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Partial Shading of Cabernet Sauvignon and Shiraz Vines Altered Wine Color and Mouthfeel Attributes, but Increased Exposure Had Little Impact

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Few studies have investigated the impact of vine shading on the sensory attributes of the resultant wine. This study examines the effects of canopy exposure levels on phenolic composition plus aroma, flavor, and mouthfeel aspects in wine. Wines were made from Cabernet Sauvignon and Shiraz grapes (*Vitis vinifera* L.) subjected to different levels of canopy exposure in a commercial vineyard in the Sunraysia region, Victoria, Australia. Canopy exposure treatments included control (standard vineyard practice), exposed (achieved with a foliage wire 600 mm above the top cordon), highly exposed (using a foliage wire with leaf plucking in the fruit zone), and shaded treatment (using 70% shade-cloth). Spectral and descriptive analyses showed that levels of anthocyanins, other phenolics, and perceived astringency were lower in wines made from shaded fruit; however, the reverse was generally not observed in wines of exposed and highly exposed fruit. Descriptive analysis also showed wines from the shaded fruit were different from other treatments for a number of flavor and aroma characters. These findings have implications for vineyard management practices.

KEYWORDS: Shading; grapes; red wine; Cabernet Sauvignon; Shiraz; phenolic composition; descriptive analysis

INTRODUCTION

Although somewhat difficult to define, there is some agreement as to which sensory attributes contribute to wine quality. Components of quality that have been examined and characterized to various degrees include, color, mouthfeel, and some aspects of the flavor and aroma of wine (*1–3*).

The best-characterized single quality component of grapes and red wine is that of color. In the fruit, color is primarily due to the presence of anthocyanins in the skin and occasionally the flesh of the mature berry. These are then extracted into the wine (*1*). However, anthocyanins are unstable in wine, and long-term color stability in wine results from interactions of anthocyanins and tannins to form pigmented polymers (*4, 5*). Boulton also proposed that anthocyanins form short-lived copigment complexes with the flavonols derived from grape skin during the early stages of winemaking (*6*). Tannins, or proanthocyanidins, are polymeric compounds derived from the seeds and skin of grape berries (*7*). Tannin content and composition as well as tannin interactions with other wine components including polysaccharides, anthocyanins and other tannins are responsible for bitterness and mouthfeel properties including astringency, as well as long-term color stability (*1, 2, 4, 5*).

Anthocyanins, proanthocyanidins, and flavonols are closely related polyphenolic compounds and form part of a large class of plant secondary plant metabolites known as flavonoids (*8*). Research to date suggests that flavonoid biosynthesis in many plants is under the control of photoreceptors (*9*). An example of this is the coloration of the skin of apples, which is completely dependent on light exposure for anthocyanin biosynthesis (*10*). In grapes, there have been a number of reports of light exposure affecting anthocyanin accumulation (*11–14*). However, this appears to be cultivar dependent, with some cultivars showing little or no response to shading (*8, 15–17*).

Although the general view is that increased exposure results in enhanced anthocyanin biosynthesis, there is a point at which the temperature load begins to have a negative impact (*8*). This temperature has been reported to be 32 °C (*8*); however, this may also be cultivar dependent.

To date, the impact of light exposure on tannin biosynthesis has attracted little attention. Early investigations in the leaves of rainforest trees showed that tannin levels were higher in sun-exposed compared to shaded leaves (*18*). In grapes, the effect

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of shading on tannin accumulation has been examined in Shiraz and Pinot Noir (*17, 19*). In both Shiraz and Pinot Noir, the level of total tannins was lower in the skin of the shaded fruit at veraison than it was in the sun-exposed fruit. At commercial harvest (around 24 °Brix), there was no difference in tannin levels between treatments for Shiraz, whereas in Pinot Noir, tannin levels remained lower in the shaded fruit (*17, 19*). In both Shiraz and Pinot Noir, the shift in anthocyanin composition with shading based on ring B hydroxylation was also reflected in tannin subunit composition (*17, 19*). To date, no data exist on the effect of shading on tannin subunit composition in warm-climate fruit.

The levels of other less abundant secondary metabolites in grapes, such as those contributing to the aroma and flavor of wine, may also be affected by canopy light exposure. Oxidative degradation of carotenoids present in the flesh and skin of the grape berry gives rise to a range of volatile compounds generally known as norisoprenoids (*20*). Readily detected in wine, these compounds contribute to the flavor and aroma of red and white wines (*3*). Previous studies have reported changes in the sensory character of wines in response to shading, with lower levels of carotenoids and higher levels of norisoprenoids in sun-exposed fruit compared to shaded fruit (*13, 21–23*).

There is a large body of published literature both on the secondary metabolite composition of grapes and, to a lesser extent, on the impact of shading on the levels of these compounds, but few studies have examined their extraction into wine and the subsequent impact on the sensory properties of that wine. Price et al. (*15*) reported lower levels of anthocyanins, flavonols, and phenolic polymers in Pinot Noir wines made from shaded fruit, whereas levels of monomeric flavan-3-ols were higher. It is interesting to note that Price et al. (*15*) observed differences in wine anthocyanins despite there being no difference in grape anthocyanin levels between treatments. Differences between grape and wine anthocyanins could be the result of differences in extraction and stability among individual anthocyanins (*24, 25*).

Few sensory studies exist of wines made from differently shaded fruit. Of these, a study of Cabernet Sauvignon showed differences in anthocyanin and total phenolic levels, but no perceived difference in wine aroma or flavor between wines made from shaded and exposed fruit (*13*). However, an informal tasting of Pinot Noir wines made from shaded and exposed fruit indicated that there were differences in the sensory character of the wines, although these were not quantified (*15*). Recently, wines made from artificially shaded and normally exposed Shiraz fruit were analyzed by descriptive sensory analysis, and it was determined that wine made from shaded fruit was rated lower for overall fruit flavor and fruit flavor persistence, as well as a number of mouthfeel characteristics including overall astringency (*21*). Although mouthfeel descriptors were different in the Shiraz wines, no analysis of grape or wine tannin composition was conducted.

Whereas there is evidence that exposure to light influences grape composition and in some cases subsequent wine composition, there is not a clear understanding of transition from grapes to wine and very little information on the impact of these changes on wine quality as defined by sensory analysis. Altering the level of canopy exposure provides a mechanism whereby the impact of light on grape and subsequent wine composition can be examined. Practically, understanding light exposure effects offers the potential to manipulate the final wine style. Here we report the influence of different levels of canopy exposure of Shiraz and Cabernet Sauvignon grapes on the phenolic composition and sensory character of the subsequent wines.

