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KEY CONSTITUENTS AFFECTING WINE BODY – AN EXPLORATORY STUDY

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ABSTRACT

Multivariate statistical modeling was used to identify significant correlations between several chemical constituents and physical properties of wine and its perceived body or viscous mouthfeel. Seventeen white wines that span an anecdotal range of perceived viscous mouthfeel, including Chardonnay, Viognier, Pinot gris, Riesling and Sauvignon blanc, were assessed using a descriptive analysis technique to determine quantitative ratings of viscous mouthfeel. These wines were also submitted to a wide range of chemical constituents and physical property analyses, including viscosity, density and concentrations of ethanol, total phenolics, organic acids (lactate, citrate, tartrate, malate, succinate), glycerol, sugars (fructose and glucose), total extract, and several inorganic anions and cations. The multivariate statistical model shows that the viscous mouthfeel of these white wines is significantly correlated with physical properties, such as viscosity and osmotic potential, chemical properties, such as lactate and total extract. This work is also consistent with previously published results from other researchers indicating that ethanol and glycerol do not significantly contribute to viscous mouthfeel.

PRACTICAL APPLICATIONS

This research provides evidence that panelists can differentiate the mouthfeel of wines that span a relatively narrow range of viscosities. The results were also correlated with various chemical and physical properties of wine. Sensory and analytical measurements such as these could provide a link from viscous mouthfeel to viticultural and winemaking practices of wine.

INTRODUCTION

One key attribute of any desired wine style is its "body." Several, sometimes overlapping, sensory and physical measures have been identified to describe wine body. Some of these textural terms include viscosity, thinness, density, and smoothness and slipperiness, which have been studied by Kokini (1985), Langstaff and Lewis (1993), Gawel *et al.* (2000) and Szczesniak (2002), respectively. Despite the importance of body to the overall quality of wines, Jackson (2002) noted that its precise origins remain unclear.

Langstaff and Lewis (1993), Gawel *et al.* (2000) and Szczesniak (2002) have reported that body plays an important role in the overall mouthfeel of wine along with other mouthfeel sensations such as astringency, warming and carbonation. Depending upon the desired wine style, the relative contributions of these mouthfeel sensations can impact the overall quality of the wine. Although much prior work has been conducted on these other elements of mouthfeel, an understanding of the key building blocks to achieve a desired wine body style has yet to be developed.

Much previous work characterizing the "body" aspect of mouthfeel has focused on correlating the viscosity of the liquid to a combination of sensory attributes used to describe this property. Kokini (1985) estimated that the liquid thickness sensation is a physical property opposite to the thinness sensation, and he found that this sensation was a function of shear force on the tongue. If the fluid is Newtonian, the thickness is proportional to the viscosity.

Specific experiments studying the relationship between the rheological properties of wine and its body style have led to a partial understanding of how a few chemical constituents influence this sensory quality. Noble and Bursick (1984) estimated that the viscosity threshold difference, i.e., the minimum difference in viscosity between two wines so that at least 75% of a trained tasting panel can correctly determine which one has the higher viscosity, was 0.141 mPa s at 20C. However, Kôsmerl *et al.* (2000) reported a range of viscosities of various dry white wines that spanned only 0.152 mPa s at 20C. This leads one to expect that only wines at the extreme ends of the range encountered within this study might be perceived as differing in wine body styles.

Noble and Bursick (1984) also showed that glycerol additions of approximately 25 g/L, which are in excess of that typically observed in table wine, can lead to statistically significant differences in perceived viscosity. Sucrose has also been shown by Burns and Noble (1985) and Nurgel and Pickering (2005) to modify the viscosity of a wine; however, these residual sugar levels are outside the realm of dry table wines (>~15 g/L).

Amerine and Roessler (1983) suggested that ethanol played a role in influencing wine body, typically increasing body with increasing alcohol content. However, Pickering *et al.* (1998) called the anecdotal evidence into question by showing that ethanol concentration did not have a statistically significant effect on perceived viscosity within the ethanol concentrations of typical dry white table wines (10–14% v/v). Nurgel and Pickering (2005) subsequently showed that ethanol might have a moderate effect on viscous mouthfeel; however, these were simple model wine solutions and thus did not contain contributions from other wine constituents. More recent data from Gawel *et al.* (2007) continue to provide evidence that ethanol has little effect, based on no significant effect at a P value of 0.05, on perceived body/viscosity of white table wines.

Extract, the components other than sugar and ethanol, has been thought to be correlated with wine body style. Zoecklein *et al.* (1999) reported that dry table wines with extract values of less than 20 g/L often appear thin on the palate, while those with 30 g/L or more have a full-bodied character. Unfortunately, no references to primary research were cited. Amerine and Joslyn (1970) reported lactic and succinic acids to be the most important acids contributing to body, although this could not be confirmed in the primary citation by Bobadilla and Navarro (1949).

