Sensory Attributes of Cabernet Sauvignon Wines Made from Vines with Different Crop Yields

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Abstract: Crop yield is widely recognized as an important factor in the quality of resultant wines, but most prior research has shown no effect of yield on wine quality. The role of yield in the sensory properties of *Vitis vinifera* L. cv. Cabernet Sauvignon was tested using pruning and cluster thinning to manipulate yield. Cabernet Sauvignon vines in the Napa Valley were subjected to six winter pruning treatments over two vintages and eight cluster-thinning treatments over one vintage, with thinning imposed at veraison. The treatments created yields that varied from 4.3 to 22.2 t/ha. Descriptive analysis conducted on the resulting wines demonstrated significant differences in several sensory attributes. Analysis of variance and principal component analysis showed that the wines made from vines pruned to low bud numbers (hence "low yield") were higher in veggie aroma and flavor, bell pepper aroma, bitterness, and astringency than "high-yield" wines. Conversely, the wines made from vines pruned to high bud numbers were higher in red/black berry aroma, jam aroma, fresh fruit aroma, and fruity flavor than low-yield wines. Regression analysis showed that, in general, veggie attributes decreased in intensity and fruity attributes increased in intensity as bud number and yield increased. In contrast, there were few sensory differences detected in wines made from the various cluster-thinning treatments, although the yield range was greater in that experiment than in the pruning experiment. We concluded that Cabernet Sauvignon aromas and flavors respond to yield manipulation, but do so significantly only when yield is altered early in fruit development.

Key words: sensory evaluation, pruning, cluster thinning, yield, canopy management

Crop yield is an inescapably fundamental component of wine business. More grapes will produce more wine. Yet, as for many horticultural crops, the quality of the grapes is also an important component. Traditionally, low-yielding vineyards have been associated with higher quality wines (Ross 1999). This belief has been held since the Middle Ages (Johnson 1989), and in France yield is regulated by law putatively for quality control (Pomerol 1999). In California, a survey of winemakers and viticulturists (n = 179) conducted in 2000 at the Grape Expectations conference in Davis, California showed that 50% agreed or strongly agreed that low grape yields produce higher quality wines, while only 19% disagreed (Chapman and Guinard 2000, unpublished data).

Crop yield is readily manipulated. Vine pruning to reduce the number of cluster-bearing buds and crop thinning to reduce the number of grape clusters are common viticultural practices used to regulate yield in commercial winegrape vineyards. Given that yield directly impacts the amount of wine that can be produced in a vintage, that yield can be readily manipulated, and the longevity and strength of the conviction that yield negatively impacts wine, surprisingly few studies have been conducted to determine how wine aromas and flavors are affected by crop yield.

Most investigations of yield effects on wine sensory properties have used either cluster thinning (Bravdo et al. 1984, 1985, Reynolds et al. 1996b) or pruning (Ewart et al. 1985, Freeman et al. 1980, Zamboni et al. 1996) to manipulate yield. These studies used two or three treatments to produce a relatively narrow range of yields, varying less than about 1.75-fold. Sinton et al. (1978) used both methods but combined the analysis of pruning and cluster-thinning treatments. Most, too, have used wine-quality scales such as the Davis 20-point scale to evaluate wine sensory properties. Seven studies (Bravdo et al. 1985, Ewart et al. 1985, Freeman et al. 1980, Ough and Nagaoka 1984, Reynolds et al. 1986, Sinton et al. 1978, Zamboni et al. 1996) found no effect or no consistent effect of yield on wine quality scores; whereas only one study (Bravdo et al. 1984) found lower wine-quality scores in the wines from high-yielding vines. In another study, wines from cluster-thinning treatments were preferred; however, the thinned samples were harvested at a higher Brix than the unthinned samples (Cordner and Ough 1978). While informative, these approaches are limited. The few treatments and narrow range of yields may not have produced wines that spanned a sufficient range of sensory differences to show significant quality differences. In addition, wine-quality scales such as the Davis 20-point scale may not find quality differences

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among wines that are free from defects, even if the wines have different sensory properties (Amerine and Roessler 1976).

Of more utility for vineyard management and winemaking decisions is information about specific sensory attributes; it is first necessary to establish objective characterizations of aroma and flavor differences caused by viticultural treatments before subjective evaluations can be made. For example, the intensity of wine aroma was not affected by yield treatments in one study with Cabernet Sauvignon (Ough and Nagaoka 1984) and was inversely related to yield in another study with Zinfandel (Sinton et al. 1978). Descriptive analytical techniques can be used to characterize sensory differences in wines across multiple attributes (de la Presa-Owens and Noble 1995, Douglas et al. 2001, Fischer et al. 1999, Guinard and Cliff 1987, Noble 1979) without judging the positive or negative impact of the differences. However, only two studies have varied yield and evaluated the resultant wine sensory attributes using descriptive analysis. These studies were conducted in Pinot noir (Reynolds et al. 1996b) and Riesling (Reynolds et al. 1994).

The objective of this study was to investigate the effects of yield manipulation through vine pruning and cluster thinning on the sensory attributes of Cabernet Sauvignon wines. The hypotheses being tested were that sensory aroma and flavor attributes are impacted by (1) changes in bud number and (2) changes in thinning severity at a constant bud number. In addition, the sensory effects of winter pruning and veraison thinning were compared.

