The influence of ethanol and pH on the taste and mouthfeel sensations elicited by red wine

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Abstract

The influence of ethanol concentration and pH on a comprehensive range of oral sensations elicited by red wines was investigated in this study. Two commercial dealcoholised red wines were adjusted with tartaric acid and/or ethanol to produce a range of samples with composition values of pH 3.2–3.8 and ethanol concentration <0.5–15% v/v. Seventeen mouthfeel and taste attributes were then determined by a trained descriptive analysis panel. Fifteen descriptors differed in intensity between samples for Wine 1, and 14 for Wine 2. Principal Components Analysis grouped 0% ethanol wines together based on higher scores for pucker, grippy/adhesive and unripe attributes, while 0% ethanol wines with pH 3.2 were further characterized by greater intensity of overall astringency, acidity and mouthcoat. Wines of 15% ethanol were loosely grouped based on positive scores for bitterness and aggressive, and at higher pH values (3.4, 3.6) formed a sub-group based on their similarly high ratings for heat, viscosity and velvet intensities. Some unique relationships between attributes were noted from correlation analysis, including those describing surface smoothness, dynamic and complex sensations. We conclude that ethanol has a much stronger influence than pH on most oral sensations elicited, and that assessing the sub-qualities of mouthfeel yields a more comprehensive and meaningful description of red wine than that obtained when just 'astringency' intensity is measured. These results should assist winemakers in optimising taste and mouthfeel sensations and profiles through production decisions.

Key words: Astringency, taste, mouth-feel, lexicon, alcohol.

Introduction

Polyphenolic constituents (tannin) extracted from grapes during vinification elicit astringency and related tactile sensations, collectively referred to as 'mouthfeel'. This group of sensations, arguably the most important encountered in red wine, is strongly associated with wine quality and yet poorly understood [1]. Astringency is a multi-perceptual phenomenon, with a range of astringent sub-qualities thought to exist, at least at the perceptual level [2-5].

The lack of sensory tools required to fully and accurately measure the range of mouthfeel sensations elicited by wines, including astringency, has contributed to the relative scarcity of literature. Recently, Gawel *et al.* [4] developed the red wine mouthfeel wheel; a hierarchical lexicon to assist in identifying and classifying these complex oral sensations. When incorporated with descriptive analysis techniques, it has been used successfully to measure the impact of processing and compositional variables on the subtle mouthfeel characteristics elicited by actual and model red wines [6-11], as well as for determining how individuals differ in their perception of these sensations [12].

A number of components and factors can affect the astringency elicited by wines/model wines, including initial wine tannin concentration [10], acids [13, 14], polysaccharides [11], anthocyanins [15] and aging [16]. The role of ethanol concentration and pH are also of interest, as they can be readily manipulated through viticultural practices and decisions, as well as winery practices, such as chaptalisation, dealcoholisation, acidification and deacidification. Geddes *et al.* [6] concluded that variable ethanol concentration was responsible for differences in intensity of mouthfeel attributes in wines produced from Cabernet Sauvignon grapes harvested at different stages of ripeness. Vidal *et al.* [10] reported lower intensity ratings for some astringent sub-qualities at higher ethanol concentrations in model wines. Lowering pH has previously been shown to increase the overall astringency of acids [17, 18], model solutions [19] and white wines [19]. Fischer [20] reported that pH had no effect on bitterness (pH 3 vs 3.6) and only a minor effect on astringency. Fischer and Noble [21] found that both bitterness and astringency varied between wines of pH 3 and 3.6, but this was strongly mediated by the salivary flow rate of the subjects. The latter two studies employed a time-intensity methodology, but no studies to our knowledge have investigated the influence of pH on astringent sub-qualities nor other non-taste oral sensations in wine.

The main objective of the current study, therefore, was to fully characterize the effects of pH and ethanol on the oral sensations elicited by actual red wines. A preliminary analysis of the data from one of the wines used in this study has previously been presented in the conference proceedings of DeMiglio, Pickering and Reynolds [22].

