no differences in leaf and bunch exposure) when shoot thinning was carried out at EL 15. According to Palliotti and Silvestroni (2004), a grapevine canopy should have between 10 and 20 % gaps, while Smart (1987) recommends values of up to 40 %. In hot Australian conditions, in order to avoid excessive bunch exposure and the risk of sunburn damage, the more conservative value of 10-20 % are considered more adequate for white varieties, such as Semillon. In all seasons, the porosity values were in the range of 15 and 25 %, in accordance with those recommended by Palliotti and Silvestroni (2004).

2. Yield components

Shoot thinning did not affect yield in this study. Reynolds *et al.* (2005) only found differences in yield when shoot thinning was applied after EL 27. The two long term studies by Silvestroni *et al.* (2016 and 2019) (four years for Sangiovese and six years for Montepulciano) did not show any differences in yield when the number of shoots was reduced by 42 % and 44 % in Montepulciano and Sangiovese respectively. Bravetti *et al.* (2012) also found no differences in yield between a control and a shoot-thinned treatment; however, in this case, the shoot thinning only lowered the number of shoots per vine from 19 to 14. Other authors have reported lower yields in shoot-thinned vines (Naor *et al.*, 2002 for Sauvignon Blanc; Morris *et al.*, 2004 for French-American hybrids; Sun *et al.*, 2012 for Corot noir; Myers *et al.*, 2008 for Sangiovese). Bernizzoni *et al.* (2011) found vegetative growth compensation in ST vines

(Barbera variety) and, despite a 60 % reduction in bunch number, yield was only 25 % lower due to compensation by heavier bunches and berries. Similarly, in this study, ST compensated for the lower number of shoots and bunches by increased bunch weight (not significantly in the first season). Other studies have also found shoot thinning to produce less, but heavier, bunches (Morris *et al.*, 2004; Bernizzoni *et al.*, 2011; Silvestroni *et al.*, 2016; Silvestroni *et al.*, 2019), while Reynolds *et al.* (2005) found no differences in bunch number and weight when shoot thinning was applied at EL 15. Naor *et al.* (2002) speculated that the reduction of sinks (bunches and growing tips) in shoot-thinned vines allows for greater allocation of assimilates and reserves to the remaining organs, thus making them stronger sinks. Berry weight tended to be higher in ST, but significantly so only in one season, similar to observations by Naor *et al.* (2002). It can thus be speculated that ST resulted in a higher number of berries per bunch, as shown by Wang *et al.*, (2019); however, berry number was not measured in this study. Moreover, the significantly heavier, and more compact bunches produced by shoot-thinned vines could make them more prone to disease (to Botrytis in particular), as shown by Wang *et al.* (2019). Numerous studies reported that pruning weight was not affected by number of shoots per vine, due to a compensation mechanism which manifests itself as increased shoot vigour (Freeman *et al.*, 1979; Reynolds and Wardle, 1989; Reynolds *et al.*, 1994b; Morris *et al.*, 2004). This study supports these findings: the pruning was the same in two of the four seasons, but the weight of the single canes was much higher for ST in three of the four seasons. In the seasons when the difference was not significant, ST canes were 30 % heavier. Naor *et al.* (2002) found an increased pruning weight at low shoot density in only the third year of a three-year study.

3. Vine balance indices

The equilibrium between vegetative growth and yield which delivers the best possible fruit composition for the target wine style is referred to as vine balance. Commonly used indicators of vine balance are the yield to pruning weight (Y/P) ratio (also known as Ravaz index (Ravaz, 1911) or crop load (Bravdo *et al.*, 1985)) and the ratio of leaf area (m^2) to yield (LA/Y).