Researchers have recently started to investigate the potential role of chemical constituents other than ethanol, glycerol and sugar. Oberholster *et al.* (2009) investigated the contribution of anthocyanins to the mouthfeel of white wines. They found no significant difference in perceived viscosity among the white wine treatments. Skogerson *et al.* (2009) identified more than 100 metabolites in white table wines by using gas chromatography-coupled time-of-flight mass spectrometry and proton nuclear magnetic resonance spectroscopy; more than 40 of these metabolites, including proline and lactate, were significantly correlated with perceived wine body classifications. Vidal *et al.* (2004) have shown that various wine polysaccharide fractions can have a significant impact on mouthfeel attributes such as fullness. Within their study, they qualitatively attributed the higher fullness ratings to polysaccharides with higher intrinsic viscosities. Polysaccharides such as these occur in wine as a carryover from juice or must extraction and microbial activity. Thus, the perceived wine body may possibly be altered by changing the chemical composition of wine through viticultural and enological practices.

Researchers are now identifying a broader range of wine constituents that are thought to influence wine body. Most studies have focused on viscosity or density as the measured parameter, and used one or two independent chemical variables in their experimental design to assess the influence of chemical parameters. These studies are limited in their practicality as a different model, which relates the chemical and physical properties to wine body, must be generated to correlate each independent variable to their wine body style descriptors.

This research takes a different approach by hypothesizing that the wine body sensation could be influenced by a combination of both chemosensory and mechanosensory attributes that are a result of multiple physical and chemical properties of the wine. This exploratory research has been structured to measure two key macroscopic chemosensory and mechanosensory variables (e.g., osmotic potential and viscosity, respectively), as well as 23 additional chemical constituents and physical properties of the wines, and to model the results. The chemical constituents were chosen to be those often measured in wines but whose role in wine body style has yet to be determined. Hypotheses relating the connection between these compounds and wine body exist in a few instances, but the majority of the compounds were measured and analyzed for exploratory purposes to correlate them with wine mouthfeel property. The intended result is to generate new ideas as to which wine constituents might be influencing wine body, and thus spur future research into this important area of wine appreciation.

MATERIALS AND METHODS

Wines

Seventeen commercial dry white table wines were used in this study (Table 1). They were chosen to span an anecdotal range of wine body styles from thin- to full-bodied. Fourteen were produced in California, one was from Oregon, one was from New York and one was from Southeastern Australia. They comprised six Chardonnays, four Sauvignon blancs, two Pinot gris, two Rieslings and two Viogniers, and one white

TABLE 1. LIST OF WINES, VARIETIES, ORIGINS AND VINTAGES

Wine	Variety	Region	Vintage
C3	Chardonnay	Napa Valley, CA	2003
C5	Chardonnay	Napa Valley, CA	2003
C6	Chardonnay	SE Australia	2004
C11	Chardonnay	Napa Valley, CA	2004
C13	Chardonnay	Monterey, CA	2003
C16	Chardonnay	Napa Valley, CA	2003
PG1	Pinot gris	Napa Valley, CA	2004
PG14	Pinot gris	Oregon	2003
R8	Riesling	Napa Valley, CA	2004
R10	Riesling	Finger Lakes, NY	2004
SB9	Sauvignon blanc	Napa Valley, CA	2004
SB12	Sauvignon blanc	Lake County, CA	2001
SB15	Sauvignon blanc	Napa Valley, CA	2004
SB17	Sauvignon blanc	Napa Valley, CA	2004
V4	Viognier	Napa Valley, CA	2004
V7	Viognier	Yolo County, CA	2004
WTW2	White Table Wine	Napa Valley, CA	2004

blend (Sauvignon blanc-based). Eleven wines were from the 2004 vintage, five from 2003 and one from 2001. The panel evaluation was conducted in late May to early June 2006.

Physical and Chemical Property Analyses

Viscosity. Viscosity was measured with a Cannon-Fenske 50 capillary viscometer (State College, PA). A Schott-Gerate CT-1150 (Elmsford, NY) constant temperature water bath was used to maintain a temperature of 30C. The viscometer constant was determined to be 0.00322 using distilled, deionized water.

