Sensory Effects of Consuming Cheese Prior to Evaluating Red Wine Flavor

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Abstract: The aim of this study was to assess, through descriptive analysis, the way in which the flavor perception of red wine was influenced by the wine pairing with a variety of cheeses. A panel of 11 trained judges evaluated the flavor of eight wines of four different varieties (Cabernet Sauvignon, Merlot, Pinot noir, and Syrah) before and after tasting cheese. Eight cheeses were selected: two soft (Mozzarella and Teleme), two medium-hard (Cheddars from Vermont and New York), two hard (Emmental and Gruyère), and two blue (Gorgonzola and Stilton). The results obtained by descriptive analysis showed that the cheese had significant effects on red wine flavor. Some attributes, such as astringency, bell pepper, and oak flavor, significantly decreased when the wine was evaluated after tasting cheese. Only butter aroma was significantly enhanced by cheese. It was also found that there was no significant wine-cheese interaction effect; in other words, the effect of any given cheese is equivalent for all wines. Although there were significant effects, the overall sensory profiles of wines without prior cheese tasting and as affected by cheese were very similar.

Key words: wine, cheese, sensory evaluation, masking effect, descriptive analysis

Wine is a delectable item by itself, but it is most commonly consumed in accompaniment with different kinds of food. These wine and food combinations have cultural, traditional, and physiological explanations. In particular, beverages help to rinse down solid food elements and may contribute to balancing electrolytes (Tuorila et al. 1994).

Cheese and wine have historically been regarded as a perfect match. However, their matching supposedly requires the precise selection of each of the elements for the ideal perception of the sensory attributes of both cheese and wine. In order to do so, many recommendations are published in popular literature (Cole 2004, Immer 2002, Maclean 2004, Matthews 1997, Werlin 2003). However, these suggestions are mostly based on the sensory experiences of professionals from the food and wine industries and may not reflect how consumers feel. Moreover, rarely are the reasons for pairing suggestions explained in terms of specific sensory attributes, and even when justified, they are not built upon a scientific and statistically representative platform and sometimes disagree with each other (Jackson 2002, Werlin 2003). Before attempting to determine the consumer aspect of cheese-wine pairing, we sought to determine the effect of cheese tastings immediately before wine evaluation on the sensory attributes of the wine.

In order to study cheese and wine pairing, an understanding of the way in which cheese affects the sensory attributes of wine is required. Since there have been numerous studies on the effect of interstimulus rinses on wine sensory analysis (for example, Colonna et al. 2004), the expectation would be that there are also numerous scientific publications relevant to wine and cheese or food interactions. However, only four published studies have been found on wine and food interactions (Nygren 2004, Nygren et al. 2001, 2002, 2003).

Nygren and coworkers (2001) found that the effect of hollandaise sauce on white wine flavor was greater than that of white wine on the hollandaise sauce flavor. Sour and bitter tastes and citrus and toast wine flavors decreased under the influence of hollandaise sauce, while buttery flavor increased. Greater fat content in the sauce enhanced the mentioned effects. In another study (Nygren et al. 2002), the authors found that blue mold cheeses affected perceived white wine attributes. Particularly, oak, citrus, and dry fruit flavors significantly decreased with some wine-cheese combinations. Sourness significantly decreased with every wine-cheese combination compared with the wines by themselves. The effect of wine on cheese flavor was to decrease the characteristic flavor attributes of each blue mold cheese (Nygren et al. 2003).

Given the few studies concerning food and wine pairing, it was important to perform a scientific study on the effects of cheeses on red wine sensory properties. The present study evaluated the sensory effects of a variety of cheeses on red wine flavor and compared the results to wine flavor when no cheese was consumed. Our null hypothesis was that the cheese would have no effect of the

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wine flavor and the alternate hypothesis, based on the discussions of synergy between cheese and wine in the popular press, was that the cheese would increase the sensory attributes of the wines.

Materials and Methods

Wines. Eight red wines were used in this study, two from each of four varieties: Pinot noir, Merlot, Cabernet Sauvignon, and Syrah (Table 1). All wines were produced in California except for one Shiraz produced in Australia. Australian Shiraz wines and Californian Syrah wines are made from the same varietal. There was an attempt to select the two wines from each varietal according to two price ranges; however, the two Pinot noir wines only differed by $4 per bottle. The bottled wines were stored at cellar temperature (about 13°C) and specific bottles were brought to room temperature 24 hours before evaluation. The entire study was completed within five weeks in the summer of 2004. New bottles of all wines were opened for each session.

Cheeses. Eight different cheeses were selected to cover a range from soft to hard cheeses. Two blue mold cheeses were included to expand the cheese flavor profiles. All the selected cheeses were cow milk based. The two soft cheeses were fresh Mozzarella and Teleme (from California), the two semi-hard ones were Cheddars from Vermont and New York, the hard cheeses were Emmental and Gruyère (from France), and the blue mold cheeses were Stilton (from Britain) and Gorgonzola (from Italy). All cheeses were purchased from Corti Brothers (Sacramento, CA) at the same time in order to have them all from the same lot within a cheese. The cheeses were cut into 0.45 kg blocks (~1 lb), vacuum-packed using a Food Saver (Tilia FoodSaver Vac 550, San Francisco, CA), and kept in a refrigerator at 4°C until used. All cheeses were used within five weeks. For the preparation of the samples, 0.5 cm around the edge of each cheese was removed each time and the cheese was cut in small cubic pieces of approximately 5 grams each.

Chemical analyses. The eight wines were chemically analyzed in triplicate for ethanol content, pH, titratable acidity (TA), volatile acidity (VA), and residual sugar. All the analyses were performed using standard procedures (Ough and Amerine 1988) except for the residual sugar determination, which was performed using an enzymatic kit (D-Glucose/D-Fructose; Boehringer Mannheim/R-Biopharm, Darmstadt, Germany). Ethanol content was determined by ebulliometry using a Dujardin-Salleron ebulliometer (Dujardin-Salleron Laboratories, Arcueil, France). pH was measured using a potentiometer (Orion 420A; Orion Instruments, Beverly, MA). Titratable acidity was determined using titration with NaOH to pH 8.2. Volatile acidity was determined using a Cash still (R.D. 80, Research and Development, Berkeley, CA) followed by titration of the distillate with NaOH. Results of the chemical analyses are shown in Table 1.

