Statistical Correlations between the In-Mouth Textural Characteristics and the Chemical Composition of Shiraz Wines

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The relationships between the levels of polyphenols, acidity, and red pigments in Shiraz wines and their perceived textural profiles as quantified by a trained sensory descriptive analysis panel were explored. A "chamois-like" feeling when the wine was held in the mouth appeared to be related to an absence of polyphenols. The in-mouth "chalk-like" texture was strongly associated with anthocyanin concentration and was negatively associated with alcohol level and acidity. The astringent subqualities of "velvet-like" and "emery-like" roughing were mostly related to polyphenol levels, but these attributes could not be adequately differentiated by the compositional variables under study. Wines that elicited a "puckery" sensation were characterized by relatively low anthocyanin levels, high acidity, and high pigmented polymer and tannin concentrations. The results of the study suggest that the in-mouth textural properties of Shiraz red wine are associated not only with their tannin composition and concentration but also with their acidity and anthocyanin and alcohol concentrations.

INTRODUCTION

Many studies have reported a positive relationship between the intensity of the astringent sensation and the concentration of tannin both in model solutions and in red wine (*1−3*). Although this quantitative relationship is well established, few studies have investigated red wine astringency from a qualitative perspective. This is somewhat surprising as the popular wine press frequently refers to differences in the textural qualities of red wines. White grapes fermented on their skins produce wines with qualitatively different astringency from that of red wine, suggesting that anthocyanin−tannin complexes are mostly responsible for the distinctive astringency of red wines (*4*). Qualititative differences in astringency due to composition have been noted. Cabernet Franc wines rich in anthocyanins and low in overall tannin were described as being "soft" in the mouth, whereas those low in anthocyanins and high in tannin or galloylated procyanidins were described as being hard and dry (*5*). Recently, it has been demonstrated that the mouthfeel of model wine can be modified by varying the degree of polymerization and galloylation of its consituent flavan-3-ols or by altering its anthocyanin composition (*6−8*). These authors also found that tannins derived from grape seeds were generally coarser than those equivalently sized tannins derived from grape skins.

Wine components other than phenolics are known to affect the strength of the astringent sensation. Decreasing pH results in higher perceived astringency (*9*), with the size of the increase being independent of the type of organic acid used to achieve the pH reduction (*10*). Some have argued that organic acids are astringents in their own right (*11*), with the intensity of elicited astringency again being dependent on pH (*12*). However, the role of acidity in modulating the textural subqualities in red wine has not been explored to date. Increased alcohol levels in wine have been shown to reduce its overall astringency (*13, 14*). In addition to reducing the overall astringency of grape seed tannins in model wine, fortification with ethanol also modified the astringent profile of the tannin by reducing the intensity of the astringent subqualities of "chalkiness" and "adhesiveness" (*8*).

Although the effects of tannins on the overall level of astringency in wines have been studied and there is some information on the influence of tannin composition on the subqualities of astringency, the impact of other wine compounds on differences in mouthfeel qualities of wine is relatively unknown. Furthermore, the majority of studies of qualitative variations in wine mouthfeel have not been undertaken in real wine.

This study explores the correlations between the acidity and phenolic and pigment compositions with the in-mouth textural profiles of Shiraz red wine. This correlative approach may help to elucidate possible relationships between important red wine components and the mouthfeel of full-bodied red wines.

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Table 1. Wine Composition (Mean of Three Fermentation Replicates)

region: irrigation treatment:	Coonawarra deficit irrigation	Coonawarra full irrigation	Barossa full irrigation	Riverland partial rootzone drying	Riverland full irrigation	p	LSD (5%)
alcohol (% v/v)	16.0 c	16.0 c	13.8 a	14.6 b	14.7 b	0.000	0.3
pH[a]	3.58 ab	3.52 a	3.54 ab	3.49 a	3.50 a	0.003	0.05
titratable acidity[a] (g/L)	7.2 c	6.9 c	5.3 a	5.9 b	6.0 b	0.000	0.2
volatile acidity (g/L)	0.35 bc	0.26 a	0.31 ab	0.41 c	0.36 bc	0.01	0.07
glycosylglucose (μM)	2478 c	2173 c	1433 ab	1248 a	1656 b	0.000	300
malvidin-3-glucoside (mg/L)	24.8 bc	26.9 c	21.6 bc	16.3 ab	15.2 a	0.007	9.2
malvidin-3-glucoside acetate[b]	182	220	256	204	178	0.336	ns[c]
malvidin-3-glucoside coumarate[b]	149	169	82	104	108	0.109	ns
total phenols (au)	46.8 d	43.4 c	29.7 b	28.8 b	25.5 a	0.000	2.0
tannins (mg/L, as catechin)	998 c	944 c	593 a	712 ab	618 ab	0.000	113
pigmented polymers (mg/L, as catechin)	69.4 b	72.1 b	47.6 a	48.2 a	40.0 a	0.000	9.6