A 7-mL aliquot of the sample was pipetted using a 10 mL pipet (Fisherbrand Serological 10 mL in 1/10 TD-EX at 20C, Hampton, NH). The samples were equilibrated in the water bath for 15 min. Two samples, i.e., different bottles, of each wine were analyzed in duplicate except V-7 which had only one sample analyzed in duplicate. Each of the wines was randomly evaluated within the replicate. In between each sample measurement, the viscometer was rinsed by a sequence of distilled, deionized water and then 95% ethyl alcohol followed by vacuum air drying until the ethyl alcohol evaporated.

Other Physical Properties. Specific gravity measurements were made in duplicate on two samples from each wine (except V-7, which had only one sample analyzed in duplicate) using a Fisherbrand hydrometer (11-556-E) with a scale from 0.940 to 1.010. The wine density at 30C was obtained from these measurements.

The osmotic potentials of each wine sample were determined using dew point osmometry (5,500 vapor pressure osmometer, Wescor, Inc., Logan, UT) at 37C as described in Serpe and Matthews (1994) and Boyer (1995). Three samples of each wine were measured one time each.

Chemical Analysis. Ethanol concentration by volume (% v/v) was quantified by packed bed column gas chromatography (GC) with a flame ionization detector (FID). A Hewlett-Packard GC (Model 5890, Palo Alto, CA) with a packed column inlet, FID and autosampler (Model 7673A) was coupled with HPChemstation software. A calibration curve was created using ethyl alcohol standards of 5, 10, 15 and 20% using 200-proof ethyl alcohol from Gold Shield Chemical Co (Hayward, CA). Ethanol concentrations were determined by comparing peak area ratios (ethanol/2-propanol) of the sample with those of the standard curve. Three samples of each wine were measured in duplicate.

Glycerol and organic acids (tartrate, citrate, malate, lactate, succinate and acetate) were quantified by normal-phase high-performance liquid chromatography. A Hewlett-Packard 1100 series model with a G-1322A degasser, G-1311A quaternary pump, a G-1313A autosampler, a G-1316A column compartment, a variable wavelength detector (data recorded at 210 nm) and a Hewlett-Packard 1047A refractive index detector were coupled to HPChemstation software. Three samples of each wine were measured in duplicate.

Total extract was determined for one sample of each wine based upon the difference calculation using the specific gravity of the wine and the specific gravity of an aqueous ethanol solution corresponding to the ethanol content (% v/v) of the wine as described in Amerine and Ough (1980). Average specific gravities for each wine were used; therefore, replication error was not estimated.

Reducing sugars, glucose and fructose, were quantified by spectrometric analysis using enzymes. The reagents and protocol came from the Boehringer-Mannheim D-Glucose/D-Fructose kit (Cat. no. 10 139 106 035, Darmstadt, Germany). Titratable acidity and pH were measured using a Mettler-Toledo DL50 with a Rondo 60 autosampler and platinum/glass BNC electrode (MTPT-701, Columbus, OH). Standard titration up to pH 8.2 of 50 mL of each sample was made with 1.0 N NaOH. Two samples of each wine were measured in duplicate.

Iron-reactive phenolics were quantified using the Harbertson–Adams Assay as described by Harbertson *et al.* (2003) and Heredia *et al.* (2006) with minor alterations; specifically, a volume of 300 μL of wine was added to 575 μL of Buffer C due to the relatively low iron-reactive phenolic content of white wines. Three samples of each wine were measured in triplicate.

Inorganic anions and cations were quantified by inductively coupled plasma – atomic emission spectroscopy (AES), flame – AES or chemical derivatization techniques depending upon the elemental ion. A single sample of each wine was analyzed a single time for each constituent.

TABLE 2. FORMULATION OF SENSORY REFERENCE STANDARDS USED TO ANCHOR ATTRIBUTES

Descriptor term	Composition
Viscous mouthfeel	4 g/L methyl cellulose
Bitter	1 g/L caffeine, Sigma-Aldrich
Astringent	1 g/L alum, McCormick
Sour	1.5 g/L citric acid, Sigma-Aldrich
Sweet	20 g/L sucrose, Sigma-Aldrich
Hot	20% ethyl alcohol (v/v), using 200-proof from Gold Shield Chemical Co
Oak	1.5 g oak powder in 150 mL water
Caramel	Vanilla extract and imitation butter in water
Vegetative	5 mL canned pea juice in 40 mL water
	5 mL canned green bean juice in 40 mL water
	Grass each in 40 mL water
Chemical	Apple cider vinegar in water
Orchard fruit	10 mL apricot heavy syrup in 40 mL water
	10 mL canned pear juice in 40 mL water
	10 mL peach heavy syrup with $^1/_2$ peach slice in 40 mL water
	Red delicious apple in 40 mL water
Tropicalfruit	10 mL canned pineapple juice in 40 mL water
	Banana in 40 mL water