Sensory analysis. *Panel.* Eleven students (five women and six men ranging in age from 22 to 45 years) from the University of California (UC) Davis Viticulture and Enology Department were selected based on availability and interest. Most of the panelists had wine-tasting experience and some had previously participated in descriptive analysis panels. All sensory evaluations were in compliance with the UC Davis Institutional Review Board.

Training. The training of the descriptive analysis panel followed the procedures outlined in Lawless and Heymann (1998). Training consisted of 10 one-hour sessions. During training sessions, descriptive terms were generated by the panelists, individually, by evaluating wines used in

Table 1 Identification and composition of wines.

				Composition[c]					
								RS	
Code	**Variety[a]**	**Vintage**	**Price[b]**	**pH**	**TA**	**Ethanol**	**VA**	**G**	**F**
CabSauv	Cabernet Sauvignon	2001	8.00	3.6	6.2	12.8	0.53	1.7	1.6
CabSauv-$	Cabernet Sauvignon	2000	20.00	3.7	6.4	13.7	0.58	0.1	0.0
Merlot	Merlot	2001	8.00	3.5	6.1	13.1	0.65	1.9	1.7
Merlot-$	Merlot	2000	20.00	3.6	6.9	12.9	0.71	0.3	0.1
Pinot	Pinot noir	2002	12.00	3.6	6.1	13.8	0.64	1.1	1.2
Pinot-$	Pinot noir	2002	16.00	3.5	6.4	14.7	0.66	0.5	0.2
Syrah	Shiraz	2002	7.00	3.5	7.1	12.9	0.64	2.8	2.8
Syrah-$	Syrah	2002	16.00	3.6	6.4	13.9	0.56	0.9	0.9

[a]Shiraz and Syrah are the same varietal. Shiraz produced in Australia, all other wines from California.
[b]Price: retail price (U.S. dollars).
[c]TA: titratable acidity (g tartaric acid/L); ethanol: % v/v; VA: volatile acidity (g acetic acid/L); RS: residual sugar (G: g glucose/L; F: g fructose/L).

the study. All wines were evaluated at least twice during training in order to define the descriptor terms. Starting with the second training session, reference standards were presented to the panelists. Initially, these were dry references (without wine). As the panelists became acquainted with the reference standards, they were presented in a base wine (2003 Mouvedre, UC Davis), except for the taste standards which were always presented in water solution. Reference standards were modified and refined as requested by the panelists. Toward the end of the training period, the panelists, through consensus, decided which descriptors to retain for the study and which reference standards were appropriate in anchoring these descriptors. The composition of the reference standards and whether the descriptors were evaluated in terms of aroma, flavor by mouth, texture, or taste are presented in Table 2. Panel performance was evaluated at the end of the training period by having the panel evaluate, in triplicate, a subset of the wines with and without cheese. These data were analyzed by three-way analysis of variance to determine whether there were significant panelists by sample interactions. As these were not found, we felt justified in starting the actual evaluation of the samples.

Experimental procedure. The evaluation was performed in two stages. The first was descriptive analysis of the eight wines without the effect of cheese. This stage consisted of three sessions in which the eight wines were provided in a randomized complete block design in triplicate. Each sample (25 mL wine) was presented in a coded tulip wineglass covered with a plastic Petri dish. All samples were served monadically and panelists were required to expectorate the wines. All evaluations were performed with the wines at ambient temperature (20°C).

During the second stage, the effect of cheese on the eight wines was evaluated. Panelists evaluated 64 wine-cheese combinations in triplicate during 24 sessions. In each session, a set of eight wine-cheese combinations was evaluated. A 5-minute break was taken after the evaluation of the fourth combination. In each wine-cheese combination, 25 mL of wine was presented in a coded tulip wineglass covered with a plastic Petri dish. Five-gram cubes of each cheese were served in a coded closed plastic cup with a wooden toothpick. Both the wine and cheese samples were served at room temperature (20°C). The evaluation was performed using sequential cheese-wine tasting, which consisted of placing the entire cheese sample in the mouth, chewing it thoroughly, and then tasting and evaluating the wine. All wines were expectorated. Drinking water (Alhambra, Sacramento, CA) and unsalted crackers (Premium Crackers, Nabisco, Orange, NJ) were provided to clean the mouth between each cheese-wine combination but not within a cheese-wine combination.

For the tasting sessions, aroma reference standards were provided at the beginning. The evaluations were performed in individual testing booths under red light. Panelists rated the intensity of the attributes using a 10-cm unstructured line scale anchored at its extremes by low and high markers. Scores were recorded directly on a computer system using FIZZ version 2.00L (Biosystemes, Couternon France).

Data analysis. The statistical analyses were performed using SAS version 8.02 (SAS Institute, Cary, NC). The sensory ratings were analyzed by multivariate and univariate analyses of variance using canonical variate analysis (PROC GLM, MANOVA canonical option), with main effects: wine, cheese, and the interaction of wine and cheese using raw data. Because of the small differences in the intensity ratings, a more stringent post-hoc mean separation technique was used, Tukey's honestly significant difference (Tukey, rather than the more usual Fisher's protected least significant difference. Bartlett's test was used to calculate the number of significant canonical variates (Heymann and Noble 1989). Once significant dimensions were found, 95% confidence intervals for the different type of cheeses and wines were determined. The angles between the canonical variates were calculated as explained by Tatsuoka (1971).

Table 2 Formulation of sensory reference standards used to anchor attributes. All aroma standards made up in 40 mL base wine (2003 Mouvedre, UC Davis).