Materials and Methods

Viticulture. Grapes (*Vitis vinifera* L. cv. Cabernet Sauvignon 110R rootstock) were planted in 1995 in the Napa Valley on a Bale clay loam at 1.8 m x 2.4 m spacing and trained to bilateral cordons. Standard pruning in the vineyard was 24 buds/vine. Yield was manipulated by winter pruning vines to 12, 18, 24, 30, 36, and 48 buds/vine in 2000 and 2001. In a separate experiment, yield was manipulated by cluster thinning in 2001. Vines were pruned to 24 or 48 buds per vine, and clusters were removed at veraison to leave 12, 24, 36, 48 clusters/vine for the 24 bud vines and 48, 64, 72, 96 clusters/vine for the 48 bud vines. In both experiments, treatments were imposed in a randomized complete block design with six replications. Nutrition, irrigation, pest control, and other vineyard operations were consistent with accepted commercial vineyard practices. Grapes were harvested at 22 ± 1.1 Brix in 2000 (early, due to imminent rain) and 23.2 ± 1.3 Brix in 2001. All wines were made in triplicate except for several treatments in the 2001 season where there was only enough crop to make two replicates. Fruit was crushed, destemmed, and separated into 55-L plastic fermentation vessels. SO_2 was added (50 mg/L) and the musts were inoculated with Premier Cuvée yeast (Red Star, Milwaukee, WI). The musts were punched down twice per day and the wine was pressed with a single basket press at 2.0 Brix. The wines were then inoculated with an active malolactic bacteria culture and were racked after the Brix had stabilized. After malolactic fermentation had completed, the wines were racked again and 25 mg/L SO_2 was added before being cold-stabilized for four weeks and then bottled. One wine was removed from the study in 2000 because of spoilage problems.

Descriptive analysis. Wines were analyzed by descriptive analysis using a hybrid consensus training method that combined elements of quantitative descriptive analysis (QDA) (Stone and Sidel 1993) and Spectrum descriptive analysis (Meilgaard et al. 1991). One panel was conducted for the 2000 wines (13 panelists: 9 male, 4 female, ages 21 to 33) and a separate panel was conducted for the 2001 wines (15 panelists: 7 male, 8 female, ages 21 to 41). Both panels were trained by the same facilitator. Panelists were selected based on interest and availability and were compensated for their participation with either a student research unit or money.

Sensory panel training. For both panels, panelists attended three one-hour sessions per week for four weeks. A brief introduction to descriptive analysis was given during the first session before wines were tasted. During the first two weeks, panelists were given three experimental wines per day that were chosen to show the range of differences in the wines. Panelists smelled and tasted the wines and first listed descriptors individually, then discussed the terms as a group, and finally ranked the wines using the descriptors they had generated. If there were disagreements among the panelists on the rank order of the wines for a given attribute, then the group discussed their differences and came to a consensus. The group also generated the scorecard, established evaluation protocols, developed and evaluated standards, and chose the scale (0 = not present, 15 = extremely intense) during those sessions. By the end of the two-week period, the scorecard was finalized (Table 1).

The final two weeks were spent training the panelists for attribute scaling. During the first four sessions, panelists were served three wines and were asked to rate them for the attributes listed on the scorecard using the 16-point scale. After individually rating the wines, the panelists shared their scores. If there were large disagreements in scores or disagreements in the rank order of intensities for an attribute, then the wines were discussed until a consensus was reached on the rank order of the wines for the attribute. The final two training sessions were in individual tasting booths. Panelists rated the same five wines in each of the two sessions using the computer software or ballots that would be used for the final collection of the data. Significant differences among the wines were found by analysis of variance (ANOVA). After completion of the two sessions, panelists were able to view their scores to see which attributes were problematic and were able to re-smell the wines in order to aid in concept alignment. The panel was deemed ready for collection of the data at the end of this period.

Table 1 Attributes and reference standards for 2000 and 2001 panels. Standards prepared in 40-mL Cabernet Sauvignon base wine.

Attribute	Reference standard
Aroma 2000	
Veggie	2.5 g chopped asparagus + 2.5 g chopped green bean
Bell pepper	5 g chopped bell pepper
Black pepper	Pinch (0.05 g) Safeway Crown Colony Coarse Ground black pepper (Pleasanton, CA)
Fresh cherry	No standard (cherries not in season)
Red/black berry	5 mL fresh strawberry/raspberry/blackberry juice (squeezed through cheesecloth)
Jam/cooked berry	1 mL each Safeway red raspberry, blackberry, boysenberry, and strawberry preserves
Dried fruit/raisin	10 crushed Safeway California seedless raisins
Earthy/musty/mushroom	1.25 g sliced fresh mushroom
Soy/molasses	2 drops Aloha Shoyu soy sauce (Pearl City, HI), 1.5 g Grandma's Robust Flavor molasses (Stamford, CT)
By mouth 2000	
Astringent	0.22 molar catechin
Bitter	0.56 molar caffeine
Acidic/sour	0.22 molar citric acid
Veggie	Bell pepper and veggie aroma standards
Fruit	Red/black berry aroma standard
Black pepper	Black pepper aroma standard
Aroma 2001	
Total aroma	No standard (overall aroma intensity)
Canned veggie	5 mL juice from Del Monte fresh-cut canned green beans (San Francisco, CA), 1 mL juice from Green Giant canned asparagus spears (Minneapolis, MN)
Bell pepper	1 g sliced bell pepper
Black pepper	Pinch (0.05 g) of Safeway Crown Colony Coarse Ground black pepper
Fresh fruit	1 g crushed fresh raspberry, 1 g crushed fresh blackberry, 7.5 mL Cherry Tree cherry juice (Corte Madera, CA), 7.5 mL R.W. Knudsen Black cherry juice (Chico, CA)
Artificial fruit	7 red Black Forest gummy bears (Forest Park, IL)
Berry jam	1 g red raspberry, 1 g blackberry, and 0.75 g strawberry Smucker's Simply 100% fruit jam (Orrville, OH)
Prune	3 sliced Sunsweet pitted prunes (Yuba City, CA)
Mushroom	1.25 g sliced fresh mushroom
By mouth 2001	
Astringent	0.22 molar catechin
Bitter	0.56 molar caffeine
Sour	0.22 molar citric acid
Veggie	Bell pepper and veggie aroma standards
Fruit	Red/black berry aroma standard

Sensory testing. The wines were stored in the University of California, Davis wine cellar at 12°C and were brought into the sensory laboratory at least two hours before testing to equilibrate with the testing environment. Fifteen minutes before the start of each tasting session, 40-mL portions of the wines were poured into clear, tulip-shaped 250-mL glasses and plastic covers were placed over the glasses to retain aromas. The glasses were coded with three-digit random numbers.