TABLE 3. DEFINITIONS OF AROMA DESCRIPTOR TERMS

Descriptor term	Supplemental definition
Caramel	Butterscotch, honey, vanilla, dried fruit
Spice	White pepper, nutmeg, mustard
Vegetative	Cooked vegetables, bell pepper, green beans, green
Oak	N/A
Hot	Alcohol
Floral	Muscat, linalool, flower, violet, honeysuckle, blossoms, jasmine
Chemical	Wet dog, meaty, musky, musty, metallic, oxidized, petroleum
Orchard fruit	Pears, apples, apricots, peaches
Tropical fruit	Litchi, banana, pineapple, passion fruit
Citrus	Lemon, grapefruit

Sensory Analysis

Descriptive Analysis Panel. Ten panelists (six women and four men ranging from 21 to 50 years in age) from the University of California, Davis, Departments of Viticulture and Enology, and Food Science and Technology, were selected based upon availability and interest. All had previous wine-tasting experience and at least half had previously participated in descriptive analysis panels. All sensory evaluations were conducted in compliance with the University of California, Davis, Institutional Review Board.

Training. The training of the descriptive analysis panel followed the procedures outlined in Lawless and Heymann (1998). Training consisted of five 1-h sessions. During the training sessions, panelists generated descriptive terms by evaluating a subset of the wines used in this study. Wines covering all five varieties were evaluated during the training to best define the descriptor terms for the panel. After the first training session, aroma and taste reference standards were presented in water solutions. Reference standards were modified and refined as requested by the panelists. By the end of the training, the panelists decided upon which descriptors to use in the study and which reference standards to use to anchor the descriptors. The compositions of the reference standards are presented in Table 2. Supplemental definitions of the descriptor terms were also provided in the evaluation booth to best ensure consistent use of the descriptors (Table 3). Panel performance was evaluated at the end of the training period by having the panel evaluate replicates of a subset of the wines.

Experimental Procedure. Panelists evaluated each of the 17 wines three times over 8 days; each replicate was split into 2 days. Bottles were opened the same day as their evaluation. Fizz data acquisition system version 2.0 by Biosystemes (Couternon, France) created a randomized block design for the presentation of the samples in each replication. The samples were also randomly presented within each block to the panelist.

For each replicate, 20 mL of each wine was presented in a tulip wine glass covered with lids (Solo Cup Co., Urbana, IL) on a single tray. The samples were evaluated monadically at air-conditioned room temperature with 30-s breaks between the end of one sample and the beginning of the next. Panelists were required to expectorate each sample. Samples were coded with three-digit random numbers. Panelists evaluated the samples in individual booths under red light to hide the slight differences in color. The intensities of the attributes were rated on a 10-cm unstructured line scale anchored at the extremes by high and low markers. Responses were recorded directly using the Fizz system.

Data Analysis and Modeling. The statistical analyses and modeling were performed using XLSTAT version 2007.2 (Addinsoft, New York) except where noted. The sensory and instrumental data were analyzed by univariate and multivariate analysis of variance. Fisher's protected least significant difference (LSD) was used with an α-risk of 0.05 to compare the means.

Interpretation of the principal component analysis (PCA) results enabled the characterization of the wines by their sensory descriptors. Intensity ratings for each descriptor were averaged across panelists and replicates for each wine. The attribute ratings created a multidimensional space on which each wine could be placed. A matrix of linear equations related the wines as the dependent variables to the

sensory descriptors as the independent variables. The eigenvector and eigenvalue pairs of this matrix described a new space with all dimensions orthogonal to each another. The first dimension in this new space is in the direction of the eigenvector with the largest eigenvalue; it represents the dimension describing the largest amount of variation in the data. The remaining eigenvalues and eigenvectors describe the other orthogonal dimensions each representing decreasing percentages of variation in the data. The original descriptors, which are often correlated, and thus not orthogonal, are related to the new orthogonal dimensions through a linear transformation of the matrix.

The 95% confidence ellipses shown graphically indicate the uncertainty in position of the wine in the PCA given by the panel. They were determined using the SensoMineR panellipse function (Rennes, France) as described by Husson and Lê (2006).

Partial least squares (PLS) regression was used to correlate the chemical and physical properties and sensory data to the viscous mouthfeel of the wine. This approach is intended to identify parameters, or a linear combination of instrumental and sensory measurements, which best model the viscous mouthfeel perception. Principal component regression (PCR) was employed to fit the instrumental data to the PCR map of the wines. The results are the same as the PLS model, but graphically highlight the various groups of wine styles.