Methods

Base wine and sample preparation: Two dealcoholised commercial red wines were used as the base for this study. Wine 1 was a 1999 Cabernet Sauvignon from Ariel Vineyards (J. LOHR Winery Corp., San Jose, CA, USA, 95126). Wine 2 was a non-vintage red blend consisting of 50% Carignane, 40% Grenache and 10% Merlot purchased from Carl Jung Inc. (Rudesheim Am Rhein, Germany, Allemagne; imported by Carl Jung Sales Inc., Mississagua, Ontario). Food grade ethanol (95% v/v, Liquor Control Board of Canada, Glendale Ave. St. Catharines, Ontario) was added to each base wine to yield ethanol levels of 6, 12 and 15% v/v. The pH of the base wines was increased via double salt de-acidification [23] to approximately pH 3.8, and L (+) tartaric acid was then added to obtain final pH values of 3.6, 3.4 and 3.2 (Orion pH meter).

Viscosity was determined after Nurgel *et al.* [24], residual sugar (RS) was measured using the Lane-Eynon method [25] and titratable acidity (TA) determined after Iland *et al.* [26]. Glycerol determination was carried out using the Boehringer Mannheim enzymatic kit, and ethanol was measured using a GC procedure employing an Agilent 6890 series GC system and 9-point calibration curve [27]. Total phenolics were estimated using both the spectrophotometric method of Iland *et al.* [26] (TP-S) and the Folin-Ciocalteu procedure described in Zoecklin [25] (TP-FC). The basic chemical composition ± standard deviation for base Wines 1 and 2 were, respectively; viscosity (cp): 1.21±0.00, 1.22±0.01; RS (g/L): 37.50±0.71, 32.25±1.06; TA (g/L): 6.35±0.07, 5.35±0.07; glycerol (g/L): 5.28±0.16, 3.86±0.03; pH: 3.45±0.1, 3.19±0.02; TP-S (au): 20.44±0.86, 37.46±2.93; and TP-FC (GAE mg/L): 1201.67±17.68, 1922.50±11.78. After the acidity adjustments, the TA (g/L) ± standard deviation of the different pH treatments for Wines 1 and 2 respectively, was pH 3.2: 8.10±0.14, 7.05±0.07; pH 3.4: 7.00±0.00, 5.40±0.14; pH 3.6: 4.90±0.14, 4.45±0.07; and pH 3.8: 4.45±0.07, 3.75±0.21. After alcohol adjustment, the viscosity (cp) ± standard deviation of the different ethanol treatments for Wines 1 and 2 respectively, was 6%: 1.42±0.00, 1.45±0.00; 12%: 1.68±0.01, 1.72±0.01; and 15%: 1.89±0.01, 1.94±0.01.

Sensory analysis: The panel (n = 9; 4 females, 5 males; 24-45 yrs) consisted of staff and students from the Cool Climate Oenology and Viticulture Institute at Brock University, and winemakers and laboratory staff from a local wine company (Andres Wines Ltd). Panellists were recruited based on availability and interest in the project. Most had prior experience with wine descriptive analysis panels although none had previously participated on a mouthfeel panel.

Training: The panel attended two, one and one-half hour training sessions per week for a total of nine sessions. In order to remove potential bias from ortho- or retro-nasal aroma in the assessment of samples, panellists wore nose plugs during all training and data collection sessions. The first two sessions were devoted to generating terms to characterize the oral sensations of the wines. The research wines were presented blind, and the panel instructed to generate as many descriptors as possible and record them on the sheets provided. For guidance, each panellist was given a copy of the red wine mouthfeel wheel [4] and instructed to use it, where needed, to help in describing the tactile sensations experienced. Aqueous solutions of tartaric acid (2 g/L), quinine

sulphate (0.1 g/L) and alum sulfate (1 g/L) were used in preliminary exercises to ensure all panellists could correctly distinguish between sour, bitter and astringent sensations.

During Sessions three to six, the lexicon was refined, redundant terms eliminated, and touch and conceptual standards/definitions were developed by panel consensus and by reference to the research wines. Definitions and touch standards developed by Gawel *et al.* [4] were presented for descriptors in common with their study, and were modified where required based on panel feedback. Development of line scales, appropriate anchor terms and evaluation protocols was also completed. The final list of descriptors, scale parameters and standards is presented in Table 1.

Sessions seven to nine were direct preparation for the data collection phase. These were carried out in isolated booths equipped with sensory data collection software (Compusense c5v4, 111 Farquhar St., Guelph, Ontario, Canada, N1H 3N4). Panellists practised the evaluation protocols and intensity ratings on individual 15 cm scales.

Panel reliability was evaluated using Sensetools™ software (Compusense c5v4, 111 Farquhar St., Guelph, Ontario, Canada, N1H 3N4) and corrective feedback provided to panellists where required.