Before entering the tasting booths, panelists smelled the aroma standards to refresh their memories. The standards were also available inside the testing room for the panelists to refer to throughout the tests.

The 18 wines from the 2000 vintage (six pruning treatments, three wines/treatment) were tested in triplicate by each of the panelists in spring 2001. The order of presentation of the wines was randomized within each of the three scoring repetitions and the judges were served four or five wines per session. Wines were presented one at a time under incandescent light and data were collected on paper ballots. Panelists rinsed with water for 10 seconds between wines. Bottles that still had wine remaining in them at the end of a day were purged with nitrogen gas to prevent oxidation of the wine and were stored at 4°C. After a second day of testing with the same bottle, the wine was discarded and a new bottle was brought from the cellar. Each judge completed three sessions per week over a period of four weeks. Sessions lasted approximately 18 to 25 minutes.

The 16 pruning wines (six treatments, two to three wines/treatment) and 20 thinning wines (eight treatments, two to three wines/treatment) from the 2001 vintage were tested in triplicate by each panelist in winter 2003. For each of the three scoring repetitions, the wines were randomly separated into six blocks of five wines and one block of six wines. This method of presentation was chosen to conserve wine. The wines in each block were different for each of the three repetitions, so that each wine was served with a different combination of wines in each repetition. The wines were randomized within each block for each panelist. The panelists rated the wines in multisample presentation mode for the aroma attributes and one at a time for the flavor-by-mouth attributes (in order to decrease the memory effect for the aroma attributes and to reduce fatigue for the flavor-by-mouth attributes). Panelists rinsed with water for 10 seconds between attributes for the aroma terms and between wines for the flavor-by-mouth terms. Data were collected with the FIZZ software (Biosystèmes, Couternon, France) under red lighting. Each judge completed three or four sessions per week over six weeks.

Data analysis. Analysis of variance (ANOVA) was performed using JMPin4 (SAS Institute, Cary, NC) on each of the sensory attributes for each of the experiments. Winemaking replications were nested within the viticultural treatments and judges were treated as a fixed effect. The model included the following factors: treatment, wine(treatment), replication(wine, treatment), judge, judge*treatment, judge*wine(treatment). A second ANOVA was also run on the sensory data from the cluster-thinning experiment using buds/vine, treatment(buds/vine), judge, judge*buds/vine, judge*treatment(buds/vine) as factors to test for sensory differences between the two pruning treatments imposed on the vines before cluster thinning was conducted at veraison.

Principal component analysis (PCA) was performed on the covariance matrix of mean attribute ratings across the wines for the attributes that differed significantly by ANOVA to illustrate the relationships between the attributes and the wines using the JMPin4 software system. PCA is a multivariate technique that can be used to show relationships among multiple sensory attributes and samples (Lawless and Heymann 1999).

Microsoft Excel (Redmond, WA) was used for all linear regression. Significance of R^2 values was determined by calculating the square root of the R^2 values and using a table for the critical values of the Pearson product-moment correlation coefficient (O'Mahony 1986).

Results

Yield. The pruning treatments resulted in yield that varied over 3-fold in 2000 and over 2.5-fold in 2001 (Figure 1). In both years, yield increased similarly and steadily with buds/vine except at the highest bud count. For that treatment, the large difference in yield between years suggests that the vines were overcropped in 2000 and that the fruitfulness of the retained buds in 2001 was diminished. That was indicated by an approximately 35% decrease in both yield and clusters/vine from 2000 to 2001 compared to similar yield and clusters/vine for the two seasons in the other treatments. Minimum and maximum yields were 6.1 t/ha and 22.2 t/ha.

The cluster-thinning treatments resulted in yields that varied 4-fold (Figure 2). As the number of clusters per vine increased, the yield increased except at the highest cluster count. Minimum and maximum yields were 4.3 t/ha and 17.5 t/ha, respectively. Two treatments had 48 clusters/per vine; one had 24 buds/vine and two clusters/bud while the other one had 48 buds/vine and one cluster/bud. The treatment with 24 buds/vine had a 23% higher yield than the treatment with 48 buds/vine.

Descriptive analysis. In addition to altering yield, the pruning and cluster-thinning treatments resulted in wines that differed in aroma and taste attributes. In 2000, there

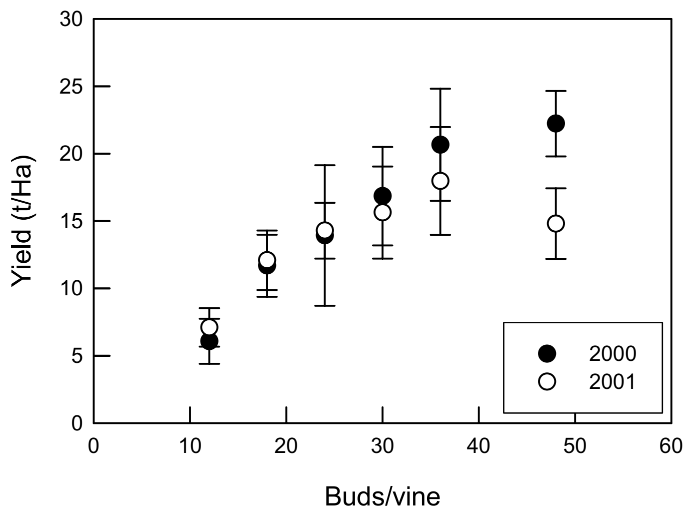

Figure 1 Yield of Cabernet Sauvignon vines pruned to retain different numbers of buds in 2000 and 2001.