TABLE 4. MEAN PERCEIVED VISCOUS MOUTHFEEL RATINGS AND VISCOSITIES

	Viscosity		Perceived viscous mouthfeel	
Wine	Mean (mPa·s)	Statistical grouping	Mean	Statistical grouping
C3	1.313	A	2.85	ABC
C16	1.307	B	2.57	BCD
C5	1.302	B	2.91	AB
C11	1.293	C	3.21	A
SB17	1.288	CD	2.33	CDE
V7	1.286	D	2.42	BCDE
V4	1.283	D	2.32	CDE
C13	1.276	E	2.55	BCD
PG1	1.266	F	2.24	DE
C6	1.264	F	2.46	BCDE
R10	1.263	F	2.63	BCD
R8	1.252	G	2.44	BCDE
SB12	1.246	H	2.16	DE
SB15	1.244	H	1.97	E
WTW2	1.241	HI	2.22	DE
PG14	1.237	IJ	2.13	DE
SB9	1.232	J	2.12	DE

Wines with the same letter (within a column) are not significantly different at alpha = 0.05.
Viscosity: Fisher LSD = 0.0056.
Perceived viscous mouthfeel: Fisher LSD = 0.579.

RESULTS

The results from viscosity measurements showed significant differences among the 17 wines (Fig. 1 and Table 4). The viscosities ranged from 1.232 to 1.313 mPa s at 30C. In general, wines considered to be typically light-bodied, e.g., Sauvignon blanc, tended to have lower viscosities while full-bodied wines, such as Chardonnay and Viognier, tended to have higher viscosities. A Fisher's protected LSD of 0.006 mPa s (df = 16, alpha = 0.05 double-sided) indicated

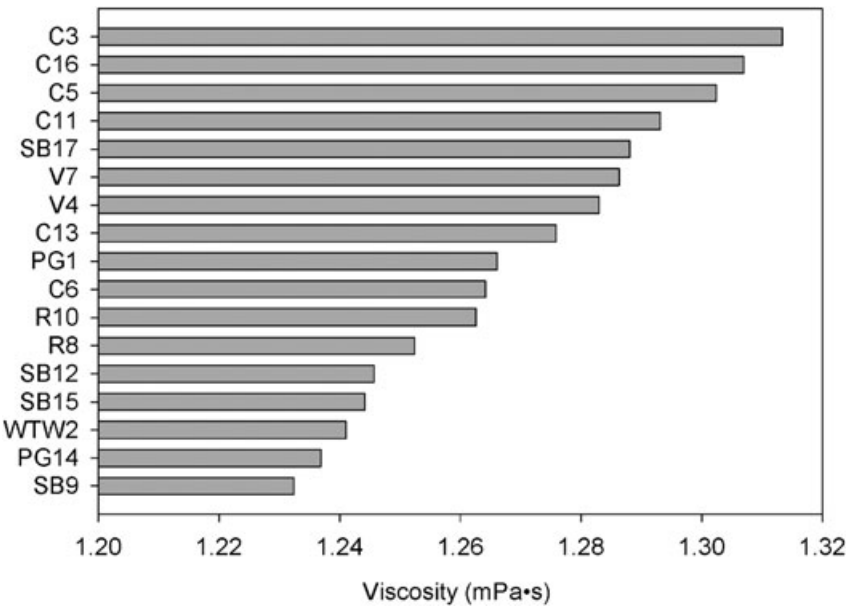


FIG. 1. VISCOSITIES OF WHITE TABLE WINES
Viscosities of white table wines at 30C. The naming of the wines begins with the initials of the wine variety (e.g., SB17 is a Sauvignon blanc).

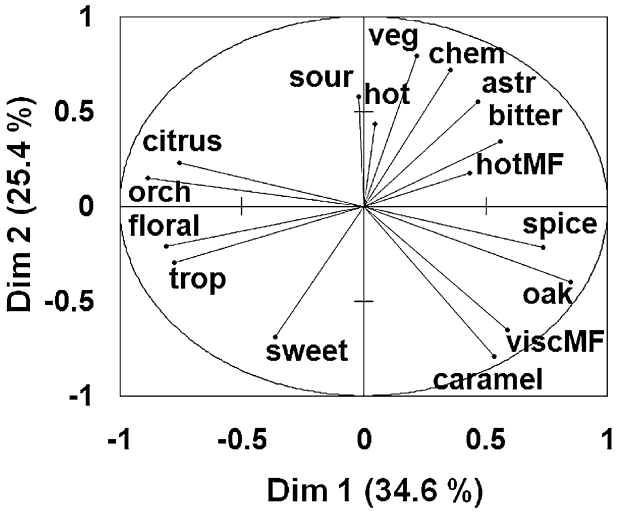


FIG. 2. CORRELATIONS OF SENSORY DESCRIPTORS FOR WINES
Correlations of sensory descriptors for wines based on PCA of descriptive analysis panel. The points and lines are the factor loading vectors; the position and length of the vector describe the correlation between the variable and the principal component. The correlation circle indicates that the coefficients are scaled to a sum of squares = 1.