Formal testing/Data collection: Testing was conducted over a period of seven days between the hours of 8:30 am and 11:30 am. Panellists were assigned to individual booths within the Brock University Sensory Lab, which is equipped with red lighting to mask wine hue (130 Volt, 100 Watt Haskellite red bulb with red cellophane cover). Wines 1 and 2 were treated as separate experimental blocks. Within each block, the twelve wines (Tables 3 and 4) were presented using a balanced design with the order of presentation randomized over the entire block. Four of the twelve wine treatments were presented at one time (one 'flight'). Panellists were required to take a minimum two-minute break between samples, and a fifteen-minute break between each flight to minimize carry-over and fatigue-related effects. Conceptual standards, touch standards, water and crackers were available to each panellist. Each sample was presented in an ISO glass at room temperature (21°C), moved around the mouth for 5-7 s, expectorated, and assessed in duplicate for the mouthfeel and taste attributes given in Table 1. Data was collected using the Compusense™ programme cited above.

Statistical analysis: All statistical procedures were performed using XLSTAT© version 7.5.2 (Addinsoft, 40, rue Damrémont, 75018 Paris, France). The data was analyzed separately for the 2 base wines (blocks). ANOVA was used to examine the relationship between oral sensations and wine treatment, and a means separation test (Tukey's HSD) was applied if the treatment F value from ANOVA was <0.05. Both wines responded similarly to changes in pH and ethanol, thus Principal Components Analysis (PCA) was applied to a combined data set of results from all 24 wines (correlation matrix without rotation). To make interpretation of the PCA clearer, the 'balance' descriptor was not included in the analysis, as it is more qualitative and was not rated for intensity, and descriptors that did not differ between wines (ANOVA) were omitted. Pearson's Correlation Coefficient (r) was calculated on the combined data sets from both wines to investigate the relationship between the attributes.

Table 1. Oral sensations rated with corresponding scale parameters and reference standards.

Classification of sensation	Attribute rated	Anchor terms	Distance from origin (mm)	Standard
Particulate	Abrasive	Absent	0	-
		Fine emery	30	Fine emery sandpaper
		Grade 2	60	Grade 2 sandpaper
		Grade 3	90	Grade 3 sandpaper
		Grade 4	120	Grade 4 sandpaper
		Coarse	150	Coarse sandpaper
Surface smoothness	Velvet	Absent	0	-
		High	150	Velvet cloth
	Silk/Satin	Absent	0	-
		High	150	Silk cloth
Complex	Fleshy	Absent	0	CD*
		High	150	CD*
	Mouthcoat	Light	0	Furry cloth – light depth
		Moderate	75	Furry cloth – moderate depth
		Heavy	150	Furry dish washing sponge – heavy depth
Dynamic	Pucker	Absent	0	CD*
		High	150	CD*
	Chewy	Absent	0	CD*
		High	150	CD*
	Grippy/Adhesive	Absent	0	-
		Suede	75	Suede
		Wet chamois	150	Damp chamois
Harsh	Aggressive	Absent	0	CD*
		High	150	CD*
Drying	Dry	Absent	0	CD*
		High	150	CD*
Unripe	Unripe	Absent	0	-
		Green	50	CD*
		Sappy	100	CD*
		Resinous	150	CD*
Weight	Viscosity	Thin	0	Brita™ filtered water
		Full	75	2% carboxymethyl cellulose
		Syrupy	150	5% carboxymethyl cellulose
Heat	Heat	Absent	0	-
		Warm	75	15% ethanol solution
		Hot/Parching	150	20% ethanol solution
Taste	Acidity	Low	0	Brita™ filtered water
		Balanced	75	-
		High	150	2 g/l tartaric acid solution
	Bitter	Absent	0	Brita™ filtered water
		High	150	0.1g/l quinine sulphate
Other	Overall astringency	Absent	0	Brita™ filtered water
		High	150	2g/l Alum Sulphate
	Mouthfeel balance	Soft	0	CD*
		Supple	75	CD*
		Harsh	150	CD*

* Conceptual definition used: refer to Table 2; all oral standards made up in distilled water unless indicated otherwise.

Table 2. Definition of conceptual terms used during training and/or testing.