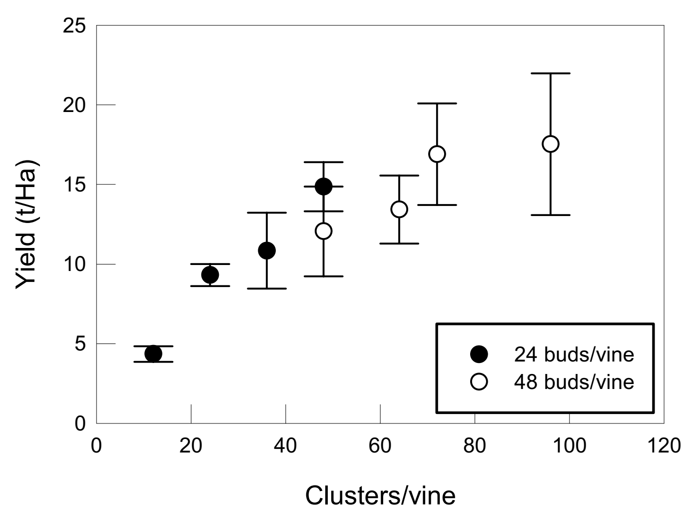

Figure 2 Yield of Cabernet Sauvignon vines cluster-thinned at veraison to different numbers of clusters/vine in 2001.

were significant differences ($p \leq 0.05$) among treatments in 10 of the 15 attributes tested (Table 2): veggie, bell pepper, black pepper, and red/black berry aromas and astringency, bitterness, acidity, veggie by mouth, fruit by mouth, and black pepper by mouth. In 2001, the same pruning treatments produced wines with significant differences ($p \leq 0.05$) in 9 of the 14 attributes that were rated (Table 3): total aroma, canned veggie, bell pepper, black pepper, fresh fruit, prune, and mushroom aromas and astringency and veggie by mouth. There were significant differences among treatments in both years for veggie, bell pepper, black pepper, and berry aromas and for astringency and veggie by mouth.

There were significant differences ($p \leq 0.05$) among the cluster-thinning treatments for only 3 of the 14 attributes tested (Table 4). These were astringency, veggie by mouth, and artificial fruit aroma. Wines made from vines with 24 buds/vine were significantly higher in black pepper aroma, astringency, and veggie by mouth than the wines made from vines with 48 buds/vine ($p \leq 0.05$).

In all cases, judges were a significant source of variation (Tables 2, 3, 4). That is to be expected in descriptive analysis when judges are not trained to produce the exact same ratings on the scale; rather, they are trained to be consistent with each other as to the relative ordering of the wines. No judge*wine(treatment) values were significant, indicating that there were no concept alignment problems within treatments (Tables 2, 3, 4). There were significant judge*treatment interactions for several attributes; however, when intensity ratings versus yield were plotted separately for each judge, only one of the 15 judges did not follow the same general trend in scores as the rest of the panel. There was reasonable concept alignment among the panelists.

Table 2 ANOVA *p*-values for wines from pruned vines of the 2000 vintage.

	Head[a]			
Attribute	**T**	**W(T)**	**R(W,T)**	**J*T**
Aroma				
Veggie	**0.004**	**0.046**	0.152	**0.001**
Bell pepper	**<0.001**	0.162	0.712	**0.050**
Black pepper	**0.032**	0.633	0.316	0.128
Cherry	0.524	0.916	0.446	**0.040**
Red/black berry	**0.001**	0.432	0.925	0.156
Jam	0.192	0.457	0.904	**0.007**
Raisin	0.084	0.516	0.792	0.191
Earthy	0.204	0.621	0.115	0.799
Soy	0.757	**0.046**	0.237	0.248
By mouth				
Astringent	**<0.001**	0.061	**0.001**	**0.028**
Bitter	**<0.001**	0.391	0.539	**<0.001**
Acidic	**0.001**	0.609	0.177	**0.004**
Veggie	**0.019**	0.594	0.875	**0.002**
Fruit	**0.001**	**0.044**	0.812	**<0.001**
Black pepper	**<0.001**	0.771	0.478	**0.005**

[a]T (treatment), W (wine), R (repetition), J (judge). Bold values are significant at the 5% level. Judge effect significant for all attributes ($p \leq 0.001$). J*W(T) not significant for all attributes ($p \geq 0.05$).

Table 3 ANOVA *p*-values for wines from pruned vines of the 2001 vintage.

	Head[a]			
Attribute	**T**	**W(T)**	**R(W,T)**	**J*T**
Aroma				
Total aroma	**<0.001**	0.656	0.725	0.652
Canned veggie	**<0.001**	0.065	**≤0.001**	**<0.001**
Bell pepper	**<0.001**	**0.003**	**0.012**	**<0.001**
Black pepper	**0.003**	0.381	**0.001**	**0.011**
Fresh fruit	**<0.001**	0.061	0.313	0.301
Artificial fruit	0.188	**0.019**	0.054	**<0.001**
Jam	0.275	**0.001**	**0.026**	**<0.001**
Prune	**0.003**	0.227	0.072	**<0.001**
Mushroom	**<0.001**	**0.007**	**0.035**	**<0.001**
By mouth				
Astringent	**0.003**	0.701	0.902	0.795
Bitter	0.074	0.209	0.424	**<0.001**
Sour	0.263	0.511	0.105	0.226
Veggie	**0.001**	0.191	0.084	**0.014**
Fruit	0.186	0.323	0.220	**0.024**

[a]T (treatment), W (wine), R (repetition), J (judge). Bold values are significant at the 5% level. Judge effect significant for all attributes ($p \leq 0.001$). J*W(T) not significant for all attributes ($p \geq 0.05$).

Table 4 ANOVA *p*-values for wines from cluster-thinned vines of the 2001 vintage.