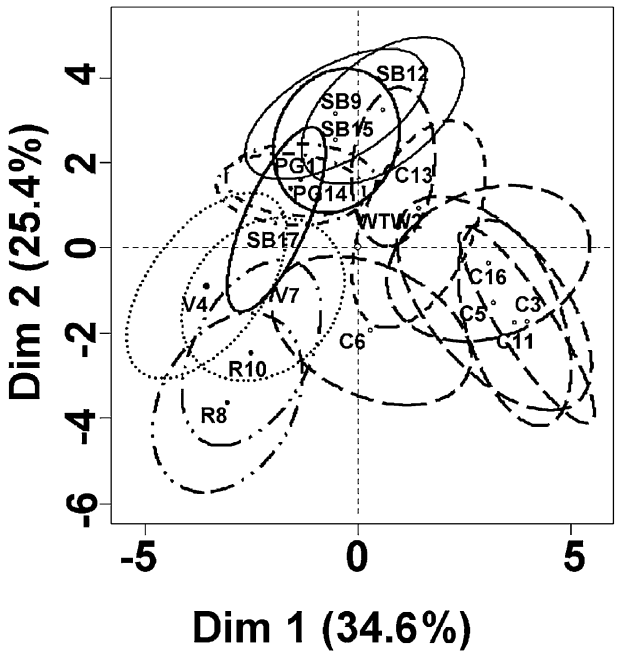


FIG. 3. PCA OF DESCRIPTIVE ANALYSIS PANEL DATA
PCA of descriptive analysis panel data of white wines. Ovals indicate 95% confidence interval. (— — — Chardonnay; – – – white table wine; – · – · – Pinot gris; ——— Sauvignon blanc; · · · · · Viognier; — · · — · · Riesling). The wines are identified in Table 1.

that viscosity differences between the wines greater than this value are considered statistically different.

The range of viscosities determined in this study is similar to that found by Kôsmerl *et al.* (2000), who documented a range from 1.119 to 1.271 mPa s in dry white wines (<15 g/L reducing sugars). These ranges, while thought to be surprisingly narrow, spanned anecdotally different styles of wine "body." However, they fell within the difference threshold of 0.141 mPa s previously reported by Noble and Bursick (1984).

The relationships among the sensory descriptors used to describe the white wines in the descriptive analysis panel are shown in Fig. 2. The descriptors were generated by the sensory panelists to describe the aroma, flavor, taste and mouthfeel of the wines. Viscous mouthfeel is the descriptor generated by the descriptive analysis panel for the wine body sensation. The relationships were determined through a PCA of the sensory panel data. Dimensions 1, 2 and 3 of the PCA explain 34.6%, 25.4% and 13.8% of the variance, respectively (only the first two dimensions are shown). The Pearson coefficient for determining significance was 0.482 (alpha = 0.05, df = 15). Correlation tables as well as means and analyses of variance for the data can be found in Supporting Information Tables S1–S3.

Analysis of the data in Fig. 2 shows that viscous mouthfeel, spice, oak and caramel are significantly related to each other. Therefore, these descriptors were typically used together to describe the same wine. Citrus and orchard were not typically used to describe the wines that were characterized by the oak and spice descriptors. Floral, citrus and tropical and orchard fruits are all significantly related to each other; thus, these four descriptors were often used together to describe a wine.

The positions of the wines in the PCA from the descriptive analysis panel are shown in Fig. 3. The plot shows in dimensions 1 and 2 that the wines tend to cluster into similar anecdotal styles. One group contained most of the Chardonnays (the Chardonnays from outside of Napa Valley are located outside of this group); a second group encompassing most of the Sauvignon blancs and the Pinot gris; and lastly a group containing the Viogniers and Rieslings. The third dimension (Supporting Information Fig. S1) provides evidence that the Rieslings are quite distinct from the Viogniers while the Napa Valley Chardonnays occupy their own distinct region in the space specified by the correlation dimensions.

Figure 3 also shows the 95% confidence ellipses that allow for visual statistical comparisons as described by Husson and Lê (2006). Wines are not significantly different from each other when their ellipses overlap. While some overlapping does occur, this plot suggests that some distinct differences among the wines and wine styles exist. For example, most Chardonnays differ from Sauvignon blanc and Pinot gris, which also differ from Riesling.