Descriptor term[a]	Composition
Berry (a,f)	2 slightly mashed frozen cherries + 2 slightly mashed frozen blackberries
Oak (a,f)	5 g oak chips
Mushroom (a)	½ fresh white mushroom, sliced
Mint (a)	1 fresh chopped mint leaf
Dried fruit (a,f)	1 prune + 5 raisins
Spice (a)	1 tsp pumpkin spice (McCormick)
Vegetal (a)	2 Tbsp canned mixed vegetables (Veg-All)
Bell pepper (a)	1 Tbsp chopped green bell pepper
Vanilla (a)	6 drops vanilla extract (McCormick)
Butter (a)	3 drops butter flavor popcorn oil (Orville Redenbacher's)
Chocolate (a,f)	1 tsp cocoa (Scharffenberger)
Leather (a)	2 cm leather shoelace
Ethanol (f)	5 mL rum (Island Pride Rum)
Bitter (t)	1 g caffeine /L, caffeine USP/FCC, anhydrous (Fisher Chemical)
Astringent (tx)	1.5 g tannic acid/L, tannic acid (Mallinckrodt)
Sour (t)	1.5 g citric acid/L, citric acid, monohydrate (J.T. Baker)

[a]Aroma (a), flavor by mouth (f), texture (tx), taste (t).

Results

The analytical results (Table 1) for volatile acidity indicated that the acetic acid concentration was below both the threshold (0.75 g/L) and legal (1.2 g/L) limits in all wines (Ough and Amerine 1988). All wines were found to be below the pH stability limit for red wines of 3.8 (Ough and Amerine 1988). The residual sugars ranged from 0.1 g glucose/L and 0.0 g fructose/L for CabSauv-$ to 2.8 g glucose/L and 2.8 g fructose/L for the Australian Shiraz (Syrah); these differences did not seem to lead to perceptible differences in sweetness, as sweetness was not an attribute that the panelists choose to use in the study. The ethanol concentration ranged from 12.8% (v/v) for the CabSauv to 14.7% (v/v) for the Pinot-$. The ethanol concentration had a correlation of 0.85 ($p < 0.05$) with the perceived ethanol as rated by the panelists.

Multivariate analysis of variance of red wines. The mean intensities of attributes for the eight wines without cheese, significant according to ANOVA, are presented in Table 3 (attributes that were not found to be significant according to ANOVA are not included). The incidences of significant differences among samples as determined by Tukey's honestly significant difference (HSD) for each attribute are also presented in Table 3. All significant attributes will be discussed in more detail later.

The canonical variate analysis (CVA) applied to the data obtained for the eight wines showed that there were significant differences at $p < 0.05$ among the red wines when they were evaluated without the influence of cheese. Results of the CVA are presented in Figure 1.

The first two canonical variates were significant according to Bartlett's test ($p < 0.05$), accounting for 33.6% and 22.3%, respectively, of the variance ratio. The two axes formed an angle of 90° (Tatsuoka 1971). The results shown in Figure 1 are complemented by the mean intensities for sensory attributes of wines without cheese shown in Table 3. The CVA plot showed that the two wines of any given variety were perceived to be significantly different, with the exception of the Pinot noir wines. In the case of Cabernet Sauvignon, CabSauv-$ had more astringency with a more intense oak flavor than CabSauv. The differences between the Merlot wines were similar, with Merlot-$ higher in astringency and oak flavor than Merlot. For the two Syrah wines, the CVA suggests that Syrah-$ may have had a more intense bell pepper character while Syrah may have had more intense ethanol and chocolate aromas. However, Table 3 shows that the two Syrah wines had practically the same values for these three attributes. The driver for the difference between the two wines was a *combination* of these and other attributes. Finally, the two Pinot noir wines were quite similar, as can be seen by the overlapping 95% confidence intervals.

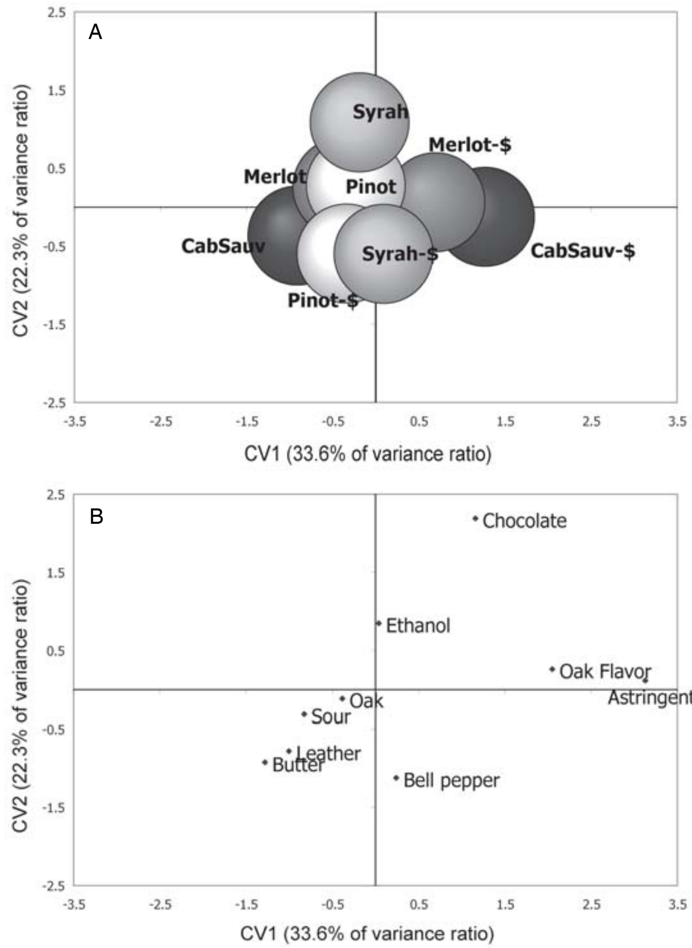

Figure 1 (**A**) Canonical variate plot of the wines evaluated without the effect of cheese. Circles indicate 95% confidence intervals. (**B**) Canonical variate plot of the significant attributes associated with the wines evaluated without the effect of cheese.

Table 3 Mean intensities and Tukey's HSD for sensory attributes of wines without cheese.