	Head[a]			
Attribute	**T**	**W(T)**	**R(W,T)**	**J*T**
Aroma				
Total aroma	0.488	0.372	0.445	**0.005**
Canned veggie	0.180	0.319	0.097	**0.003**
Bell pepper	0.535	**0.002**	**0.006**	0.189
Black pepper	0.093	0.098	0.268	0.342
Fresh fruit	0.365	0.598	0.303	0.959
Artificial fruit	**0.001**	**0.018**	**0.039**	0.198
Jam	0.450	0.073	**0.023**	0.205
Prune	0.225	0.471	**<0.001**	0.059
Mushroom	0.946	0.127	**0.017**	0.432
By mouth				
Astringent	**0.015**	0.984	0.763	**0.001**
Bitter	0.223	0.701	0.465	0.317
Sour	0.338	0.248	0.098	0.059
Veggie	**0.008**	**0.008**	0.314	0.735
Fruit	0.383	0.158	**<0.001**	0.999

[a]T (treatment), W (wine), R (repetition), J (judge). Bold values are significant at the 5% level. Judge effect significant for all attributes ($p \leq 0.001$). J*W(T) not significant for all attributes ($p \geq 0.05$).

Significant regressions were seen in the intensity scores across treatments for many attributes. In both years, fruity by mouth (Figure 3A) and fruity aromas (cherry and red/black berry in 2000, fresh fruit in 2001) (Figure 3B) increased as the number of buds/vine increased. Bell pepper aroma (Figure 4A) and veggie aroma (Figure 4B) ratings decreased as the number of buds/vine increased and veggie by mouth (Figure 4C) decreased in 2001. In addition, astringency ratings decreased with respect to yield in both vintages (Figure 5). For the 2000 wines, black pepper aroma, earthy aroma, and bitterness decreased as the number of buds/vine increased ($p \leq 0.05$; regressions not shown). In 2001, total aroma and canned veggie aroma decreased as the number of buds/vine increased, and sourness increased as the number of buds/vine increased ($p \leq 0.05$). In general, and for both vintages, as number of buds/vine increased, veggie aromas decreased and fruity aromas increased.

For the wines from the cluster-thinning treatments, when the average attribute intensities versus the number of clusters per vine were plotted, astringency decreased ($p \leq 0.01$), sourness increased ($p \leq 0.05$), and bitterness decreased ($p \leq 0.1$) (data not shown). No significant regressions were found between the aroma attributes and crop yield.

PCA was performed using the attributes that differed significantly by ANOVA for the 2000 pruning wines (Figure 6). The positions of the wine replications within the treatments were averaged on the PCA graph. PC1 explained 64.5% of the variation in the data and ran from fruity on the negative end to veggie/bitter/astringent on the positive end. In general, the wines made from grapes with fewer buds/vine were located on the veggie side of PC1 and the wines moved progressively further toward the fruity side of PC1 as the number of buds/vine increased. The wines with 48 buds/vine, the highest bud level in the study, broke this

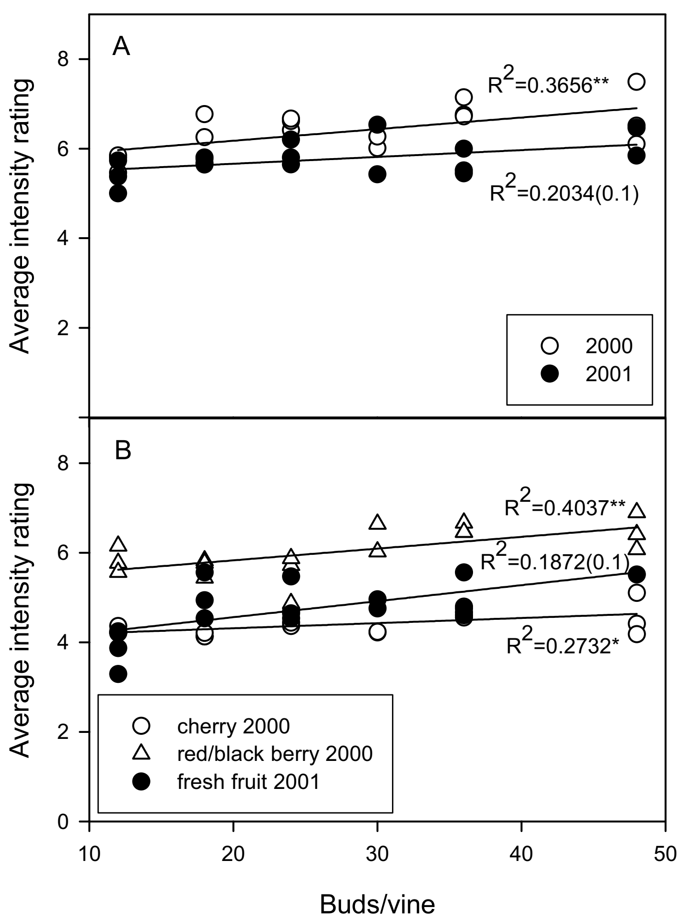

Figure 3 Change in (**A**) fruit-by-mouth and (**B**) cherry aroma (2000), red/black berry aroma (2000), and fresh fruit aroma (2001) intensity ratings with response to pruning in 2000 and 2001. *, **, *** indicate significance at $p \leq 0.05$, 0.01, and 0.001, respectively.