MATERIALS AND METHODS

Field Site and Viticultural Treatments. Trials were conducted in a commercial vineyard (Wingara Wines) located in Iraak, Victoria, Australia (34° 27′ S, 142° 19′ E). Canopy exposure treatments were applied to *Vitis vinifera* L. vines of Cabernet Sauvignon and Shiraz during the 2003–2004 growing season. Vines were approximately 10 years old, on their own roots, trained to a two-wire vertical trellis and drip irrigated. Vines were grown in three vine panels, spaced at 1.8 m intervals, with a row spacing of 3.0 m and an east–west row orientation.

Four exposure treatments were applied, with the first treatment designated the "control", for which there was no change to the canopy. The controls spanned nine panels in each of three rows. Other treatments were applied to the two rows between the control rows. The second treatment involved the canopy being lifted approximately 600 mm using a trellis extension and a foliage wire. This treatment was the "exposed" treatment. The third treatment also consisted of the canopy being lifted 600 mm but, in addition, leaves were removed in the fruit zone, further increasing canopy exposure to light. This was the "highly exposed" treatment. The final treatment was a "shaded" treatment, for which the canopy was lifted 600 mm, leaves were removed in the fruit zone, and 70% shade-cloth was applied to both sides of the row to partially cover the canopy, resulting in all of the remaining leaves on the shoots and fruit below the lifting wire being shaded.

Treatments alternated between the exposed, highly exposed, and shaded treatments, with each treatment occurring three times in the same row. This pattern is repeated in two rows with a control treatment row between and on either side. A two-panel (six vine) buffer was retained between treatments and the end of the row.

The lifting of the canopy and removal of the leaves for various treatments took place 4 weeks post fruit-set, and the shade-cloth was applied to the shaded treatment the following week. In Shiraz, veraison occurred at 7 weeks post fruit-set for the control, exposed, and highly exposed treatments, whereas veraison for the shaded Shiraz treatment occurred 1 week later. In Cabernet Sauvignon, veraison for the control also occurred 7 weeks after fruit-set; however, veraison for the exposed and highly exposed treatments did not occur until the following week, and in the shaded Cabernet Sauvignon veraison was at 9 weeks post fruit-set. Veraison was defined as the week before a marked increase in total soluble solids was measured in the fruit. Total soluble solids (°Brix) were measured by refractometer. Fruit was monitored throughout berry development for maturity and hand-harvested at commercial ripeness for small-scale winemaking. Juice °Brix, pH, and titratable acidity (TA) were determined, and must pH was adjusted to 3.5 prior to fermentation.

Small-scale Winemaking. Wines were made in the Experimental Winery at the CSIRO Plant Industry (Merbein, Victoria) according to a standard protocol (*26*). Fruit from each treatment was crushed and divided among three replicate fermentation vessels. Wines underwent 3 days of maceration during fermentation; maceration time refers to the duration of contact between juice and skins. At the completion of fermentation wines underwent 3 months of cold storage at 1 °C, after which wines were bottled into 375 mL bottles, closed with Stelvin closures. Wines did not undergo malolactic fermentation. Finished wines were stored at 18 °C until descriptive sensory and wine chemical analyses were performed after 2 years of bottle aging.

Chemical Analysis of Juices and Wines. At the time of wine sensory evaluation, wines were analyzed for pH, TA, free and total SO_2, and volatile acidity using standard analytical techniques (*27*). Alcohol was measured using an Anton Paar Alcolyzer. The phenolic parameters of wine color density, wine hue, total phenolics, total tannins, non-tannin phenols, total anthocyanins, total polymeric pigments, and small and large polymeric pigments were determined by the Harbertson−Adams assay (*28*). Total phenolics as expressed here refers to those phenolics that react with ferric chloride and does not include anthocyanins or monohydroxylated phenolics (*28*).

Sensory Analysis of Wine. A descriptive analysis (DA) was performed to quantitatively characterize differences in the perceived organoleptic profile between wine treatments and between fermentation replicates within treatments. Wine replicates were evaluated over August, September, and October of 2006 by a panel of 11 (4 females and 7 males) and 10 (4 females and 6 males) people for Cabernet Sauvignon and Shiraz, respectively. Panelists were University of Adelaide students enrolled in postgraduate coursework enology programs aged between 22 and 49 years. Panelists underwent 5 weeks of high-level training in aroma, taste, and trigeminal (mouthfeel) sensation detection and evaluation prior to the formal DA training. Despite a high level of wine evaluation skills within the group, none of the students had previous experience with descriptive analysis.

Six 1 h sessions were held over 5 weeks to train the panel. During training, panelists were presented with a selected replicate of each experimental wine treatment in coded, covered, XL5 (ISO standard), 215 mL tasting glasses and asked to individually generate and then reach panel consensus on appropriate descriptive terms for each variety. Descriptive terms were narrowed to three color, eight aroma, four flavor (where flavor is defined as aromas by mouth), two taste, and three mouthfeel attributes for Shiraz and two color, eight aroma, four flavor, three taste, and three mouthfeel descriptive terms for Cabernet Sauvignon. Panelists practiced rating the wines for each term using an unstructured 100 mm line scale with anchor points at each end of the scale in conditions identical to those used in the subsequent formal tasting session. Intensity standards (crushed cloves = *10, high intensity*; a 1 in 8 dilution of raspberry cordial = *5, medium intensity*; a 1 in 40 dilution of raspberry cordial = *0, low intensity*) representing points on the scale were provided at each session as an intensity rating aid. Some aroma references (in covered wine tasting glasses) and color charts were presented at subsequent sessions and modified in response to panelist suggestions (**Table 1**). No references were provided for the taste and mouthfeel attributes as all panelists had extensive training in that area of wine tasting as part of their postgraduate study program.

Formal Sensory Evaluation. A final discussion session followed by three 2 h formal rating sessions for each wine variety was held under controlled temperature conditions and natural light. At every rating session, each panelist was presented with 12 wines (four treatments by three replicates) in random order. Each wine was evaluated in triplicate over the course of the formal rating period. Thirty milliliter samples were presented in coded, clear, XL5 (ISO standard) 215 mL tasting glasses covered with small Petri dishes. Distilled water was provided for palate cleansing, and panelists had a forced rest of 30 s between each sample. At the beginning of each session, panelists familiarized themselves with the aroma standards and had access to the intensity standards within their booths.