In an experiment conducted in California, Kliewer and Dokoozlian (2005) found that the optimal LA/Y ranged from 0.5 to 1.2, while Y/P varied from 4 to 10 depending on the cultivar, site and management. Smart and Robinson (1991) recommend LA/Y values of 1.2 m^2/kg . In this study LA/Y and Y/P were different between treatments in only one of the four seasons (S3), when they were respectively lower and higher for ST. This was an unusually wet season, with the highest measurements of yield for both treatments in the whole trial and the largest amount of canopy (highest LA) and pruning weight for C vines. Bravetti *et al.* (2012) also found lower LA/Y in ST, while Silvestroni *et al.* (2019) report no effect of ST on the Ravaz index. In the four seasons, LA/Y varied from 1.1 to 1.8 m^2/kg in C, and from 1.1 to 1.6 in ST, with a four-year average of 1.5 and 1.4 respectively; these values are slightly higher than recommendations by Kliewer and Dookozlian (2005) and Smart and Robinson (1991). Despite yields of over 5 kg/m, the vines in this experiment can be considered to have been under-cropped according to these indices, thus confirming once again their dependence on site, climate and cultivar (De Bei *et al.*, 2019; Myers *et al.*, 2008). The crop load only differed between treatments in S3, varying from 7.1 to 11.7 for C and 8.1 to 12.3 for ST (average C = 8.7, ST = 10.5), and thus falling, on average, within range of what is considered balanced, with a tendency of shoot-thinned vines to show higher Y/P. In contrast, other authors have reported lower crop load at lower shoot densities (Naor *et al.*, 2002; Morris *et al.*, 2004; Sun *et al.*, 2012). When considering cane weight at pruning as an indicator of balance, Smart and Smith (1988) suggested an optimum between 20 and 30 g/cane. In this study, all the shoot-thinned vines can be considered out of balance with canes weighing above 30 g in all seasons. Naor *et al.* (2002) also showed the two indices to be highly correlated ($R^2=0.86$); in this study however, no relationship was found between the indices ($R^2=0.1$).

4. Berry and wine chemistry

The trial was harvested at TSS between 20 and 22 °Brix to align with commercial harvest levels for Semillon. In S3, the harvest TSS for ST was much lower than for the C, indicating a delay in ripening in this treatment. Similarly, the TSS in S4 was 1.5 °Brix lower for ST (not significant), again indicating a delay in the ripening process

compared to the C. This could be attributed to the greater crop load of ST vines in the last two seasons, as confirmed by the high Y/P. This aligns with findings from Naor *et al.*, (2002) which showed a delay in ripening when crop load increased; however, in contrast to the present study, their crop load increased with higher shoot densities. Geller and Kurtural (2013), on the other hand, observed faster ripening at lower shoot densities, and Reynolds *et al.* (2005) found higher TSS at harvest in shoot thinned vines. Bernizzoni *et al.* (2011) also found increased TSS in shoot thinned vines, but their yield differed between treatments and was lower for ST. Of the other measured berry chemistry attributes, in S2, only TA differed between treatments and was higher for ST. This is in agreement with Reynolds *et al.* (2005), who found that shoot thinning generally reduced TA, unless it was carried out before EL 15, in which case it increased. Regarding berry chemistry parameters, Silvestroni *et al.* (2016 and 2019) and Bravetti *et al.* (2012) did not report any differences between control and shoot thinned vines for Montepulciano and Sangiovese. Morris *et al.* (2004) did not find any differences in TSS, pH and TA after shoot thinning the varieties Aurore and Viollard Noir, while shoot-thinned Chancellor vines had higher TSS and pH at harvest.

5. Berry and wine sensory

Despite the recognised importance of Berry Sensory Assessment (BSA) as a tool for helping growers and winemakers to understand the link between berry and wine characteristics (Olarie Mantilla *et al.*, 2012), its use is limited in scientific research. BSA has been previously used to assess the effect of canopy management strategies, such as leaf plucking, on the sensory profile of berries (Lohitnavy *et al.*, 2010; De Bei *et al.*, 2019); however, to the best of our knowledge, no other studies have reported the effect of shoot thinning on the sensory characteristics of the grapes.