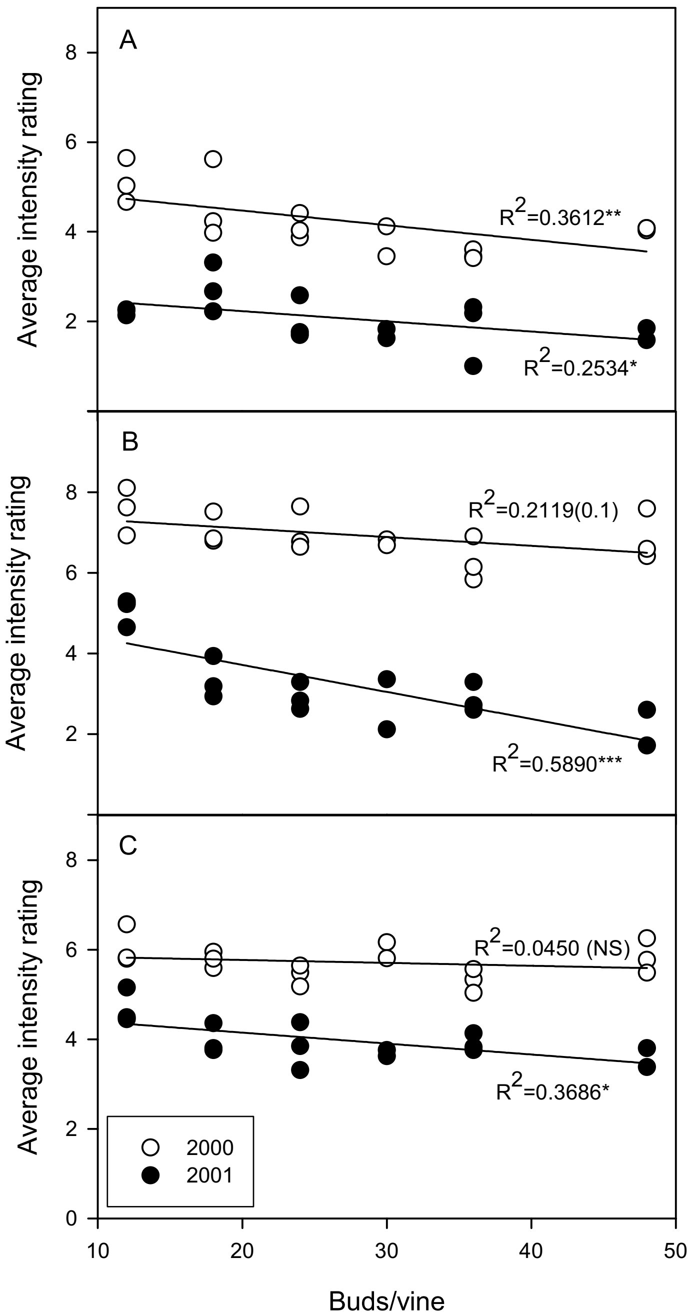

Figure 4 Change in (**A**) bell pepper aroma, (**B**) veggie aroma, (**C**) and veggie-by-mouth intensity ratings with response to pruning in 2000 and 2001. *, **, *** indicate significance at $p \leq 0.05$, 0.01, and 0.001, respectively.

trend and were more veggie than the wines with 36 buds/vine. PC2 explains only 11% of the variation in the data and runs from fruity and astringent on the positive end to veggie on the negative end.

The PCA for the 2001 pruning wines was run using the attributes that differed significantly by ANOVA (Figure 7). Additionally, bitter and fruit by mouth were included in the analysis in order to compare the 2001 and 2000 PCA results. The wine positions were averaged within treatments. PC1 explained 51.6% of the variation in the data and, similar to the 2000 PCA, ran from fruity on the negative end to veggie on the positive end. Again, the wines moved from the veggie side of PC1 to the fruity side of PC1 as the number of buds per vine increased. The wines made from 36 buds/vine were the only ones that broke this trend. PC2 ran from prune and mushroom on the positive end to astringent and bitter on the negative end and explained 11.7% of the variation in the data.

The PCA for the 2001 cluster-thinned wines was created using the four attributes that showed significant differences among the thinning treatments or between the two pruning treatments by ANOVA (Figure 8). PC1 explained 40.9% of the variation in the data and PC2 explained 36.3% of the variation in the data. Veggie by mouth, black pepper aroma, and astringent are located in the upper right quadrant of the PCA while artificial fruit was located in the lower right quadrant. The PCA separated the wines made from vines with 24 buds/vine from the wines made from vines with 48 buds/vine. The wines made from vines with 24 buds/vine were higher in black pepper aroma, veggie by mouth, and astringency than the wines made from vines with 48 buds/vine, which is consistent with the pruning experiment results. There did not seem to be a sensory trend with respect to the number of clusters remaining on the vine, although the thinning treatments differed with respect to artificial fruit aroma. Two sets of wines were made with 48 clusters/vine (one with 24 buds/vine and another with 48 buds/vine). These wines were not grouped closely by the first two principal components, but they were grouped with

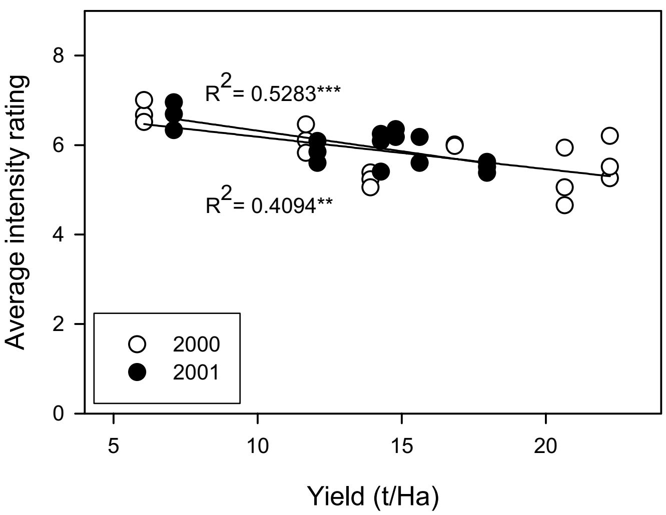

Figure 5 Astringency ratings with respect to crop yield for the 2000 and 2001 pruning wines. *, **, *** indicate significance at $p \leq 0.05$, 0.01, and 0.001, respectively.