[a] The wines were adjusted with tartaric acid in an attempt to equalize their pH values. Therefore, these data do not necessarily reflect the irrigation treatments applied. [b] Peak area. [c] Not significant at 5% level.

METHODS AND MATERIALS

Fruit Sources and Vinification. Shiraz grapes grown under a variety of irrigation regimens and sourced from Riverland, Barossa Valley, and Coonawarra were vinified. Different irrigation regimens were applied as it is well-known that the water status of the vine has the potential to significantly affect the production of color, tannin, and flavor in the grape berry and subsequent wine. Details of the viticultural treatments are given in **Table 1**.

An attempt was made to harvest all of the treatments at a similar maturity (23.5−24.5 °Brix). However, the Coonawarra grapes were unexpectedly riper at harvest, resulting in wines of higher alcohol content (**Table 1**). The musts were ameliorated with 40 mg/L sulfur dioxide, 100 mg/L diammonium phosphate, and tartaric acid to a pH of 3.5. Triplicate fermentations in 20 L glass vessels were conducted at 25 °C after initiation with a 5% w/v inoculum of *Saccharomyces cerevisiae* (EC 1.1.1.8, Lalvin). The caps were hand plunged twice each day. The wines were drained off skins when at approximately 2 °Brix, and the pH was adjusted using tartaric acid to around 3.5 before fermentation had been completed. The wines were not inoculated for malolactic fermentation (MLF), but the low malic and high lactic acid levels in some of the wines (data not shown) suggest that some went through MLF naturally. Following fermentation the wines were racked off gross lees and were dosed with 40 mg/L of SO₂. They were then cold stabilized at 2 °C for 21 days and bottled into 750 mL glass bottles under nitrogen gas cover and sealed with screw-caps. Before bottling, two additional Riverland wines were constructed by blending the three fermentation replicates in equal proportions. The wines were then stored at 18 °C for 28 months before being subjected to sensory evaluation.

In total, data from 12 wines were used to correlate mouthfeel attributes with wine composition. These were three winemaking replicates of the irrigated Barossa, full-irrigated Riverland, and irrigated Riverland wines plus one unirrigated Barossa wine and two blended Riverland wines.

Sensory Assessment. A panel of 10 volunteer tasters comprising three female and seven male employees of the Australian Wine Research Institute and the University of Adelaide was convened. All panelists except one had at least 4 years of wine-tasting experience that was obtained as part of their formal profession. Six tasters had also previous experience in red wine mouthfeel profiling.

Blind tastings of three wines were conducted each session. Three training sessions per week over a 6 week period were conducted. The wines tasted during each session typically included one example of each of the viticultural regions represented in this study. The sessions involved selecting terms that adequately described the wines' mouthfeel both while the wines were held in the mouth and following expectoration. Mouthfeel terms were initially selected from a defined list derived during a previous mouthfeel study (*15*). The initial selection was followed by group discussion, whereby agreement regarding the terms that adequately described the wines was obtained. Touch finger standards that had previously been found to aid tasters in concept formation relating to the astringent sensation (*16*) were also selected during this stage of training. Commercial wines of various ages and

countries of origin and wines altered in their acidity, flavor, and overall astringency were also presented sporadically throughout the training period in an attempt to assist in concept formation.

Following attribute selection, tasters were familiarized with a 10 cm labeled magnitude scale (*17*). They then rated the intensity of the chosen attributes for three wines presented twice over two occasions. Tasters were provided with feedback regarding their reproducibility and intrataster agreement, which they discussed as a group. This exercise was conducted twice during the final 2 weeks of training.