Three of the four Chardonnays from Napa Valley are significantly different from the California Central Coast Char-

donnay (C13). The Australian Chardonnay (C6) is not significantly different from three of the California Chardonnays in the first two dimensions; it appears to occupy its own unique space when considering the third dimension (Supporting Information Fig. S1). The Rieslings and Viogniers are significantly different than most Chardonnays and most Sauvignon blancs while only Rieslings are significantly different than all Pinot gris.

Combining Figs 2 and 3 shows that the Napa Valley Chardonnays are primarily correlated with spice, oak, caramel and viscous mouthfeel. The Rieslings and Viogniers are highly correlated with tropical, orchard fruit and floral. Additionally the Rieslings are correlated with sweet taste using the third dimension (Supporting Information Fig. S1), which separates them from Viognier.

The key finding for this study emerges from these data (Figs 1–3), which have established that significant differences in the viscosities of the wines exist and that panelists can perceive significant differences among the wines. A qualitative comparison can be made from the data in Table 4, which presents the mean perceived viscous mouthfeel ratings and the viscosities of each of the wines. The viscosities are listed from highest to lowest. The viscous mouthfeel ratings of each of these wines are given in the adjoining columns. Comparing the perceived viscous mouthfeel ratings with the viscosities, one qualitatively finds a similar trend. This trend is seen through the different letters which indicate that wines with the same letter within a column are not significantly different for either the viscosity or sensory data. For example, the perceived viscous mouthfeel of SB17 is not statistically different from any wine that has C, D or E in the same column. Wines that are grouped by the same letter within a column do not differ by more than the Fisher LSD, and are not significantly different at alpha = 0.05. Wines that do not have any letters in common are statistically different from each other. Generally, for both sets of data, the letters describing the data are in ascending order. Wines at the top of the table are, in general, statistically different than those at the bottom suggesting a strong relationship between viscosity and viscous mouthfeel; quantitative analysis is needed to provide stronger evidence.

Multivariate data analyses of these sensory, chemical and physical properties data using PLS regression (Supporting Information Fig. S2) indicate, quantitatively, that approximately 80% of the variance in viscous mouthfeel could be explained by the sensory, chemical and physical properties data (alpha = 0.05, df = 15, Pearson's coefficient = 0.48). The analysis also indicated that a significant correlation between viscous mouthfeel and viscosity (correlation value = 0.75) of a wine. However, viscosity does not explain all of the variance in the viscous mouthfeel ratings. In addition to viscosity, osmotic potential (0.58), lactate (0.57), magnesium (0.55) and total extract (0.49) are also significantly correlated with viscous mouthfeel, i.e., their correlation values are greater

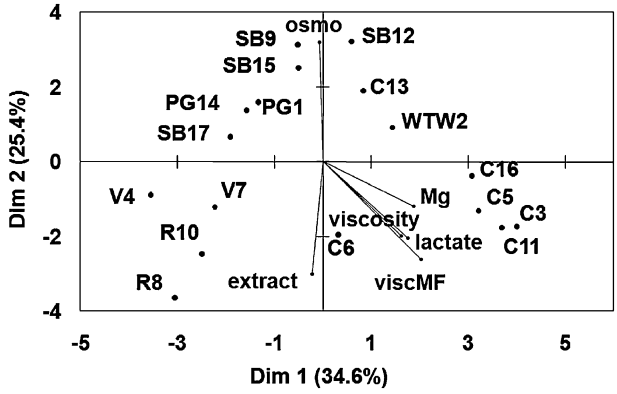


FIG. 4. PRINCIPAL COORDINATE REGRESSION OF WINES
Principal coordinate regression of wines with the significantly correlated physical and chemical properties.

than the Pearson's coefficient for determining significance. The correlation tables for the PLS analysis can be found in Supporting Information Table S4.

In Fig. 4, the chemical and physical properties which are significantly correlated with perceived viscous mouthfeel are plotted along with the positions of the 17 wines using principal coordinate regression. The graph visually shows the correlations between these properties and the wines. Viscosity, lactate and magnesium are correlated with the Chardonnays. Extract and osmotic potential differentiate the Sauvignon blanc and Pinot gris from Chardonnay, Riesling and Viognier. The values of osmotic potential are negative (the greater the potential, the more negative the value), and therefore it is negatively correlated with extract which are represented by positive values. However, they are similar, correlated measures of the amount of dissolved solids.

DISCUSSION

The sensory descriptive analysis of the 17 wines resulted in two important observations. The first observation is that panelists considered some of the wines to be different from each other (essentially grouped into style types). This observation may seem trivial; however, it can be difficult to correctly identify a wine. The result implies that the panelists used similar descriptors to describe wines that are expected to be generally more similar. This observation attests to the ability of the panel and the quality of their training.