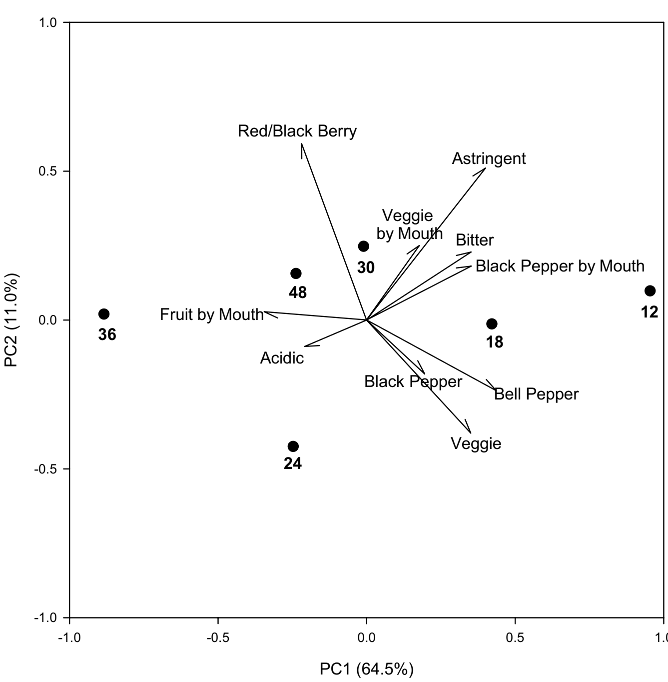

Figure 6 Projection of sensory attributes on principal components 1 and 2 for wines made from six pruning treatments (12, 18, 24, 30, 36, and 48 buds/vine), 2000. Wines are plotted as the average position for the three fermentation replications.

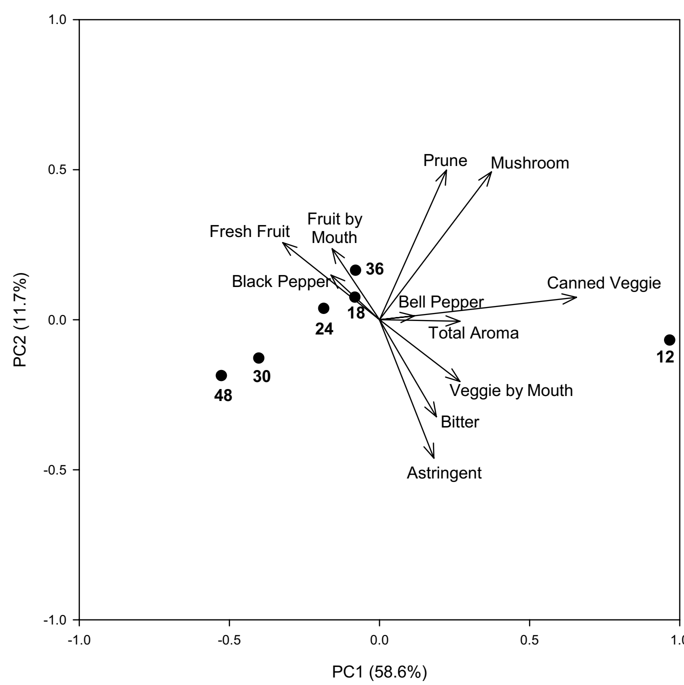

Figure 7 Projection of sensory attributes on principal components 1 and 2 for wines made from six pruning treatments (12, 18, 24, 30, 36, and 48 buds/vine), 2001. Wines are plotted as the average position for the three fermentation replications.

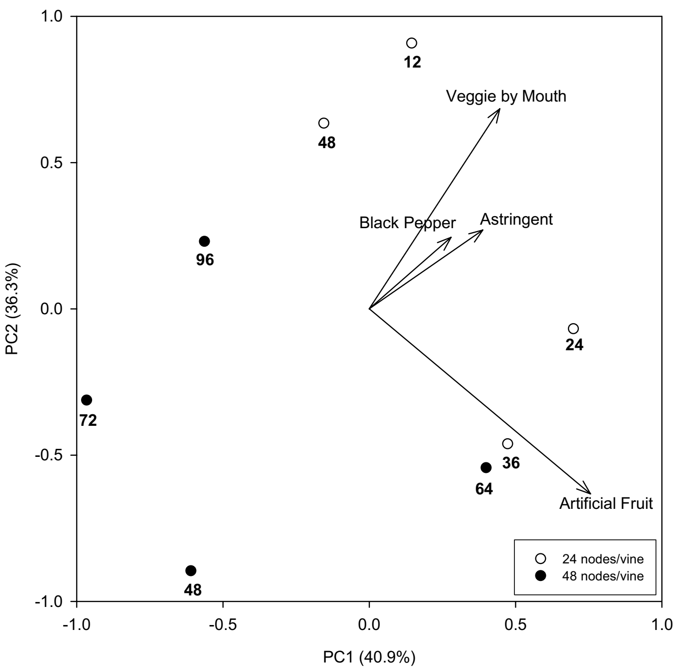

Figure 8 Projection of sensory attributes on principal components 1 and 2 for wines made from eight cluster thinning treatments (12, 24, 36, and 48 clusters/vine with 24 buds/vine; 48, 64, 72, and 96 clusters/vine with 48 buds/vine), 2001. Wines are plotted as the average position for the three fermentation replications.

the other wines in their respective pruning treatments. When a PCA was run with all of the attributes on the scorecard, a similar pattern emerged (data not shown).

Discussion

Wines made from vines with different yields had significantly different sensory attributes. In general, lower yields produced wines with higher intensities of astringency and veggie aromas and flavors. However, the impact of yield on wine sensory attributes was greatly dependent on the method by which yield was altered. When yield was established by pruning, several aroma attributes were affected, and the intensity of veggie aromas and flavors was inversely related to yield. In contrast, cluster-thinning treatments had little effect on wine aroma and created no significant regressions with particular aroma attributes. The decrease with yield of the intensity of some sensory attributes could perhaps be anticipated. The cultivated grapevine can produce more fruit than it can mature to the point of commercial harvest. Somewhat surprising was the consistent observation that the intensity of fruity aromas and flavors was directly positively correlated with yield.

In the cluster-thinning experiment, it was necessary to incorporate two pruning levels in order to carry the wide range of crop loads in the experimental design. The two preseason pruning conditions that were imposed on the vines before the thinning treatments occurred did lead to aroma and flavor differences. The vines that received the more severe preseason pruning treatment were significantly higher in black pepper aroma, veggie by mouth, and astringency. These results are consistent with the pruning experiment results in that vegetative attributes and astringency decreased as buds/vine increased. The same panel tested both the 2001 vintage pruning and thinning wines and was able to detect many more differences among the pruning treatments than among the thinning treatments. We interpret these results to show that, despite the larger variation in yield for the thinning experiment, the winter pruning treatments had a greater effect on wine sensory attributes.