Immediately after training, the tasters rated the chosen mouthfeel attributes of the wines in triplicate. The wines were 30 months old at the time of tasting. Tastings were conducted in white booths with approximately 50 mL of wine being tasted in black cups at room temperature (23 ± 2 °C). Three wines per day were presented, the tasting requiring 18 sessions to complete. The samples were presented in random order across judges, with the order over sessions that of a randomized block design. Tasters were required to taste the wines in the order in which they were presented, but retasting without restraint on the timing or method of tasting employed was permitted. The mouthfeel attributes were rated on a 10 cm labeled magnitude scale with the word anchors and relative positions of the scale points being the same as those given in ref *17*. The ballots were served to tasters by the FIZZ v 1.30 sensory data acquisition software (Biosystemes, Couternon).

Chemical Analysis. The HPLC apparatus used for phenolic compositional analysis was a Hewlett-Packard HP1100. In the developed method, the column used was a 250 × 4.6 mm polystyrene divinyl-benzene reverse phase column (PLRP-S 100 Å 5 μm, Polymer Labs) with a guard cartridge packed with the same material. The injection volume was 20 μL, and the wine pigments were eluted by a gradient with a flow rate of 1 mL/min of solvent A [aqueous 1.5% (w/w) H₃PO₄, 1% CH₃CN] from 92 to 73% solvent A in the first 55 min, held isocratic at 73% from 55 to 59 min, reduced from 73 to 34% from 59 to 64 min, held at 34% from 64 to 73 min, and increased to 92% from 73 to 78 min. Solvent B was 20% (v/v) solvent A in CH₃CN. Wine samples were centrifuged at 12000 rpm in a Mikro 12-24 centrifuge (Hettich) for 4 min before being placed in 2 mL screw-cap vials for sampling by the autosampler of the HPLC. Data were recorded at 280 and 520 nm. All compounds were identified as previously described (*18*); that is, malvidin-3-glucoside was identified by comparison of its retention time, UV−vis spectra, and mass spectra to those of an authentic standard (Polyphenols Laboratories AS, Sandnes, Norway); malvidin-3-glucoside acetate and malvidin-3-glucoside *p*-coumarate were identified by their elution characteristics relative to malvidin-3-glucoside, their UV−vis spectra and mass spectra compared to literature, and pigmented polymers and tannins identified by comparison of their relative retention time, UV−vis spectra and mass spectra to that of standards prepared from wine by Sephadex LH20 chromatography as described (*18*). Total phenolics were measured spectroscopically (*19*), titratable acidity was measured by titration to an end point of pH 8.2, and alcohol levels were measured by NIR spectroscopy. A glycosyl-

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glucose assay (*20*) was used to determine the total concentration of glycosidically bound flavor and anthocyanins.

The wine samples were stored at 4 °C prior to compositional analysis. The alcohol, glycosylglucose, total phenolics, and acidity parameters were measured approximately 1 month following the completion of tasting, and the phenolic and anthocyanin compositional analysis was performed 5 months thereafter.

Statistical Analysis. The compositional data were analyzed using a one-way analysis of variance with mean separation conducted using Fisher's least significant difference. The sensory data were analyzed using a two-way ANOVA with fermentation replicates nested within irrigation treatments and judges treated as random factors. Between and within assessor agreements were assessed by considering the judge × wine interaction plots for each sensory attribute and Kendall's coefficient of concordance, respectively.

The relationships between the analytical measures were investigated using principal component analysis (PCA) with varimax rotation. Principal component regression (PCR) was then used to regress the mean sensory ratings on the orthogonal principal component scores of the analytical variables. To model sensory ratings directly onto the analytical variables, partial least-squares regression (PLSR) was also applied. The optimal number of PLSR model components and their predictive ability were determined using a cross-validation method whereby various models were calculated by leaving out one observation at a time. All analyses were conducted using Minitab 14.13.

Two of the three unirrigated replicate wines from Nuriootpa were excluded as they displayed perceptible levels of oxidation. Data from the Coonawarra wines were also excluded as these wines were higher in alcohol, acidity, and secondary metabolites compared with the wines produced from the other regions (**Table 1**). When included, the resultant analytical and sensory spaces simply reflected the macrodifferences that would be expected between wines made from grapes of differing maturities and higher acidities, and doing so obscured the relationships between composition and perceived mouthfeel.