Attribute	CabSauv	CabSauv-$	Merlot	Merlot-$	Pinot	Pinot-$	Syrah	Syrah-$	Tukey's HSD
Bell pepper aroma	0.9 ab[a]	1.4 ab	1.4 ab	1.6 a	0.6 b	0.9 ab	1.2 ab	0.9 ab	0.84
Butter aroma	0.4 ab	0.2 b	0.6 ab	0.3 ab	0.4 ab	0.8 a	0.4 ab	0.4 ab	0.47
Chocolate aroma	0.5 ab	0.5 ab	0.9 a	0.9 a	0.7 ab	0.5 ab	0.5 ab	0.4 b	0.40
Oak flavor	1.8 b	2.7 a	1.9 ab	2.4 ab	2.2 ab	2.4 ab	2.2 ab	2.2 ab	0.83
Ethanol	1.4 b	1.9 ab	1.7 ab	1.9 ab	2.0 ab	2.5 a	1.9 ab	2.0 ab	0.76
Astringency	1.7 c	3.6 a	1.9 c	3.0 ab	1.8 c	2.3 bc	2.4 bc	2.5 bc	0.83
Sourness	3.0 a	1.9 b	2.4 ab	2.4 ab	2.5 ab	2.9 ab	2.7 ab	2.0 ab	1.00

[a]Means within a row followed by the same letter are not significantly different at $p < 0.05$.

Multivariate analysis of variance of red wines under the effect of cheeses. The scores for the combinations of the eight wines with the eight cheeses, plus the wines without prior intake of cheese (considered as an extra cheese labeled "None"), were considered for the analysis of the effect of cheese on wine flavor. All terms except for mint, spice, and chocolate aromas, dried fruit flavor by mouth, sour, and bitter were significantly different across wines for $p < 0.05$ (Table 4). For cheese, all attributes with the exceptions of vanilla, leather, chocolate, dried fruit flavor, chocolate flavor, ethanol, and bitter were significantly different at $p < 0.05$. There were no significant wine and cheese interactions for any attribute. The mean intensities of significant attributes for the eight wines as affected overall by cheese and the significant differences between wines based on Tukey's HSD for each attribute are presented in Table 5.

The statistical analysis of the red wine sensory attributes affected by eight different cheeses indicated that both the wine and the cheeses were significant at $p < 0.05$. However, the cheese and wine interaction was not significant. That means the effect of each cheese was in general terms consistent over the eight different wines. The results of the CVA show the red wines as affected by the cheeses (Figure 2).

Table 4 Analysis of variance of attribute ratings for the wines after tasting cheese.

	F ratios/sources of variation			
Attribute	Wine[a]	Cheese[b]	Wine x cheese	Error (mean square)
Berry aroma	3.26*[c]	2.68*	0.61	0.31
Oak aroma	8.00*	4.92*	0.77	0.21
Mushroom aroma	5.93*	4.60*	0.80	0.19
Mint aroma	1.30	5.20*	0.94	0.10
Dried fruit aroma	2.54*	2.51*	0.81	0.18
Spice aroma	1.03	2.25*[d]	0.93	1.16
Vegetal aroma	5.63*	6.75*	0.71	0.19
Bell pepper aroma	5.44*	8.29*	1.19	0.15
Vanilla aroma	4.43*	1.29	1.29	0.14
Butter aroma	2.17*[d]	2.67*	0.77	0.12
Leather aroma	3.31*	0.60	0.74	0.15
Chocolate aroma	1.66	1.69	0.56	0.12
Berry flavor	2.62*	6.41*	0.45	0.28
Oak flavor	9.32*	8.07*	0.69	0.15
Dried fruit flavor	0.32	0.83	0.40	0.28
Chocolate flavor	2.41*	1.78	0.49	0.13
Ethanol	3.95*	1.07	0.67	0.16
Astringent	13.90*	3.90*	0.55	0.38
Sour	1.75	4.66*	0.58	0.36
Bitter	1.74	0.65	0.35	0.59
df	7	8	56	360

[a]Essentially the effect of wines averaged over all cheeses.
[b]Essentially the effect of cheeses averaged over all wines.
[c]Asterisk (*) indicates significance at $p < 0.05$.
[d]Spice and butter were significant, yet when Tukey's HSD was calculated, none of the cheeses significantly affected the wines; therefore, this attribute was not used in the specific canonical variate analysis.

The first two canonical variates were significant according to Bartlett's test ($p < 0.05$) accounting for 49.2% and 17.2%, respectively, of the variance ratio. The two axes had an angle of 90° (Tatsuoka 1971). The patterns of the sensory profiles of the wines as affected by the cheeses were similar to those of the wines by themselves in terms of significant differences among wines of the same variety. That is because, once again, the two wines of any given variety, except for Pinot noir, were significantly different. The differences between the two Cabernet Sauvignon wines and the two Merlot wines as affected by the cheeses were similar to those found between the wines by themselves. CabSauv-$ had a more intense oak flavor and astringency than CabSauv. Similarly, Merlot-$ had a higher astringency and oak flavor than Merlot. For the Syrah wines, Syrah-$ was perceived to have a more intense berry aroma. As seen in Table 5, the berry aroma was significantly different between Syrah-$ and Syrah.

The average intensities of the significant attributes for the eight wines as affected by each specific cheese and the incidences of significant differences for each attribute are shown in Table 6. The results of the CVA and the overall effect of each cheese as well as the effect of no cheese on the wine sensory attributes are shown in Figure 3. The first two canonical variates were significant according to Bartlett's test ($p < 0.05$), accounting for 65.5% and 13.9%, respectively, of the total variance, and formed an angle of 90° (Tatsuoka 1971). This plot shows that there is a significant difference between tasting the wine by itself without cheese and tasting the wine after eating cheese. Most of the attributes are displayed on the right side of the plot, indicating that the intensity of these attributes was lower when the wines were affected by cheese, since the effects of the individual cheeses were displayed toward the left side of the plot versus the wines tasted without cheese (None). There are no significant differences among the effects of the pairs of similar cheeses, although there are significant differences among some different types of cheese, particularly blue mold and soft.

It is important to note that although canonical variate analysis shows a significant effect of cheese on wine sensory profiles, the attribute means in Tables 3 and 5 indicate that the general wine profiles remain quite similar independently of the wine being paired with any cheese. The observed patterns for every significant attribute are described next in terms of the wines tasted without cheese, the wines as affected by cheese, and the effect of the individual cheeses on the wines.

Berry aroma. Berry aroma was not significantly affected by the cheese except for Gorgonzola, which reduced the perception of this attribute. The other cheeses also reduced berry aroma perception, although not significantly. When the wines were evaluated by themselves without cheese, none differed significantly in berry aroma. When evaluated after cheese, Syrah and CabSauv-$ had significantly lower berry aroma than Syrah-$.