Data Analysis. Chemical composition data between treatments were analyzed with one-way analyses of variance (ANOVA) and all pairwise multiple comparisons with the Tukey Test using SigmaStat 3.5 Jandel Scientific. Sensory data were collected using the 1994–2001 Biosystèmes FIZZ for Windows Acquisition version 2.00E software application. Mean ratings and Fischer's least significant differences for each attribute were calculated by analyses of variance (ANOVA) using the 1994–2001 Biosystèmes FIZZ Calculations for Windows version 2.01b software application (Couternon, France). Differences among attributes for each variety were assessed with mixed model ANOVAs, in which judges were considered a random effect. No comparisons were made between varietals. Principal component analysis (PCA) was also performed using the 1994–2001 Biosystèmes FIZZ Calculations for Windows version 2.01b software application.

Table 1. Aroma and Palate Attribute List with Agreed Definitions for Cabernet Sauvignon and Shiraz

attribute	definition
	Color
ruby[f]	red with a purple-blue tint
garnet	red with an orange tint
violet[s]	purple with bluish tint
pink rim[s]	pink hue at edge of wine when glass is tilted
depth[f]	(intensity) appearance of wine in the glass such as pale to opaque
	Aroma
plum[a,f]	whole plums in juice
earthy[a]	soil, dirt
mint/green[a,f]	fresh or dried mint
spirity	clean alcoholic aroma such as clear drinking spirits and methylated spirits
blackberry[a]	blackberries, blackberry jam
black cherry[a]	cherry pulp, fresh cherries with stones, skins, and stems removed
rose perfume[a]	rose essential oil
dried fruit[a]	mixed dried fruit such as dried apricots, raisins, sultanas, apples
green pepper[a,s]	green bell pepper (green *Capsicum*)
oregano[a,s]	fresh or dried oregano
stalky[a,s]	stems from grapevine
eucalyptus[a,s]	eucalyptus essential oil
menthol[a,s]	menthol throat lozenges
canned bean[a,s]	canned green beans in liquid
	Palate
spice[a]	mixture of cinnamon and nutmeg
pencil shavings[a]	shavings of a gray-lead or graphite pencil
blackberry[a]	blackberries, blackberry jam
plum[a]	whole plums in juice
blackcurrant[a,s]	black currant juice
dark fruit[a,s]	blackberry, black cherry, prune
balsamic[a,s]	balsamic element of balsamic vinegar, minus the acetic acid
vinegar[a,s]	white wine vinegar
bitterness	harsh taste of caffeine, usually noticed at back of palate
acid[f]	fresh sharp taste, such as lemon
sour[f]	tart taste, vinegar, sour cream
astringency[f]	feelings of lack of lubrication in the mouth, a sensation of dryness; all astringency − can include that from tannin and acid
tannin	tactile feeling of wine in mouth, such as fine, soft, smooth to aggressive, related to the wine structure; contributed by inherent characters in the grapes/wine and from wood
body[f]	roundness and fullness of wine in mouth, from empty and thin to robust
length[s]	persistence of wine in the mouth after expectoration

[a] Reference aromas that match the definition were provided for those attributes. [s] Indicates sensory attributes specific for Shiraz wines. [f] Indicates sensory attributes shared by both varietals.

RESULTS

Chemical Composition of Juices and Wines. Cabernet Sauvignon and Shiraz juices were analyzed at the time of crushing to determine sugar level (°Brix), pH, and TA (**Table 2**). In both Cabernet Sauvignon and Shiraz juices, sugar levels were lower in the highly exposed and shaded treatments compared with the control. Juice from the shaded treatment had lower sugar levels than highly exposed juice. In Cabernet Sauvignon, there was no difference in juice pH between any of the treatments. However, TA of juice from the shaded fruit was higher than those of the other three treatments. In Shiraz, the pH of juice from highly exposed and shaded fruit was higher than the control and exposed juices. Juice pH from the shaded treatment was higher than juice pH from the highly exposed treatment. TA in Shiraz juices of all treatments was lower than the control. TA of highly exposed and shaded treatments was lower than the TA from the exposed treatment. After crushing, must pH was adjusted to pH 3.5 for Cabernet Sauvignon and to pH 3.35 for Shiraz through the addition of tartaric acid.

At the time of sensory assessment (2 years postbottling), wine pH, TA, volatile acidity (VA), and alcohol (%v/v) were determined. With the exception of the shaded wine VA, in Cabernet Sauvignon wines, there was no difference in wine pH, TA, and VA between any of the treatments (**Table 2**). In Shiraz,

Table 2. Chemical Measures for Cabernet Sauvignon and Shiraz Juices and Wines[a]

	control	exposed	highly exposed	shaded
		Cabernet Sauvignon		
juice °Brix	23.67 ± 0.06 a	23.63 ± 0.23 a	22.30 ± 0.03 b	19.80 ± 0.21 c
juice pH	3.89 ± 0.01 a	3.89 ± 0.01 a	3.86 ± 0.03 a	3.89 ± 0.00 a
juice titratable acidity (g/L)	3.91 ± 0.05 a	3.99 ± 0.05 a	3.95 ± 0.00 a	4.72 ± 0.04 b
adjusted wine pH	3.49 ± 0.04 a	3.50 ± 0.04 a	3.50 ± 0.01 a	3.50 ± 0.03 a
adjusted titratable acidity (g/L)	7.38 ± 0.04 a	7.41 ± 0.14 a	7.39 ± 0.07 a	7.43 ± 0.12 a
volatile acidity (g of acetic acid/L)	0.22 ± 0.01 a	0.20 ± 0.01 a	0.18 ± 0.01 a	0.13 ± 0.01 b
alcohol % v/v 20 °C	13.58 ± 0.05 a	13.51 ± 0.04 a	12.12 ± 0.01 b	10.29 ± 0.01 c
		Shiraz		
juice °Brix	21.40 ± 0.00 a	21.57 ± 0.03 a	20.53 ± 0.15 b	18.90 ± 0.00 c
juice pH	3.93 ± 0.02 a	3.95 ± 0.01 a	4.09 ± 0.01 b	4.15 ± 0.01 c
juice titratable acidity (g/L)	3.46 ± 0.03 a	3.32 ± 0.01 b	3.13 ± 0.02 c	3.11 ± 0.01 c
adjusted wine pH	3.34 ± 0.04 a	3.40 ± 0.01 a	3.33 ± 0.04 a	3.34 ± 0.02 a
adjusted titratable acidity (g/L)	8.48 ± 0.07 a	8.25 ± 0.04 a	8.89 ± 0.10 b	8.85 ± 0.04 b
volatile acidity (g of acetic acid/L)	0.24 ± 0.00 a	0.22 ± 0.00 a	0.22 ± 0.01 a	0.16 ± 0.01 b
alcohol % v/v 20 °C	12.66 ± 0.02 a	12.88 ± 0.03 b	12.11 ± 0.03 c	10.34 ± 0.06 d

[a] Juice data were collected at time of crushing; wine data were collected at time of sensory evaluation of wines (2 years postbottling). Data represent mean ± standard error ($n = 3$). In each row, mean values followed by different letters are significantly different ($p < 0.05$).