Second, despite the narrow range of viscosities, the panelists found some of the wines to differ significantly in perceived viscous mouthfeel (wine body style). This observation was quantitatively found by using PLS, which indicated that viscous mouthfeel is significantly correlated with measured viscosity, lactate, osmotic potential, magnesium and extract. It was anticipated that the viscous mouthfeel of the wines would

be highly correlated with the measured viscosity of the wines as shown by Noble and Bursick (1984) and for other foods by Kokini (1985). However, in this study, the minimum difference in viscosity between wines perceived to have significantly different viscous mouthfeels was 0.027 mPa s; this difference is five times smaller than the difference threshold of 0.141 mPa s, which was estimated by Noble and Bursick (1984). This finding is important as it indicates that one's ability to perceive differences in viscosity might be more sensitive, i.e., have a more narrow range, than previously established.

In addition, perceived viscous mouthfeel of these wines was also significantly correlated with lactate. Lactate is present in wines primarily as a result of its conversion from malate during malolactic fermentation; details of the microbial process are described by Boulton *et al*. (1998). In many cases, the malolactic fermentation is completed in oak barrels as opposed to stainless steel tanks. Thus, it is anticipated that other constituents that are exchanged to and from the oak barrel may be correlated with lactate concentration and may be providing some effect on viscous mouthfeel. Further work must be done in this area to better quantify the components from the oak barrel and determine their influence on viscous mouthfeel.

The osmotic potential of the wines was significantly correlated with viscous mouthfeel. The exact reason for this correlation is not yet known, but it is speculated that it might involve the change in concentration gradients across cell membranes in the mouth. Lyall *et al*. (1999) suggest that stimulus properties such as viscosity and tonicity do not activate the peripheral taste organs directly, but they may exert a modulatory effect on the response of the taste receptor cells. In addition, some of the chemical constituents that produce the osmotic pressure may also increase the viscosity.

It is important to note that the two physical properties that are highly correlated with viscous mouthfeel are not well correlated with each other. It is speculated that these two physical parameters could be an indication that one incorporates sensory information for viscous mouthfeel from multiple sources – mechano- and chemo-sensory receptors – or that these stimulus properties exert a modulatory effect on the response of receptor cells as suggested by Lyall *et al*. (1999).

Increasing concentrations of glycerol or ethanol (within the range of 10–15% ethanol) in a water solution increase the measured viscosity. However, the lack of a strong direct correlation with perceived viscous mouthfeel may be due to other biochemical processes that are concerted with increasing glycerol or ethanol content; for example, changes in other chemical components within the berry or wine may result from leaving the grape berry on the vine longer, which increases its sugar concentration and the potential ethanol concentration of the resulting wine.

Although the data show that viscous mouthfeel is highly correlated with measured viscosity and osmotic potential, it is still not known how to influence these parameters or what chemical constituents are possibly most responsible for differences between wines.

CONCLUSIONS

The objective of this study, to identify which wine properties might be influencing the perception of wine body, was achieved. The contributions of more than 20 chemical constituents and physical properties were investigated. Of these variables, five were identified as being significantly correlated with perceived viscous mouthfeel: viscosity, lactate, osmotic potential, magnesium and total extract. Viscosity was the most highly correlated with perceived viscous mouthfeel. Although each of the five is significantly correlated with viscous mouthfeel, they do not explain all of the variation in this sensory attribute. Thus, these individual constituents are not solely responsible for the perceived wine body; additional research should investigate other compounds that could be correlated with viscous mouthfeel such as polysaccharides and proteins.

Overall, the influence of chemical and physical properties can be more thoroughly investigated and understood by evaluating wines from other regions around the world and by utilizing nonlinear modeling approaches to assess their contributions such as in the case of saturation of receptors. A further understanding of the physiology of the tongue and mouth should be pursued to develop improved hypotheses regarding the contribution of both measured viscosity and osmotic potential to the wine body style. Lastly, to fully understand the wine body perception of the consumer, the contribution of color and aroma must be understood.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

FIG. S1. Dimension 3 of PCA of white table wines (left) and of descriptive analysis data (right) from descriptive analysis panel

FIG. S2. PLS1 loading plot (dimensions 1 and 2) of viscous mouthfeel (Y) and chemical, physical and sensory data (X) for 17 white wines

TABLE S1. Correlation matrix for PCA of sensory panel data

TABLE S2. Mean values and significances1 for aroma/flavor sensory attributes of white table wines

TABLE S3. Mean values and significances1 for mouthfeel and taste sensory attributes of white table wines

TABLE S4. Correlations between viscous mouthfeel, sensory and analytical data

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