Oak aroma. Oak aroma was significantly diminished after tasting all cheeses, except Mozzarella, compared with the wines by themselves without cheese. The wines when evaluated without cheese did not differ in oak aroma, but the higher-priced Cabernet Sauvignon (CabSauv-$) and Merlot (Merlot-$) had significantly higher perceived oak aroma than other wines under the effect of cheese.

Mushroom aroma. The detection of mushroom aroma was significantly reduced by the effect of all eight cheeses compared with the wines by themselves. The wines when tasted without cheese did not differ in mushroom aroma, but the CabSauv-$, Merlot-$, and Syrah-$ had more perceived mushroom aroma than CabSauv, Merlot, and Syrah, respectively.

Mint aroma. Mint aroma was not found to be significant in the comparisons among the wines under the effect of cheese or by themselves. However, it was significant in terms of the effect of the specific cheeses on the wines. Similar to the oak, berry, and mushroom aromas, the mint aroma was reduced when wine was tasted after tasting of cheese. However, the wines did not differ in mint aroma when evaluated without cheese.

Dried fruit aroma. Wine dried fruit aroma perception was significantly reduced when the wines were tasted after tasting Gruyère and Cheddar from Vermont. The wines did not differ in dried fruit aroma when evaluated without cheese, but when evaluated after tasting cheese the Merlot-$ was perceived to be significantly higher in dried fruit aroma than the CabSauv-$ and Pinot.

Vegetal aroma. The perception of vegetal aroma was significantly higher for wines tasted without cheese than for wines tasted after cheese. Wine evaluated without cheese did not differ significantly in vegetal aroma; wines evaluated after tasting cheese did differ significantly. The Syrah-$ wine had the lowest perceived vegetal aroma and the Syrah had the highest perceived vegetal aroma. Moreover, vegetal aroma is one of the drivers for the significant differences between Syrah and Syrah-$ observed in Figure 2.

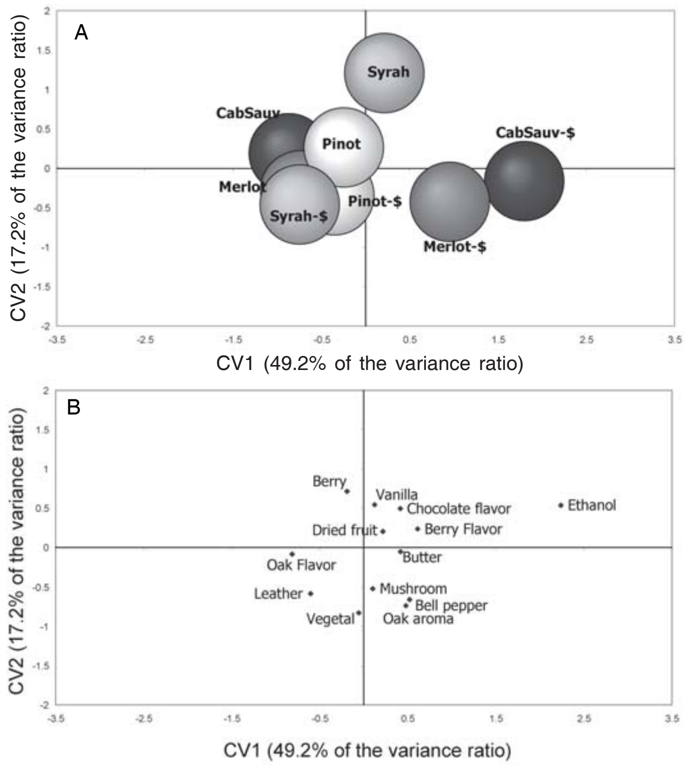

Figure 2 (**A**) Canonical variate plot of the wines as affected by the cheese. Circles indicate 95% confidence intervals. (**B**) Canonical variate plot of the significant attributes associated with the wines affected by the cheese.

Table 5 Mean intensities and Tukey's HSD for sensory attributes of each wine as affected by cheese.

Attribute	CabSauv	CabSauv-$	Merlot	Merlot-$	Pinot	Pinot-$	Syrah	Syrah-$	Tukey's HSD
Berry aroma	2.0 ab[a]	1.7 b	1.8 ab	1.8 ab	1.8ab	1.8 ab	1.7 b	2.1 a	0.32
Oak aroma	1.8 c	2.2 a	1.9 bc	2.2 a	1.8 c	1.8 c	1.8 c	1.8 c	0.27
Mushroom aroma	0.8 bc	1.0 ab	0.8 bc	1.1 a	1.0 ab	1.0 ab	1.1 a	0.7 c	0.25
Dried fruit aroma	1.5 ab	1.4 b	1.5 ab	1.7 a	1.4 b	1.5 ab	1.4 b	1.6 ab	0.25
Vegetal aroma	0.8 bc	0.9 abc	0.8 bc	1.1 ab	0.9 abc	0.9 abc	1.2 a	0.7 c	0.26
Bell pepper aroma	0.7 bc	0.9 a	0.6 c	0.9 ab	0.7 bc	0.6 c	0.8 abc	0.6 c	0.23
Vanilla aroma	0.8 bc	0.8 bc	0.9 ab	0.9 ab	0.9 ab	1.1 a	0.7 c	0.9 ab	0.22
Leather aroma	1.1 ab	1.3 a	1.0 b	1.3 a	1.2 ab	1.2 ab	1.2 ab	1.1 ab	0.23
Chocolate flavor	0.5 ab	0.4 b	0.6ab	0.5 ab	0.5 ab	0.4 b	0.7 a	0.5 ab	0.21
Oak flavor	1.6 d	2.1 a	1.7 cd	2.0 ab	1.8 bcd	1.7 cd	1.7 cd	1.9 abc	0.23
Ethanol	1.6 c	1.8 ab	1.7 bc	1.9 a	1.7 bc	1.9 a	1.8 ab	1.8 ab	0.24
Astringent	1.7 c	2.6 a	1.7 c	2.2 b	1.8 cd	1.8 cd	1.8 cd	2.2 b	0.36

[a]Means in the same row followed by the same letter are not significantly different at $p < 0.05$.