Table 3. Spectral Analyses of Color and Phenolics for Cabernet Sauvignon and Shiraz Wines[a]

	control	exposed	highly exposed	shaded
		Cabernet Sauvignon		
wine color density (AU)	12.75 ± 0.66 a	10.80 ± 0.09 b	10.68 ± 0.25 b	5.43 ± 0.21 c
wine color hue (AU)	0.72 ± 0.01 a	0.77 ± 0.02 ab	0.79 ± 0.00 bc	0.85 ± 0.03 c
total phenolics (mg/L CE)	927.9 ± 71.0 a	905.83 ± 28.0 a	945.9 ± 34.2 a	663.2 ± 12.0 b
total anthocyanins (mg/L M3G)	150.6 ± 10.8 a	161.9 ± 7.0 a	150.0 ± 8.5 a	81.4 ± 2.2 b
total tannins (mg/L CE)	274.3 ± 29.4 a	214.1 ± 7.1 a	246.6 ± 10.0 a	142.9 ± 8.7 b
non-tannin phenolics (mg/L CE)	691.1 ± 31.8 abc	653.6 ± 52.1 a	699.3 ± 27.2 b	520.3 ± 16.0 c
small pigmented polymers (AU)	2.60 ± 0.13 a	2.17 ± 0.05 b	2.02 ± 0.08 b	1.20 ± 0.08 c
large pigmented polymers (AU)	1.88 ± 0.14 a	1.33 ± 0.11 b	1.30 ± 0.11 b	0.60 ± 0.07 c
total pigmented polymers (AU)	4.48 ± 0.24 a	3.50 ± 0.13 b	3.31 ± 0.19 b	1.80 ± 0.15 c
		Shiraz		
wine color density (AU)	7.82 ± 0.12 a	7.57 ± 0.10 a	7.04 ± 0.54 a	4.56 ± 0.08 b
wine color hue (AU)	0.69 ± 0.01 a	0.75 ± 0.01 b	0.72 ± 0.02 ab	0.75 ± 0.01 b
total phenolics (mg/L CE)	624.8 ± 18.7 a	581.0 ± 39.9 a	628.4 ± 33.4 a	440.5 ± 23.4 b
total anthocyanins (mg/L M3G)	43.9 ± 7.0 a	53.0 ± 8.5 a	57.5 ± 11.9 a	26.8 ± 8.0 b
total tannins (mg/L CE)	339.6 ± 10.1 a	268.2 ± 6.2 ab	251.8 ± 26.6 b	197.1 ± 17.3 b
non-tannin phenolics (mg/L CE)	285.2 ± 22.0 ab	312.8 ± 37.8 ab	376.6 ± 22.4 b	243.4 ± 6.8 a
small pigmented polymers (AU)	2.62 ± 0.04 a	2.44 ± 0.03 a	2.33 ± 0.16 a	1.53 ± 0.04 b
large pigmented polymers (AU)	0.85 ± 0.02 a	0.82 ± 0.04 a	0.62 ± 0.09 a	0.91 ± 0.14 a
total pigmented polymers (AU)	3.47 ± 0.05 a	3.25 ± 0.02 a	2.94 ± 0.20 ab	2.44 ± 0.16 b

[a] Wines were analyzed at the time of sensory analysis after 2 years of bottle aging. Data represent mean ± standard error ($n = 3$). In each row, mean values followed by different letters are significantly different ($p < 0.05$). Phenolic and tannin values are expressed as mg/L catechin equivalents (CE), anthocyanins are expressed as mg/L malvidin-3-*O*-glucoside equivalents (M3G); wine color density, hue, and polymeric pigment values are expressed as absorbance units (AU).

there was no difference in wine pH between treatments; however, TA was higher in highly exposed and shaded fruit wines compared with the control and exposed fruit wines. Furthermore, VA was lower in wine made from the shaded fruit than in all other treatments.

In both Cabernet Sauvignon and Shiraz, alcohol levels were higher in wine made from control and exposed fruit compared with wines made from highly exposed and shaded fruit (**Table 2**). Additionally, for both varieties, alcohol levels in wine made from the shaded treatments were lower than those in wine from the highly exposed treatment. There was no difference in the levels of free and total SO_2 between any of the treatments for either Shiraz or Cabernet Sauvignon (data not shown).

Spectral Analysis and Phenolic Measurement of Wine. Immediately prior to sensory assessment, wines were analyzed for wine color density, wine hue, and a number of phenolic parameters determined by the Harbertson−Adams assay (*28*). In Cabernet Sauvignon, wines from all treatments had lower wine color density than the control (**Table 3**). Cabernet Sauvignon wines made from the exposed and highly exposed treatments had similar wine color densities, whereas wine made from the shaded fruit had around half that level. In Shiraz, only wines made from the shaded fruit had significantly lower wine color density than the control. In both Cabernet Sauvignon and Shiraz wines, hue was higher in the wines made from shaded fruit relative to the control (**Table 3**). Hue was also higher than the control in the Cabernet Sauvignon wine made from the highly exposed treatment. In Shiraz, wine from the highly exposed treatment had a hue similar to that of the control, whereas wine from the exposed treatment had a lower hue.

In both Cabernet Sauvignon and Shiraz, the levels of total iron-reactive phenols were similar between wines made from the control, exposed, and highly exposed fruit (**Table 3**). Wines made from shaded fruit of both cultivars were 60% lower in total phenolics relative to the control. Total anthocyanins were also (50–60%) lower in the wines made from the shaded fruit from both cultivars compared to the control (**Table 3**).

Total tannin in the wine made from shaded Cabernet Sauvignon fruit was lower than all other treatments and around half the level observed in the control (**Table 3**). In the Shiraz

wines, total tannin was 75 and 60% lower than the control in the highly exposed and shaded treatments, respectively.