RESULTS AND DISCUSSION

Intrajudge reliability was found to be adequate (concordance > 0.5). However, the ratings given by one judge were not used as the interaction plots showed that he disagreed significantly with the other judges on a majority of sensory attributes.

The attributes selected by the tasters to represent the texture of these wines when the wine was held in the mouth were chamois, silk, talc, velvet, fine emery, and chalky. The descriptors chosen to describe the texture of the wines after being expectorated were talc, velvet, fine emery, emery, drying, and pucker. Significant differences in mean ratings were found for all of the attributes with the exception of in-mouth talc and silk and velvet after expectoration ($p < 0.05$), suggesting that the wines selected for the study had different textural profiles.

PCA of the compositional data showed that the first principal component (PC 1) was heavily positively weighted on anthocyanins and glycosylglucose and negatively weighted on alcohol level (**Table 2**). Glycosylglucose concentration is known to be a good indicator of perceived flavor and color intensity of red wines (*21*). PC 2 can be interpreted to reflect the overall impact of wine polyphenols as it is heavily weighted on pigmented polymers, tannins, and total polyphenols. PC 3 weighted heavily on acid parameters of titratable acidity, pH, and volatile acidity.

Ratings of the intensity of the chamois-like sensation when the wine was held in the mouth were negatively correlated with the scores generated by the second compositional PC ($r = -0.58$, $p < 0.05$) (**Figure 1a**). This PC was heavily weighted on polyphenol concentration (**Table 2**). Furthermore, modeling the mouthfeel attributes on the compositional variables using PLSR showed that the in-mouth chamois sensation was negatively correlated to the analytical variables that may be reason-

Table 2. Rotated Principal Component Loadings of the Compositional Data and Proportion of Variance Explained

	PC 1	PC 2	PC 3
alcohol	−0.705	−0.297	0.607
total phenolics	0.545	0.721	−0.334
glycosyl-glucose	0.877	0.127	0.056
anthocyanins[a]	0.922	0.288	−0.144
pigmented polymers	0.323	0.892	−0.234
tannins	−0.029	0.932	0.290
VA	0.127	0.006	0.867
pH	0.580	−0.059	−0.708
titratable acidity	−0.652	−0.118	0.708
% variance explained	36.6	29.6	26.6

[a] Summed peak areas of malvidin-3-glucoside, malvidin-3-glucoside acetate, and malvidin-3-glucoside coumarate.
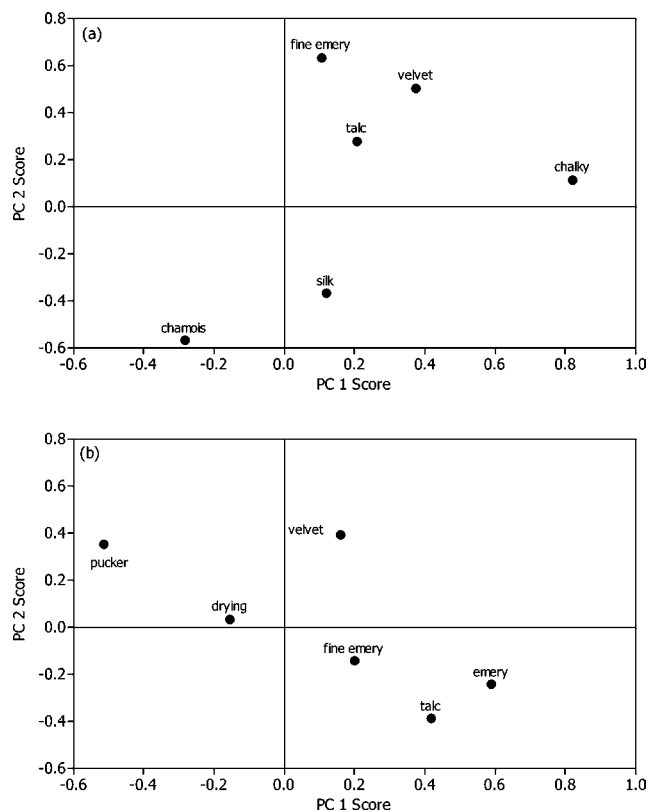

Figure 1. Correlations between mean (**a**) in-mouth attribute ratings and (**b**) postexpectoration attribute ratings with the compositional principal component scores ($n = 12$).

ably expected to affect astringency, that is, total phenolics, pigmented polymers, and tannins (**Figure 2**). Both of these analyses support the notion that the tasters were rating on chamois when a low level of astringency was perceived.