Bell pepper aroma. Perceived bell pepper aroma differed significantly among the wines when evaluated without cheese, among the wines when evaluated with cheese, and due to the effects of the specific cheese. This attribute was significantly higher when the wines were evaluated without cheese and there was no significant difference between the effects of the eight cheeses. Perceived bell pepper aroma was found to be significantly higher in Merlot-$ than in Merlot when the wines were evaluated without cheese. When wines were evaluated after tasting cheese the perceived bell pepper aroma of CabSauv-$ and Merlot-$ was significantly higher than in CabSauv and Merlot, respectively.

Vanilla aroma. Vanilla aroma was not a significant attribute in terms of the wines by themselves or due to the effect of the particular cheeses; however, it was significant in differentiating between Syrah-$ and Syrah.

Butter aroma. The butter aroma presented a completely different behavior than the rest of the attributes. That is because the effect of some of the cheeses on the wine profile was to significantly *enhance* perceived butter aroma. The cheeses with the greatest effect were Emmental, Gruyère, Teleme, and both Cheddars.

Leather aroma. Merlot had significantly lower leather aroma than Merlot-$ under the effect of cheese.

Chocolate aroma. The two Merlot wines, evaluated without cheese, had significantly more perceived chocolate aroma than the Syrah-$. However, when the wines were evaluated after tasting cheese these differences were no longer perceptible.

Berry flavor. Berry flavor perception significantly decreased under the effect of some of the cheeses. The mildest cheeses in terms of berry flavor reduction were Mozzarella, Teleme, and Cheddar from Vermont, while the one with the greatest effect was Gorgonzola, which yielded significantly lower berry flavor scores than the other cheeses. When wines were tasted by themselves there were no significant differences in berry flavor.

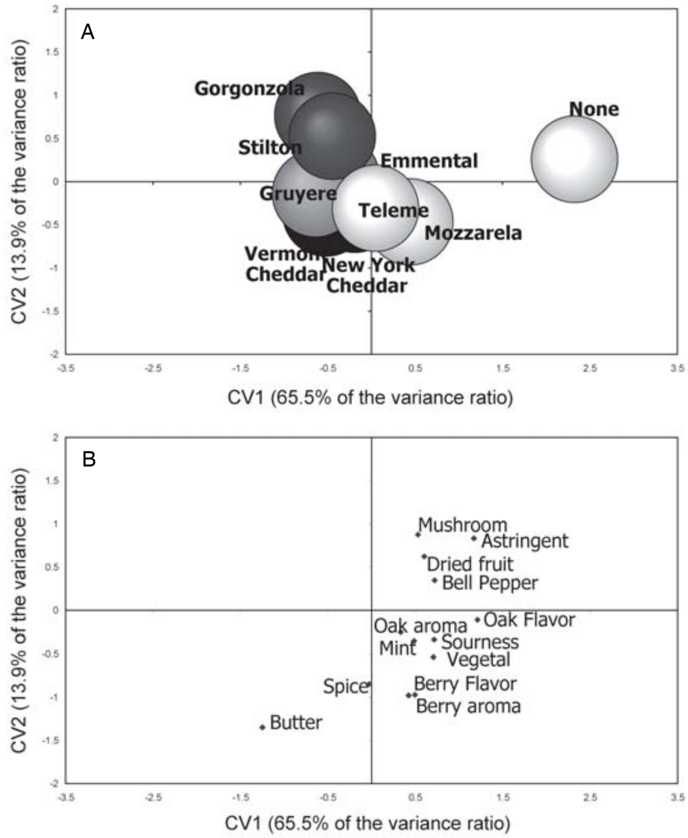

Figure 3 (**A**) Canonical variate plot of the effect of the cheeses on the wine sensory data averaged over all wines. Circles indicate 95% confidence intervals. (**B**) Canonical variate plot of the significant wine attributes associated with the effect of the cheeses.

Table 6 Mean intensities and Tukey's HSD for sensory attributes of the wines overall as affected by each cheese.

Attribute	None	Emmental	Gruyère	Mozzarella	Teleme	Vermont Cheddar	New York Cheddar	Stilton	Gorgonzola	Tukey's HSD
Berry aroma	2.0 a[a]	1.8 ab	2.0 a	2.0 a	1.8 ab	1.9 ab	1.8 ab	1.7 ab	1.6 b	0.35
Oak aroma	2.2 a	1.8 b	1.9 b	2.0 ab	1.9 b	1.8 b	1.9 b	1.8 b	1.8 b	0.29
Mushroom aroma	1.3a	0.9 b	0.8 b	0.9 b	0.9 b	0.9 b	1.0 b	0.9 b	1.0 b	0.28
Mint aroma	0.7 a	0.4 b	0.5 b	0.5 b	0.5 b	0.5 b	0.5 b	0.4 b	0.5 b	0.20
Dried fruit aroma	1.7 a	1.5 ab	1.4 b	1.5 ab	1.6 ab	1.4 b	1.5 ab	1.5 ab	1.5 ab	0.27
Vegetal aroma	1.3 a	0.8 b	0.8 b	1.0 b	0.9 b	0.8 b	0.9 b	0.8 b	0.9 b	0.27
Bell pepper aroma	1.2 a	0.7 b	0.7 b	0.7 b	0.8 b	0.7 b	0.7 b	0.6 b	0.6 b	0.25
Butter aroma	0.4 b	0.7 a	0.7 a	0.6 ab	0.7a	0.7a	0.7 a	0.6 ab	0.6 ab	0.22
Berry flavor	2.1 a	1.6 bc	1.6 bc	1.8 ab	1.8 ab	1.8 ab	1.7 bc	1.6 bc	1.4 c	0.33
Oak flavor	2.2 a	1.8 b	1.8 b	1.8 b	1.8 b	1.7 b	1.8 b	1.8 b	1.7 b	0.25
Astringent	2.4 a	1.9 b	1.9 b	2.1 ab	2.0 b	1.9 b	1.9 b	1.9 b	2.0 b	0.39
Sourness	2.6 a	2.1 bc	1.9 c	2.4 ab	2.2 abc	2.1 bc	2.0 bc	2.0 bc	2.2 abc	0.38

[a]Means in the same row followed by the same letter are not significantly different at $p < 0.05$.