In Cabernet Sauvignon wines, non-tannin phenols in the wine made from the shaded fruit were 75% lower than the control (**Table 3**). Wine made from the highly exposed fruit did have a significantly higher level of non-tannin phenols than wine made from the exposed treatment; however, there was <10% difference.

In Shiraz, there was no difference in the level of non-tannin phenols between the control and any of the treatments (**Table 3**). However, there was a difference between the highly exposed and shaded treatments, with the level in wine from the shaded treatment only around 65% of the level of non-tannin phenols in wines made from the highly exposed treatment.

The levels of polymeric pigments in wines from both cultivars were also determined (**Table 3**). In the Cabernet Sauvignon wines, the pattern across treatments was the same for all three pigmented polymer measures: small polymeric pigments, large polymeric pigments, and total pigmented polymers (the sum of small and large polymeric pigments). The level in the control wines was significantly higher than those in all other treatments and around 2–3-fold higher than the level in wines made from the shaded fruit.

In the Shiraz wines, there was no difference in large polymeric pigments between any of the treatments (**Table 3**). However, small polymeric pigments were significantly lower in wines made from the shaded fruit than in wines made from all other treatments. This pattern was duplicated in the observations for total pigmented polymers in Shiraz wines, except for there being no difference between highly exposed and shaded treatments.

Descriptive Analysis (DA). DA was used to quantitatively characterize differences in the perceived organoleptic profile of the wines made from grapes subject to different shading treatments. **Table 4** lists all of the attributes examined by the DA panel for each varietal and shows the *F* values for the mixed-model ANOVAs. For Cabernet Sauvignon, wines made from the shaded fruit were different from all other treatments in 10 of the 20 attributes measured (**Figure 1**): color, depth, plum aroma, black cherry aroma, spice flavor, blackberry flavor, bitterness, body, astringency, and perceived tannin. Grapes from the shaded Cabernet Sauvignon vines produced wines more garnet than ruby in hue and of lower color intensity (depth). Shaded wines were also perceived as lower in tannin, astringency, body (all $p < 0.001$), bitterness, blackberry aroma, black cherry aroma, spice flavor, and blackberry flavor, but higher in plum aroma (all $p < 0.05$). Spirity aroma, which is related to the alcohol content of the wine (**Table 2**), was only significantly lower in the wine made from the shaded fruit than in the control. Wine made from the exposed treatment had a lower level of blackberry aroma than wine made from the highly exposed fruit ($p < 0.05$).

In the Shiraz wines, 7 of the 20 attributes measured differed between shaded wines and wines of all other treatments (**Figure 2**): color, depth, body, length (all $p < 0.001$), dark fruit flavor, astringency, and sourness (all $p < 0.05$). Highly exposed wines were significantly sourer ($p < 0.05$) than the control. Grapes from the shaded Shiraz vines produced wines more ruby than violet and of lower color intensity (depth), lighter body, softer astringency, shorter length, and less intense dark fruit flavor and were sourer.

Judges are not trained to allocate each wine with the same rating; rather they are trained to consistently rate the wines in the same relative order. As such, for descriptive analysis, judges typically are a source of significant variation. Although for Shiraz the pink rim attribute appears to be different between treatments, there was a significant wine × judge interaction (**Table 4**), indicating that panelists had difficulty rating this attribute.

Table 4. Analyses of Variance Ratings for Sensory Attributes of Cabernet Sauvignon and Shiraz Wines

	F values			
attribute	wines (W)	judges (J)	interaction W × J	LSD
Cabernet Sauvignon ($n = 9$)				
color	30.86[c]	9.21[c]	1.11	0.89
depth	38.20[c]	18.17[c]	1.20	0.67
plum aroma	2.96[c]	14.46[c]	0.86	0.67
earthy aroma	0.34	46.92[c]	0.86	
mint/green aroma	1.50	67.83[c]	1.31[a]	
spirity aroma	4.49[c]	42.19[c]	0.71	0.43
blackberry aroma	2.09[a]	42.72[c]	1.08	0.55
black cherry aroma	1.92[a]	53.66[c]	1.00	0.54
rose aroma	0.75	53.24[c]	1.50[b]	
dried fruit aroma	0.68	16.26[c]	1.12	
spice flavor	5.69[c]	39.37[c]	1.20	0.57
pencil shaving	1.17	72.71[c]	0.98	
blackberry flavor	4.57[c]	59.20[c]	1.02	0.52
plum flavor	0.62	33.90[c]	1.54[b]	
bitterness	3.67[c]	50.87[c]	0.90	0.49
sour	1.32	59.34[c]	1.38[a]	
acid	1.35	57.40[c]	1.06	
body	21.08[c]	64.78[c]	0.79	0.53
astringency	8.78[c]	103.86[c]	0.83	0.63
tannin	20.72[c]	88.23[c]	0.69	0.55
Shiraz ($n = 11$)				
attribute				
color	18.45[c]	35.14[c]	0.95	0.84
pink rim	4.56[c]	59.24[c]	1.38[a]	0.94
depth	25.69[c]	38.21[c]	1.03	0.62
green pepper aroma	0.93	77.03[c]	1.07	
mint aroma	1.63	56.34[c]	0.86	
oregano aroma	1.09	33.77[c]	0.76	
canned bean aroma	2.07[a]	52.84[c]	0.75	0.37
eucalyptus aroma	1.39	50.17[c]	0.93	
menthol aroma	0.91	48.09[c]	1.19	
stalky aroma	0.63	87.93[c]	1.05	
plum aroma	0.86	52.94[c]	1.19	
dark fruit flavor	3.93[c]	46.05[c]	1.10	0.49
black currant flavor	1.99[a]	99.19[c]	1.12	0.46
balsamic flavor	0.90	65.59[c]	1.20	
vinegar flavor	1.51	46.32[c]	1.08	
sour	2.61[b]	42.67[c]	1.09	0.60
acid	1.02	38.92[c]	0.74	
body	10.57[c]	60.45[c]	0.69	0.51
astringency	4.86[c]	70.27[c]	0.69	0.56
length	8.33[c]	83.87[c]	0.88	0.57

[a] Significant at $p < 0.05$. [b] Significant at $p < 0.01$. [c] Significant at $p < 0.001$.