The in-mouth chalky sensation was significantly correlated with the principal component scores generated by the first compositional PC 1 (**Figure 1a**), which in turn most reflected the anthocyanin concentration and other secondary metabolites represented by glycosylglucose concentration. Indeed, this was the strongest association observed ($r = 0.819$, $p < 0.001$). The PLSR coefficients for this attribute also suggested a stronger influence of anthocyanins than polyphenols in this attribute (**Figure 2a**). The PLSR analysis also revealed a possible negative effect of acidity on in-mouth chalkiness, with its being negatively related to titratable acidity and positively related to pH. However, it is worth noting that in-mouth chalkiness was also negatively associated with alcohol level, which was both
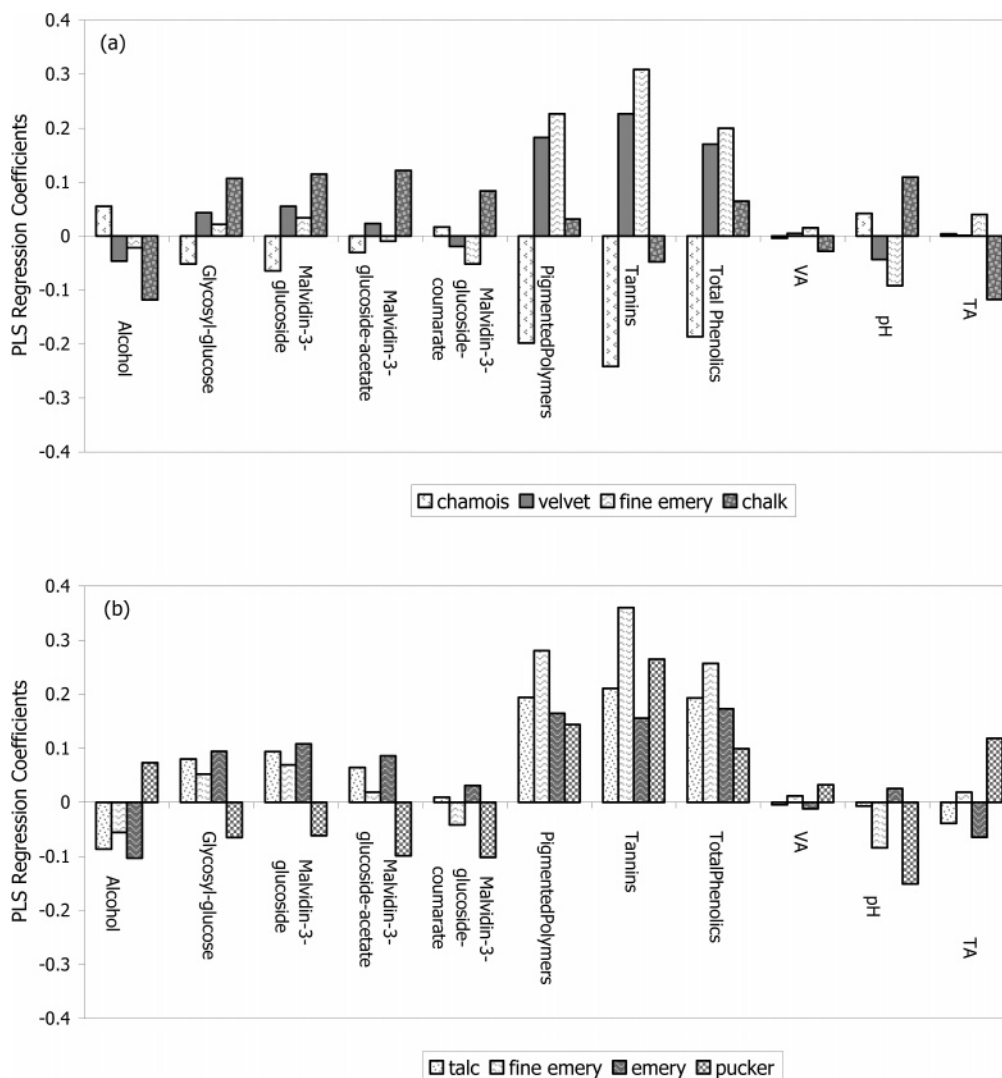
Figure 2. Partial least-square regression coefficients of (**a**) in-mouth and (**b**) postexpectoration attributes modeled on composition variables (*n* = 12). Only sensory attributes that significantly contributed (*p* < 0.05) to the model fit are included.