Attribute	Definition
Fleshy	Astringency with suppleness
Pucker	A reflex action of mouth surfaces being brought together and released in an attempt to lubricate mouth surfaces [1]
Chewy	Gives the feeling that movement (chewing) can displace the astringent sensation [1]
Aggressive	Wine is bitter and/or astringent from the start
Dry	A loss of lubrication [1]
Green	Combined effect of excess acidity and astringency [1]
Sappy	Astringency with high acidity and slight bitterness. Reminiscent of the astringency elicited as if chewing on a grape stalk [1]
Resinous	Astringency elicited as if chewing on a piece of raw wood [1]
Soft	Balance term indicating a light, finely textured astringency [1]
Supple	Balance term indicating low to moderate astringency with an appropriate level of acidity
Harsh	Wine is bitter and/or astringent in the finish

[1] Definition from Gawel *et al.* [4]

Table 3. F-ratios, mean intensity scores and groupings for oral sensations elicited by Wine 1[a] with differing pH and ethanol concentration.

Attributes	F-ratio & sig.	Wine pH and ethanol concentration (%v/v)											
		3.2 0%	3.2§ 0%	3.4 0%	3.6 0%	3.8 0%	3.2§ 6%	3.2§ 12%	3.2§ 15%	3.4 12%	3.4 15%	3.6 12%	3.6 15%
Velvet	5.78 ***	4.43a	5.93abc	4.26a	4.70ab	4.45a	4.49a	6.98abc	8.58c	7.30abc	6.69abc	7.75bc	7.96c
Silk/satin	2.74 **	1.67ab	1.41ab	1.63ab	2.04ab	3.15ab	2.61ab	1.29ab	0.53a	0.66a	1.71ab	0.38a	0.81ab
Fleshy	2.85**	3.71a	3.81ab	3.85ab	4.27ab	3.41a	5.21ab	4.99ab	3.93ab	5.28ab	4.49ab	6.02b	3.79ab
Pucker	4.47***	6.12c	5.57bc	4.56abc	3.67ab	3.84ab	2.98a	3.13a	4.31abc	3.83ab	3.28a	2.83a	3.63ab
Abrasive	1.02NS	3.69	3.57	3.25	2.66	3.16	2.84	3.40	3.61	3.65	3.60	2.88	3.22
Chewy	0.56NS	2.98	3.06	3.02	3.10	2.38	2.57	2.56	3.40	2.01	2.84	2.28	2.47
Grippy/Adhesive	2.34*	8.26ab	9.78b	8.34ab	7.68ab	7.60ab	7.46ab	8.50ab	7.58ab	7.13ab	7.51ab	6.62a	6.76a
Aggressive	6.07***	2.60abcd	2.48abcd	1.41abc	1.39ab	0.71a	0.98a	1.78abc	3.32cd	1.60abc	3.76d	1.28ab	3.14bcd
Drying	2.17*	5.94	5.11	4.88	3.74	4.03	3.79	4.56	5.53	4.56	3.84	3.74	4.64
Unripe	10.34***	3.40bc	3.64c	2.08ab	1.68a	2.07ab	1.53a	0.83a	1.42a	0.76a	1.06a	0.74a	1.65a
Viscosity	12.73***	4.46ab	3.98a	4.29ab	3.72a	3.81a	5.13abc	5.78bcd	6.66cd	6.43cd	7.09d	6.73cd	7.13d
Heat	48.73***	1.57a	1.50a	1.08a	0.75a	0.97a	1.41a	5.97b	9.96d	6.83bc	9.27cd	6.04b	9.28cd
Acidity	10.95***	9.50f	8.00ef	7.40cde	5.24a	5.60ab	5.72abc	7.53de	8.04ef	7.33bcde	6.69abcde	6.09abcd	6.66abcde
Bitterness	3.85***	1.23ab	1.03ab	0.33a	0.64ab	0.33a	0.36a	1.09ab	1.99b	1.01ab	1.67ab	0.74ab	1.79b
Balance	11.41***	7.87bcd	7.67bcd	6.06ab	5.32a	4.34a	5.16a	7.72bcd	8.86d	7.56bcd	8.34cd	6.37abc	8.82d
Overall astringency	2.37*	4.99ab	5.27b	4.56ab	3.99ab	3.31a	3.87ab	4.67ab	4.56ab	3.74ab	3.62ab	3.56ab	3.98ab
Mouthcoat	2.41*	6.39b	5.46ab	4.11ab	4.39ab	3.51a	3.88a	4.59ab	5.30ab	3.97ab	4.13ab	3.95ab	4.33ab

[a] 1999 Cabernet Sauvignon from Ariel Vineyards, CA, USA; § indicates base wine with no acidity adjustment; data represent the average scores of 9 judges and duplicate assessments; for each attribute, means with different letters differ significantly (Tukey's HSD$_{05}$); NS = not significant.