Principal Component Analysis (PCA). The correlation matrix generated from the mean ratings of each wine replicate across the list of attributes was analyzed by PCA. The first principal components (PC) accounted for 90.7 and 87.4% of the variance in the PCA of the data for 12 wines for Cabernet Sauvignon (**Figure 3**) and Shiraz (**Figure 4**), respectively. As illustrated in **Figures 3a** and **Figure 4a**, the first PC contrasted wines on the basis of depth, hue (color), and mouthfeel. Cabernet Sauvignon shaded wines, which were more garnet than ruby in hue and lower in depth, body, astringency, and perceived tannin, were separated from the rest of the treatment wines (**Figure 3b**). Similarly, Shiraz shaded wines, which were more ruby than violet in hue and lower in depth, body, astringency, and length, were separated from the other treatment wines (**Figure 4b**). The second PC explained only 4.6 and 5.0% of the variance in the data for Cabernet Sauvignon and Shiraz, respectively. Eigen-

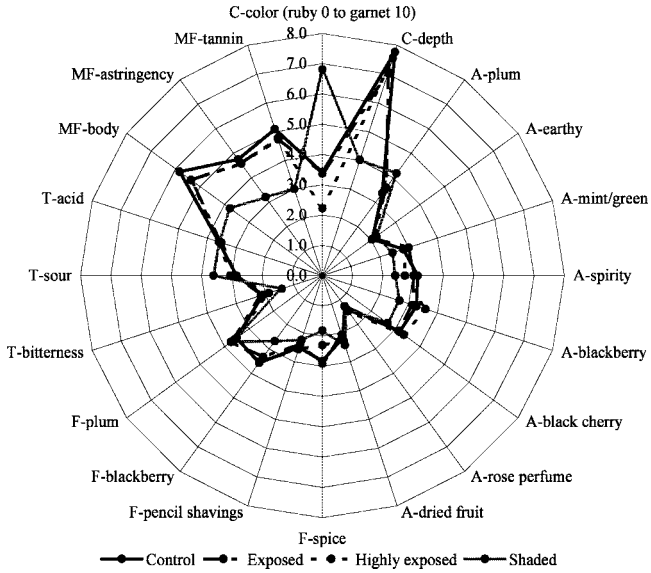

Figure 1. Polar coordinate (spider plot) graph of the mean intensity rating of sensory attributes for Cabernet Sauvignon wines (C = color, A = aroma, F = flavor, T = taste, MF = mouthfeel).

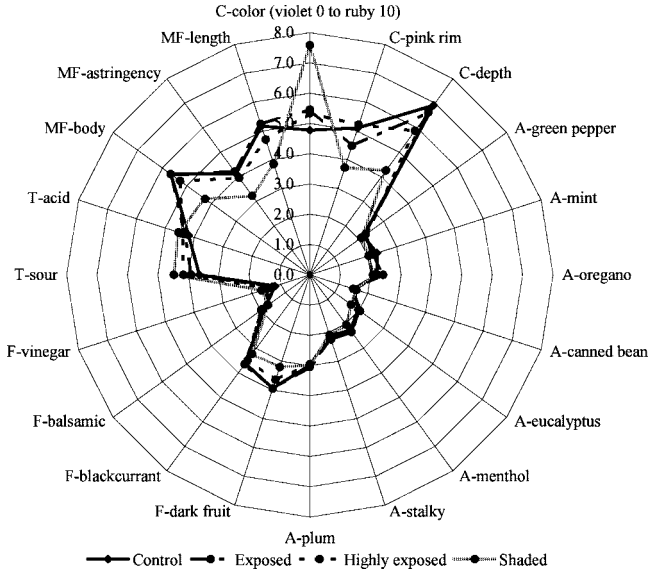

Figure 2. Polar coordinate (spider plot) graph of the mean intensity rating of sensory attributes for Shiraz wines (C = color, A = aroma, F = flavor, T = taste, MF = mouthfeel).

values of the second PC for both varietals are <1, confirming this PC does not contribute to the variance observed in the data.

DISCUSSION

Previous research has examined the impact of shading on fruit composition (*17*, *19*) and, to a lesser extent, explored the influence of these changes on the sensory character of wine (*21*). Although the effect of increased bunch exposure on fruit and juice composition has been explored (*29*), no studies have investigated in detail the sensory attributes of the resultant wine. Here we report on the effect of both increased and decreased canopy exposure on chemical and phenolic composition, along with sensory characteristics of Shiraz and Cabernet Sauvignon wines.

Ripening of fruit was delayed in the shaded treatment for both cultivars as indicated by juice °Brix levels. A study by Spayd et al. (*16*) had previously observed a delay in ripening of shaded Merlot fruit without significant leaf removal. In both the Cabernet Sauvignon and Shiraz wines, the level of sugar in the fruit at harvest was lower in the highly exposed and shaded treatments than in the control. This is reflected in the final alcohol concentrations of wine made from those fruits. Decreased sugar levels in fruit from these treatments is likely the result of decreased photosynthetic capacity of the vines (*30*). In both the highly exposed and shaded treatments extensive leaf plucking was conducted in the fruit zone. In the highly exposed treatment the purpose was to increase sun exposure of the fruit. In the shaded treatment, leaf plucking was designed to create a comparison for the highly exposed treatment, for which leaves had been removed, without increasing the sun exposure of the fruit. Leaf plucking and shading appear to have additive effects in reducing photosynthetic capacity by shading many of the remaining leaves.

Whereas there were differences in fruit pH and TA between treatments for both varieties at crushing, these were largely eliminated in the wine through the addition of tartaric acid during winemaking. Differences in pH and TA in grapes in response to light and temperature have previously been reported (*8*, *13*, *30*).

In both Shiraz and Cabernet Sauvignon wines, wine color density was lower in the wines made from shaded fruit, consistent with previous work in Shiraz (*21*). This was also consistent with the lower level of total anthocyanins in these wines and in the Shiraz wines from Ristic's previous work (*21*). This result was also reflected in the different color rating scores from the DA of the wines. Wines produced from shaded fruit were rated lower in color intensity, consistent with the measured wine color density, lower total anthocyanin, and pigmented polymer measurements. Although Cabernet Sauvignon wine color density for exposed and highly exposed fruit was lower than control, sensory color intensity ratings for these treatments were not lower. Lower perceived color in wines with lower levels of anthocyanins and pigmented polymers was consistent with the contribution of these compounds to wine color (*1*, *4*–*6*).