Chocolate flavor. This attribute only significantly differentiated the wines under the effect of cheese. Syrah was observed to be significantly higher in terms of perceived chocolate flavor than CabSauv-$ and Pinot-$. The perception of chocolate flavor was not a significant attribute in terms of the effect of particular cheeses.

Oak flavor. Oak flavor was also significantly decreased under the effect of cheese compared to the wines by themselves. Whether tasted with or without cheese, CabSauv-$ had significantly higher perceived oak flavor than CabSauv. When the Merlot-$ was evaluated after tasting cheese it also had a higher perceived oak flavor than the Merlot.

Ethanol. The perception of ethanol was not a significant attribute in terms of the effect of particular cheeses. Pinot-$ was perceived to have a significantly higher ethanol intensity, than CabSauv when evaluated without cheese. When the wines were evaluated after tasting cheese, the Pinot-$ and Merlot-$ had significantly higher perceived ethanol than CabSauv. The high scores for Pinot-$ are in line with the chemical analyses, as they show it as the wine with the greatest ethanol content. CabSauv was the lowest scoring wine for ethanol, both in the sensory analysis and the chemical analysis; however, it was not much lower in ethanol than Syrah as determined by chemical analysis (Table 1). It is remarkable that with the exception of the two Syrahs, the higher priced wines had higher, although not always significantly, mean perceived ethanol scores than the lower-priced wines with the cheese influence.

Astringency. This attribute was significantly decreased under the effect of all cheeses except Mozzarella. In terms of the wines, in the absence of cheese the higher priced exemplar of each variety, except Syrah, was significantly more astringent than the less expensive one. When wines were evaluated after tasting cheese, the higher priced exemplar of each variety, except for Pinot noir, was the more astringent. CabSauv-$ was significantly more astringent than the rest of the wines under the effect of cheese.

Sourness. Perceived sourness decreased significantly when wine was evaluated after tasting cheese except when the cheese was Mozzarella, Teleme, or Gorgonzola. In the absence of cheese, CabSauv was perceived to be significantly more sour than CabSauv-$, while the other wines did not differ significantly. The sensory results are not in agreement with the chemical analyses for titratable acidity and pH. This disagreement may be due to a masking of perceived acidity by other attributes.

Discussion

The assessment of the particular effects of a variety of cheese on a range of wines requires the previous evaluation of the actual characteristics of such wines without the cheese in order to make a valid comparison. Wines were significantly differentiated based on the CVA when evaluated without previous tasting of cheese. A possible expectation was to observe a specific trend for each of the four varieties evaluated; that is, to have similar profiles for the two wines of each variety according to their varietal characters. However, the two wines of each variety were significantly different between themselves for all varieties, except for Pinot noir. Since these wines came from different producers, it should not be too surprising that their sensory profiles were very different as they were likely produced using different production methods, viticultural practices, and so on.

For the Cabernet Sauvignon, astringency and oak flavor acted as drivers to bring about a significant difference in perception between the two wines of this variety when tasted without cheese. For the Merlot wines tasted without cheese, astringency seemed to be the major differentiator. When the Cabernet and Merlot wines were evaluated after tasting cheese, the differences between the two wines of each variety seemed to be enhanced. The more expensive wines of each variety were perceptibly higher in oak aroma and flavor as well as bell pepper aroma, astringency, and ethanol. For the Merlots, the higher priced wine was also significantly higher in perceived mushroom and leather aromas when the wines were evaluated after tasting cheese. Oak flavor is attributable to several flavor compounds, with ß-methyl-γ-octalactone as one of the most important. It is extracted during fermentation and/or aging in oak barrels (Ebeler 2001), while higher astringency is commonly achieved with riper grapes and better extraction procedures as well as with oak contact (Noble 1994). All these processes entail a cost increase for wineries; therefore, greater astringency and oak flavor is more commonly expected in higher-priced wines, such as CabSauv-$ and Merlot-$. Syrah was the other variety in which the two wines were perceived to be significantly different in certain attributes when the wines were evaluated after tasting cheese; however, the wines were not differentiated when they were evaluated in the absence of cheese. The California Syrah (Syrah-$) had perceptibly higher berry and vanilla aromas as well as higher perceived astringency, while the Australian Syrah had more vegetal and mushroom aromas, both of which can be expected from the typical varietal characteristics described in the literature (Abbott et al. 1991, Ebeler 2001, Jackson 2002). A true price comparison is not possible in this case, as these two wines were produced in different countries and under different production costs. The Pinot noir wines were not differentiated when evaluated with or without cheese.

The study of mixture interactions is a complex one, as many factors such as flavor-by-mouth, aroma, taste, and texture must be evaluated. The mixture may yield many outcomes depending on the specific attributes and levels, some of which may be enhancement, suppression, unmasking of an attribute not previously observed, or even chemical synthesis of new compounds (Keast and Breslin 2003). In the present case, a sequential interaction with wine following cheese was studied. Wine attribute perception was observed to be modified by the previous intake of any of the cheeses used and varied depending on the particular cheese selected.

The overall observed trend was that the tasting of cheese previous to the evaluation of wine characters decreased the perception of wine attributes. That was the case for all the attributes except for butter aroma. This observation is in agreement with the results of Nygren and coworkers, as they found that all the main attributes of white wines were reduced after tasting blue mold cheese, while all except for butter were reduced after tasting hollandaise sauce (Nygren et al. 2001, 2002). According to Lawless (2000), the recurring effect in controlled studies of tastes has been that most taste qualities partially mask or suppress one another. Researchers have found that in two-component mixtures, taste qualities are usually suppressed when compared to the components tasted separately (Breslin 1996, Keast and Breslin 2003). It has been suggested that this happens because when two compounds are mixed they may interfere with each other's taste receptor cells or taste transduction mechanisms (Keast and Breslin 2003). These last results have been obtained for taste mixture combinations rather than aroma or flavor by mouth; however, we may speculate that similar processes affect flavor and aroma perceptions in mixtures. A physiological study is necessary to confirm this speculation.