strongly co-correlated with titratable acidity (TA) (*r* = 0.913, *p* < 0.001) and pH (*r* = −0.759, *p* = 0.007). Therefore, it is not possible to conclude from these wines whether in-mouth chalkiness was mediated by alcohol or acidity. When alcohol was added to model wines, they became perceptibly less chalky in character (*8*), supporting a direct suppressive role of ethanol on this attribute. However, the role of acidity cannot be ruled out. PLSR analysis of a set of 1997 South Australian Shiraz wines profiled in a similar manner but with uncorrelated levels of acidity and alcohol showed low PLSR coefficients for alcohol (0.0080) compared with that for pH (0.058) and TA (−0.110) (data not shown). This supplementary result favors the notion that acidity may also contribute to the in-mouth chalky character of red wines.

Ratings for in-mouth fine emery and velvet were very highly correlated (*r* = 0.850, *p* < 0.001), suggesting term redundancy. Their PLSR coefficients were most heavily weighted on polyphenol types, but particularly that of tannins. PCR also showed strong correlations between the ratings of in-mouth velvet and fine emery with PC 2.

With the exception of pucker, the PLSR coefficients for all attributes perceived after expectoration displayed a similar pattern (**Figure 2b**). PCR also showed that most of the postexpectoration attributes were not significantly correlated with either PC 1 or PC 2 (**Figure 1b**). The exceptions are that

of emery and pucker, which were moderately correlated with PC 1. Thus, most of the sensory attributes perceived following expectoration appear not to be well differentiated on the basis of chemical composition. The exception was the puckery sensation, which was positively associated with pigmented polymer and tannin concentration but negatively associated with concentrations of the three anthocyanin species (**Figure 2b**). Others have also noted a positive effect of nonpigmented tannins derived from grape seeds on the intensity of the pucker sensation (*7*). Anthocyanin coumarates have been reported to produce a puckery sensation when added to a model wine, whereas malvidin glucoside does not (*22*). However, these results are not strictly comparable to this study. First, the anthocyanin levels found here were substantially lower than those added to the model wine. Second, the astringent impact of the coumarate was made in isolation from other anthocyanins. Here, the malvidin-3-glucoside was the strongly dominant anthocyanin species, showing a peak area consistently at around 16 times that of the coumarate. Perhaps the lack of any positive effect of anthocyanins on pucker in this study was also due to the lower levels of the coumarates and the dominance of malvidin-3-glucoside in these wines. Finally, pucker intensity was also associated with increased acidity. Therefore, the wines evaluated in this study that produced a higher pucker sensation were characterized by having higher concentrations of pigmented

polymers, tannins, and acidity and lower anthocyanin levels. It could be argued that the Nebbiolo wines from the Barolo and Barbaresco subregions of Piemonte, which are typified by puckery aftertastes, also fit this compositional profile.

Finally, it is prudent to emphasize that due to the relatively small number of wines profiled here, and because many of the possible explanatory variables that are necessarily correlated, it is not possible to identify the specific causes of the mouthfeel attributes. Further studies whereby a single or small number of possible explanatory variables are varied in isolation from the others are required to unequivocally establish causative effects between red wine composition and its mouthfeel. In addition, it is important to note that wine composition is not static but changes as wines age. This means that compounds could have a major influence on wine sensory properties when wines are young but become relatively unimportant as wines age, and vice versa.

In conclusion, the relationships between the chemical composition and the perceived texture of Shiraz red wine were explored. Although some mouthfeel attributes were associated with certain compositional profiles, it must be acknowledged that the observed patterns may have been the result of co-correlation with a common causative factor. Furthermore, many of the compositional variables were found to be highly correlated, making separation of their individual effects impossible. However, the study does provide some insight into the effects of different tannin classes, color, and acidity on red wine mouthfeel. In particular, the tentative relationship between anthocyanin concentration, alcohol level, and acidity in producing particulate-like textures in Shiraz red wines is worthy of further study.

ACKNOWLEDGMENT

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