Although earlier work showed no difference in pigmented polymers with shading (*21*), the results presented here showed that in both Shiraz and Cabernet Sauvignon wines, there were lower levels of total pigmented polymers in the wines made from shaded fruit. This is consistent with the lower levels of tannins and total phenolics in wine made from these fruit. Lower total phenolics in fruit from the shaded treatment could be due to down-regulated flavonoid biosynthesis under decreased light conditions. However, previous studies suggest the light sensitivity of flavonoid biosynthesis is quite low in Shiraz (*14*, *17*, *21*). Although this has not been well established in Cabernet Sauvignon, the indication is that anthocyanins increase with increasing light; however, at high exposure levels increasing fruit temperature results in decreased anthocyanin accumulation and even degradation (*8*, *17*). What seems the most likely explanation of the results observed here is that the combination of both shading and leaf removal resulted in substantially decreased photosynthetic capability of these vines, resulting in decreased accumulation of all metabolites, both primary (e.g., sugar) and secondary (flavonoids, etc.; reviewed in ref *8*).

Previous work suggested that wines made from shaded fruit would have lower levels of phenolics (*21*). On the basis of these observations and research that had shown increases in some phenolic classes with increasing bunch exposure (*8*), higher levels of phenolics might have been expected in wines made from the exposed and highly exposed treatments. However, this was not the observed trend, as phenolic levels in wines made

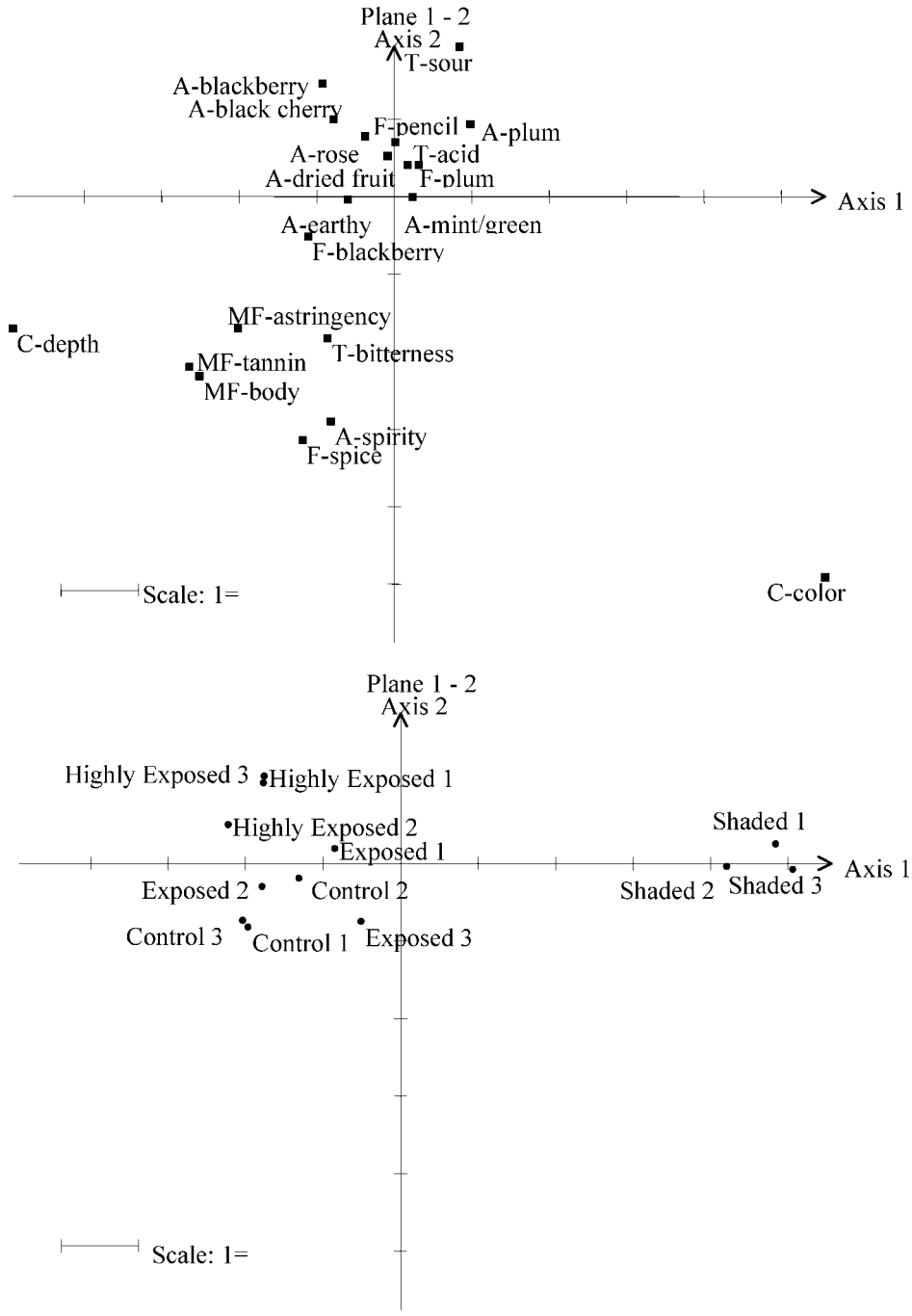

Figure 3. Principal component analysis of the mean ratings of (**a**, top) the 20 Cabernet Sauvignon and (**b**, bottom) the 12 Cabernet Sauvignon wine sensory attributes (C = color, A = aroma, F = flavor, T = taste, MF = mouthfeel).

from both exposed treatments did not significantly differ compared to control wines.

DA of the wines identified differences in the perceived color of the wines made from shaded fruit consistent with the measured changes in total anthocyanins, wine color density, and phenolic measures such as pigmented polymer levels. Wines made from shaded fruit were perceived as lower in astringency than the control and those wines made from exposed and highly exposed fruit. PCA also supports the chemical data that wine color, mouthfeel, and body are the most important attributes in separating the shaded wines from the others. This observation was consistent with the shaded wines having lower levels of total tannins, where tannin concentration is strongly correlated with perceived astringency (*31*) and lower alcohol, which is a contributor to wine body. Similar observations were made of Shiraz wines made from fruit grown in complete darkness (*21*). The level of total tannins was lower in the wine made from the shaded fruit compared to the control, and these wines scored lower for overall astringency (*21*). Wines made from shaded fruit also scored lower for coarse and grainy mouthfeel characters that were not identified in the current study. In the previous study of wine made from shaded Shiraz fruit there was no difference in perceived bitterness. However, in the current study, bitterness was not perceived in any of the Shiraz wines, but Cabernet Sauvignon wines made from shaded fruit were perceived as being less bitter than wines made from other treatments. Unlike astringency, it is not possible to correlate changes in bitterness with any of the current chemical measures. Flavan-3-ol monomers have a reportedly bitter character, and this sensation increases with increasing alcohol concentration