These results were illustrated by both PCA and linear regression analysis. Furthermore, the magnitude of effects of yield on sensory attributes was relatively small; the intensity ratings differed by less than 25% of the highest intensity rating across the full range of yields. Thus, it was important to establish a wide variation in yield in order to resolve the sensory responses. It is possible that more significant differences could have been detected in earlier studies had a greater range of yields been tested.

However, those earlier studies relied primarily on wine-quality scores. Quality is a complex concept that can be defined in several ways. It can be measured by expert ratings, trueness to type, absence of defect, or consumer acceptance (Guinard et al. 1999). Different results may be obtained depending on which definition of quality is chosen in a study. Although no quality data were collected in this study, overpowering veggie aromas and flavors in Cabernet Sauvignon wine are generally not considered desirable (Allen et al. 1994, Noble et al. 1995), and the data clearly show a reduction in vegetative intensity with increasing bud number.

In the one application in red wine of descriptive analysis to evaluate wine sensory responses to two yields in Pinot noir created by either cluster thinning at fruit set or shoot thinning (Reynolds et al. 1996b), the intensities of astringency and currant aroma were greater when cluster thinning reduced yield. The astringency response is consistent with the results in the present study with Cabernet Sauvignon, but the currant aroma behavior in Pinot noir is opposite to that of the fruity aromas in the present study. Also contrary to the results of the present study, Reynolds and collaborators (1996b) reported less veggie aroma and flavor in wines made from vines with lower yields when the yields were altered by shoot thinning.

Two or three fermentation replications were made from each treatment, and there was significant variation among these replicates for several terms in each study. These included artificial fruit, jam, veggie, and mushroom aromas and fruit by mouth and veggie by mouth. These sensory differences within the treatments arose even though the fruit source within each treatment was the same and all fermentations were conducted according to standard experimental winemaking protocol. For the veggie, mushroom, and artificial fruit aromas and the fruit-by-mouth and veggie-by-mouth attributes, the treatment effect was as significant or more significant than the enological replication [wine(treatment)] effect, indicating that, despite the flavor differences because of fermentation variation, there were still significant sensory differences because of viticultural treatments. Prior winemaking descriptive analysis studies have blended fermentation replications such that the effect of winemaking replication could not be tested (Schmidt and Noble 1983) or have not examined winemaking as a potential source of variation in their sensory data (Reynolds et al. 1996a,b). Sensory differences because of fermentation may be inherent even when a controlled experimental winemaking protocol is used (Ewart et al. 1985), especially with small batch sizes (in this study 56 liters). That does not diminish the importance of the significant sensory differences due to the viticultural treatments imposed on the vines.

Altering yield necessarily affects the source-sink relationship on a shoot. When more buds are left, shoot length and leaf area are generally less, although the crop load per shoot is relatively unaffected. When clusters are thinned at veraison, crop is reduced but leaf area per shoot remains unchanged. It is clear that when crop yield is very high, sugar accumulation and, presumably, other aspects of ripening are delayed (Bravdo et al. 1984). Accordingly, the color of red wine is usually reduced at high yield (Bravdo et al. 1984), but not in some studies (Freeman and Kliewer 1983). Thus, differences in wine sensory attributes could arise from differences in fruit development at harvest if harvests occur on the same date but at different Brix (Cordner and Ough 1978). In this study, fruit was harvested within 1.0 Brix standard deviation of the mean. If fruit are harvested at the same Brix but different dates, then the confounding factor of fruit stage of development is avoided, although it is not clear whether differences in wines are in part due to the different periods in which the fruit developed.

The pruning treatments necessarily altered the canopy structure, but it is not clear to what extent the cluster microclimate was different among the various treatments or whether microclimate was a factor in sensory results. There were significant regressions of sensory attributes with both positive and negative slopes. Thus, it is important to develop hypotheses for the regulation of specific wine sensory attributes, vis-à-vis wine quality, with respect to yield. There is some evidence that veggie and bell pepper aromas are reduced in high temperatures (Allen et al. 1994, Lacey et al. 1991) or high light environments (Noble et al. 1995). However, these observations cannot explain the differences in veggie aromas in the present study because they suggest trends in the opposite direction. Thus, had it been possible to alter yield independent of the canopy structure, greater differences than reported here may have been observed. The intensity of bell pepper aromas and flavors in wines are positively correlated with the concentration of methoxypyrazines, primarily 2-methoxy-3-isobutylmethoxypyrazine (MIBP) (Allen et al. 1991, Roujou de Boubée et al. 2000). In both years of the pruning experiment, bell pepper aroma decreased significantly as the number of buds per vine and yield increased (Figure 4). Fittingly, as bud number increased, MIBP concentration decreased in both vintages ($p \leq 0.001$) and the bell pepper intensity ratings were positively correlated with the MIBP concentrations ($p \leq 0.05$) (Chapman et al. 2004). The decrease in the intensity of the fruity attribute with increasing bud number may have been due to masking by MIBP (Cain and Drexler 1974).

The pruning treatments established differences in crop load that were present on the vines throughout berry development, whereas the cluster-thinning treatments were imposed at veraison. Perturbations of light and water availability in the vine environment have been shown to have greater effect on fruit composition (Dokoozlian and Kliewer 1996, Hashizume and Samuta 1999, Matthews and Anderson 1989) and wine composition (Matthews et al. 1990) when imposed before veraison than after veraison. There may be similar mechanisms involved in the responses of fruit development to pruning and cluster-thinning treatments.

Conclusion

We interpret the results to indicate that the preseason pruning treatments had a larger effect on the sensory properties of the resulting wines than the midseason thinning treatments. As bud number increased by winter pruning, fruity attributes increased in intensity and veggie attributes decreased in intensity. While these sensory differences detected by a trained descriptive analysis panel were statistically significant, more testing is needed to determine whether the differences can be perceived by less experienced consumers and how sensory attributes affect wine preferences.

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