The specific case of sourness is consistent with the observed suppression in taste mixtures. Cheese is a product with a high salt concentration and we can safely assume that the saltiness is clearly suprathreshold for salt. As for wines, all have concentrations of over a thousand times the threshold values for tartaric acid (Stahl 1973), and, therefore, are also clearly suprathreshold for acid. Suprathreshold concentrations of salts and acids tend to suppress one another (Breslin 1996), which may explain the sourness decrease under the effect of cheese observed in the current study. Moreover, umami, a taste characteristically high in cheeses (Ninomiya 2002), has also been found to suppress sourness (Keast and Breslin 2003).

Like sourness, bitterness was expected to decrease under the effect of cheese, as it has been found that saltiness and umami tastes have similar effects on bitterness as those found for sourness (Breslin 1996, Ninomiya 2002). However, our results show that there was no significant decrease in the perceived bitterness under the effect of any cheese compared to the wines by themselves. One possible explanation is that individuals present great differences in sensitivity for bitterness compared to other tastes (Breslin and Beauchamp 1995). Also, the perception of the bitterness of the cheese (Pillidge et al. 2003, Singh et al. 2005) may have brought about the observed behavior rather than the expected perceived bitterness decrease.

The reduction in the perceived intensities of the wine attributes can also be brought about by protein binding. When aroma or flavor compounds are put in contact with proteins, they may be bound and cannot be volatilized until separated. Protein as a food constituent has been widely studied in connection with the binding of flavors, and reductions of up to 80% in vapor pressure of specific flavor compounds have been found as a result of protein binding (Overbosch et al. 1991). Also, protein-based fat-replacement systems have been used to reduce undesirable aftertastes by the same mechanism (Lucca and Tepper 1994, Morris 1992). The cheeses used were high-protein matrixes, with typical protein contents ranging from 18% protein in Teleme to 28.5% in Emmental (Fox et al. 2000, Kosikowski 1977); therefore, protein-binding of cheese and wine components may have had a perceptible sensory effect. However, in order for this to have a significant effect, a large amount of cheese protein would have to remain in the mouth. Therefore, to confirm this point, the presence of protein after swallowing/spitting cheese, either by itself or within the fat mouth coating, would have to be studied.

An additional explanation for the decreased intensity perception of the wine attributes after tasting cheese is the possible formation of a fat coating in the oral cavity. This formation can be caused by the high fat content in cheese, ranging from 18% in Mozzarella to 35% in Stilton (Fox et al. 2000, Kosikowski 1977). The presence of a fatty layer in the mouth has two effects on sensory attributes. It modifies the partitioning of specific compounds between the food, saliva, taste receptors, and headspace and, therefore, the perceived concentration of the given compound reaching the olfactory receptors (Lynch et al. 1993). That is likely to delay the volatilization of aromatic substances or the diffusion toward taste receptors (Bauer 1995). The second effect is a physical interference in the compound's access to taste receptors or to the mouth headspace (Lynch et al. 1993). A good example of the effect of such physical barrier is the reduction of astringency. Astringency is recognized as the result of the precipitation of tannins with lubricating salivary proteins, hence reducing the lubricating effect (Kallithraka et al. 2001). Given a fat coating between the salivary proteins and tannins, the precipitation rate, and therefore the perceived astringency, may be reduced.

Butter was clearly the wine attribute that differed from the other attributes, since butter aroma was increased under the effect of all eight cheeses compared to the wines by themselves. These results are in line with Nygren and coworkers (2001) and indicate that mixture effects not only cause attribute suppression or masking but also may bring about enhancement. It is possible that cheese flavor, containing butter characters, remained in the mouth until tasting the wine and therefore increased the headspace concentration and hence the butter aroma perception. Also, the tasting of cheese before wine with an increased diacetyl concentration may have led to a cognitive effect that allowed judges to better identify the butter aroma in the wines (Nygren et al. 2001). Regardless of the specific reason, it has been found that enhancement is commonly related to mixtures of similar tastes and odors, while suppression is more frequently found in mixtures of dissimilar stimuli (Frank et al. 1991). This finding is in agreement with our results, since the butter aroma is the one that is most similar to cheese flavors.

It is important to stress that not only butter aroma but also many other attributes may have increased as a result of mixed tasting of wine and cheese. However, the attributes with greater intensity are more likely to present suppressive interactions (Keast et al. 2003). As the attributes in this study were selected as the most representative of the evaluated wines, their concentrations are likely to be above threshold, and therefore suppression would be the general expectation. Attributes with concentrations below threshold in wines or characteristic of the evaluated cheeses would be more likely expected to present other enhancement interactions.

When analyzing the results it is important to remember that the wine and cheese interaction was not significant. Therefore, we can assume that each individual cheese had, in general, the same effect on all eight wines. The cheeses with the largest effects on perceived wine attributes were the blue and hard cheeses. Anecdotally, these cheeses were the ones with the strongest flavors of the eight evaluated. This strong flavor may have caused a greater overwhelming effect, bringing about the larger decrease in the perceived wine attribute intensities. On the other hand, Teleme and Mozzarella were the cheeses with the least effect on wine attributes, perhaps because they had the mildest flavors of all cheeses, combined with the fact that they had the lowest fat and protein contents, which as explained previously may contribute to lessen perceived wine attributes.

Finally, it is important to emphasize that although the intake of cheese had a significant effect on the perceived flavor of red wine, the mean values for all the attributes show that the general profile of the eight red wines was only *slightly* modified. Even for berry flavor, which had the most difference with and without cheese, the greatest difference in perceived intensity was only of 0.7 rating points on a 10-point scale.

Conclusions

Results showed that the tasting of cheese prior to evaluation of wine brings about a decrease in most of the characteristic wine attributes, such as astringency, oak flavor and aroma, and berry flavor and aroma. Also, an enhancement is caused in at least one attribute, namely butter aroma. Contrary to common perception, the cheese and wine pairing translates into wine character suppression more than enhancement. Also, it was seen that although there is an effect of pairing wine with cheese, the red wines maintained the same overall sensory profiles relative to each other. It is important to be cautious in viewing these results since the wines were essentially a convenience sample of two exemplars from each of four varietals; a broader range of wines within each varietal would need to be studied in order to draw wider conclusions. However, it is clear from these data and from the work by Nygren and coworkers that the effect of cheese on wine flavor is likely not as large as is often stated in the popular press and that it certainly does not seem to be enhancing wine flavor. The authors feel that the practical significance of these results is that one could probably enjoy any preferred cheese with any preferred red wine.

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