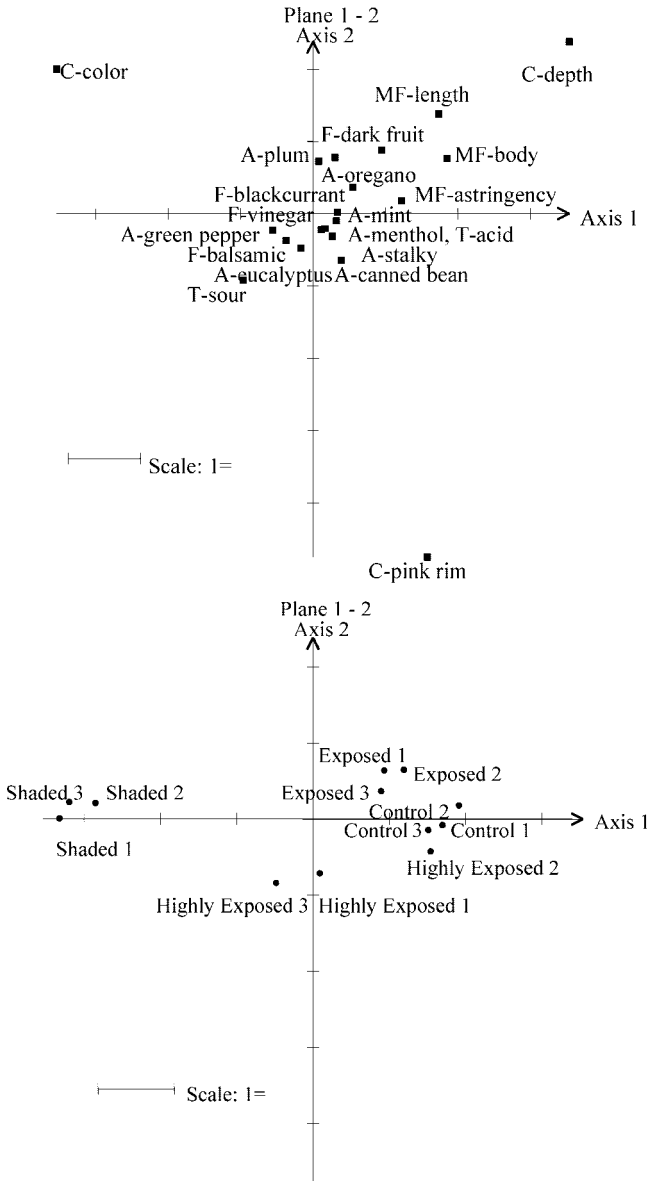

Figure 4. Principal component analysis of the mean ratings of (**a**, top) the 20 Shiraz and (**b**, bottom) the 12 Shiraz wine sensory attributes (C = color, A = aroma, F = flavor, T = taste, MF = mouthfeel).

(*32*); however, flavan-3-ols were not measured in the current study. Although flavan-3-ols were not measured directly, they would be included in the determination of total phenolics (*28*). Compared to the Shiraz wines, total phenolics were around 50% higher in the Cabernet Sauvignon wines, which may be why bitterness was detected in the Cabernet Sauvignon wines and not in Shiraz. Furthermore, the level of total phenolics in the Cabernet Sauvignon wine made from the shaded fruit was lower than in any of the other treatments, which may account for the lower perception of bitterness in this wine. In addition, alcohol was lower in the wine made from the shaded Cabernet Sauvignon fruit. Taken together, lower total phenolics, which may represent lower flavan-3-ols, and lower alcohol, which would reduce the perceived bitterness of flavan-3-ols, were consistent with lower perceived bitterness in the wine made from shaded Cabernet Sauvignon fruit.

In this study, a number of fruit characters were also different between treatments. In Shiraz, dark fruit flavor was lower in the wine made from the shaded fruit compared to all other treatments, whereas between the other treatments there was no difference in this attribute. Previously in wines made from shaded Shiraz fruit, overall fruit flavor and fruit flavor persistence were rated lower for wines made from the shaded fruit (*21*). We also observed that persistence, or length, was rated lower in the Shiraz wine made from shaded fruit. Whereas persistence was not different between Cabernet Sauvignon wines, there were differences in a number of fruit flavor and aroma characters. Generally, all of these were lower in the wines made from shaded fruit.

Whereas lower levels of any secondary metabolite in wines made from fruit of the shaded treatment might be a reflection of the lower maturity of that fruit, lower levels of some flavor aroma compounds suggest that their metabolism may be under photocontrol. Norisoprenoids are a class of secondary metabolites that have been identified as contributing to flavor and aroma characters in wine (*3*). Previous research has shown that accumulation of norisoprenoids increased with increasing bunch exposure (*13*, *21–23*). Whereas the results presented here tend to support the observation that flavor and aroma compounds are likely to be lower in wines made from shaded fruit, the reverse postulate was not generally observed, with the exception of perceived blackberry aroma, which was higher in Cabernet Sauvignon wines made from the highly exposed treatment relative to the exposed treatment. In this study, there was no perceived increase in any flavor or aroma attribute between the control and wines made from the exposed and highly exposed treatments.

The level of sun exposure received by the exposed and highly exposed treatments did not affect the sensory profile of the wines compared to the control. Given the location of the field trial in Sunraysia (Victoria, Australia), it is likely that light levels in the control treatment were sufficient to up-regulate any aspects of flavor and aroma metabolism under photocontrol. Thus, increased canopy exposure in the exposed and highly exposed treatments had little additional effect. This may limit the potential to manipulate wine flavor and aroma in the vineyard in warm irrigated vineyards. In addition, a number of measured parameters were lower in wines made from highly exposed fruit compared to the control. Although this may represent slightly lower photosynthetic capacity due to leaf removal, there is also a possibility that increased exposure resulted in an excessive heat-load within the fruit, inhibiting some metabolic processes or initiating degradation of metabolites (*8*). This indicates potential merit in repeating these experiments in cool-climate viticulture production areas. That substantial differences in measured parameters or sensory characters were not observed with increasing canopy exposure relative to the control suggests that increased canopy exposure as a consequence of other management practices, for example, deficit irrigation reducing effective leaf area, may not have a detrimental impact on perceived wine quality.

ABBREVIATIONS USED

ISO, International Standards Organization; TA, titratable acidity; VA, volatile acidity; ANOVA, analysis of variance; PCA, principal component analysis; LSD, least significant difference; PC, principal component.

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