In this study, BSA was carried out by an expert panel in all four seasons and it was found that shoot thinning affected the sensory profile of the berries. Particularly in the first season, the ST berries were juicier, the skins were less acidic and did not have as much of a grassy flavour as the control, and the seeds were less astringent. These attributes correspond to berry ripeness, despite TSS not differing between treatments.

Higher juiciness was also found in the pulp of ST vines in S3; however, ST berries were also described as grassy/green, which is indicative of less ripe fruit (Le Moigne *et al.*, 2008) and in agreement with the delay in ripening observed for ST in this rainy season (see above). Juiciness was different in all four seasons, and was lower for ST in S2 and S4, which may suggest that this attribute is linked more to the season (weather conditions, irrigation) than to the canopy management treatment. In S2, ST berries were described as being more tropical, which is a desirable descriptor for Semillon. The berries were also generally characterised by enhanced flavour intensity; in a commercial setting this is indicative of better-quality fruit.

In their shoot thinning trial, Reynolds *et al.* (2005) only found minor differences in wine sensory among all treatments. In our study, the results of the wine sensory analysis uncovered differences between treatments in all the seasons and showed greater differences compared to the BSA. As many as ten out of the 21 assessed attributes differed between treatments in S1. ST had an enhanced confectionary aroma and flavour, together with a greater tropical flavour and an overall higher fruit length, which could all be considered as desirable attributes for Semillon wine and to be preferred by consumers (Bogart and Bisson, 2006). Naor *et al.* (2002) and Sun *et al.* (2012) also found an increase in fruity characters at lower shoot densities. Work on Merlot by Nicolli *et al.* (2018) found that lower bud load left at pruning, and hence lower shoot densities, produced more aromatic and floral wines. On the other hand, in the same season, less desirable attributes, such as bitterness, acidity and astringency were more apparent in the control wines. In agreement with the BSA, which showed enhanced flavour intensity for ST, the wines in S2 were more intense in all the four different attributes (grassy aroma, floral flavour, body and alcohol length). In the third season, the control wines were described as higher in all the different attributes, except for astringency. This is most likely due to the unfavourable weather conditions, leading to the harvest of ST at a much lower TSS, which were hence less ripe than C. Interestingly, in the last season, C wines were assessed as being higher in all the attributes that were found to be significantly different; however, in this case, they were not positive attributes, and in fact, ST wines were preferred (greater likeability score).

CONCLUSIONS

Semillon vines grown in a hot Australian climate responded to an early season severe reduction in shoot number with an increase in leaf area per shoot and a higher cane weight. Meanwhile, yield compensated for the reduced bunch number via an increase in bunch weight and berries per bunch. Berry and wine chemistry and sensory were differentially affected by the treatment depending on the season; however, the effect on these parameters was minimal.

In contrast to what has been reported in previous literature, our study showed that in this trial the variety Semillon achieved better vine balance with shoot densities of between 20 and 40 per m. Probably due to the early application (EL 15), lower densities were associated with excessive vegetative growth, which may have negatively affected exposure. In Australian vineyards, it is common to carry out shoot thinning at EL 15 (but not at the intensity reported in this study). Practical implications, such as the difficulty in removing shoots at later stages, must be taken into account when considering the timely application of this management practice. The estimated cost of 700\$/ha is likely to increase if the operation is carried out at a later phenological stage, since the removal of more vigorous shoots could require the use of secateurs, and extra time could be required to remove the shoots from the canopy (if the wires have already been lifted in a VSP system for example).

The findings from this study showed no evidence to support the use of shoot thinning as a management practice to obtain balanced vines, or as a method of crop control, in Semillon in Australian conditions. Alterations of the vine balance did not influence fruit composition; this study might therefore also suggest that new methods to determine vine balance may need to be adopted for more dependable results when developing management strategies for different climates, regions and varieties.

This study also confirms previous findings that management practices aiming to manipulate canopy microclimate might be more effective in cool climates than in the hot Australian climate. More research is needed to investigate the effect of time and intensity of shoot thinning for other varieties in Australian environments.

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