Table 4. F-ratios, mean intensity scores and groupings for oral sensations elicited by Wine 2[a] with differing pH and ethanol concentration.

Attributes	F-ratio & sig.	Wine pH and ethanol concentration (%v/v)											
		3.2 0%	3.4 0%	3.4§ 0%	3.6 0%	3.8 0%	3.4§ 6%	3.4 12%	3.4§ 12%	3.4 15%	3.4§ 15%	3.6 12%	3.6 15%
Velvet	14.44***	3.52a	3.52a	3.50a	4.09a	5.02ab	3.86a	7.51bc	8.97c	8.04c	7.74c	8.49c	7.65bc
Silk/satin	2.901**	1.24abc	1.19abc	1.73abc	2.30abc	2.66c	2.54bc	1.29abc	1.35abc	0.98abc	1.21abc	0.55a	0.61ab
Fleshy	6.414***	3.11a	3.25ab	4.2abcde	3.88abcd	3.55abc	3.68abcd	5.32de	4.97cde	5.27de	5.24de	5.60e	4.81bcde
Pucker	8.19***	6.79d	5.75cd	4.67abc	5.53bcd	4.09abc	3.28a	3.91ab	3.79ab	3.96ab	4.25abc	3.26a	3.89ab
Abrasive	1.19 NS	4.19	3.09	3.64	3.69	3.52	3.21	3.40	4.04	3.17	3.64	3.62	3.68
Chewy	1.19 NS	3.11	1.71	3.26	2.73	3.38	2.52	2.66	2.47	2.61	3.04	2.35	2.68
Grippy/Adhesive	3.76***	9.94c	7.05ab	9.06bc	8.48ab	8.32abc	6.77a	7.65ab	8.91abc	7.44ab	7.51ab	7.76abc	7.64ab
Aggressive	2.45**	3.34b	1.91ab	1.83ab	2.08ab	1.70a	1.99ab	1.49a	2.14ab	1.68a	2.44ab	1.42a	1.52a
Drying	1.53 NS	5.86	5.22	4.97	5.92	5.14	4.77	4.97	5.74	4.87	6.04	4.09	4.97
Unripe	19.06 ***	4.44	3.61e	2.92de	2.22cd	1.41abc	2.05bcd	1.09abc	0.67a	1.28abc	1.53abc	0.91ab	1.06abc
Viscosity	17.45***	4.35a	3.51a	3.94a	4.19a	3.71a	4.77ab	6.09bc	6.54c	6.38c	7.00c	6.84c	6.76c
Heat	51.04***	1.73a	1.45a	1.81a	1.21a	1.04a	2.80a	5.04b	8.58d	7.21cd	8.76d	6.14bc	7.32cd
Acidity	15.03***	10.17e	9.44de	8.58cd	8.29bcd	6.23a	7.64bc	7.82bc	7.62bc	7.66bc	7.56bc	7.45abc	7.27ab
Bitterness	2.17*	1.59ab	1.12ab	0.92ab	0.71a	0.75a	1.21ab	1.12ab	1.17ab	0.89ab	2.03b	0.87ab	0.72a
Balance	6.44***	9.33c	7.99bc	7.41b	7.79bc	5.34a	6.67ab	7.07ab	8.16bc	7.36b	8.55bc	6.87ab	7.28b
Overall astringency	1.99*	5.83b	4.20ab	4.47ab	4.83ab	4.52ab	4.17b	4.51ab	4.52ab	4.66ab	4.98ab	3.72a	3.76a
Mouthcoat	2.13*	6.37b	4.56ab	5.38ab	4.38ab	4.98ab	4.31ab	4.14a	4.79ab	4.91ab	5.26ab	3.76a	4.94ab

[a] non-vintage Carl Jung red blend (Rudesheim Am Rhein, Germany; 50% Carignane, 40% Grenache, 10% Merlot); § indicates base wine with no acidity adjustment; data represent the average scores of 9 judges and duplicate assessments; for each attribute, means with different letters differ significantly (Tukey's HSD$_{05}$); NS = not significant.

Results and Discussion

Main effects: Tables 3 and 4 give the F-ratios and average attribute scores for Wines 1 and 2, respectively. Fifteen of the 17 attributes assessed differed between Wine 1 samples, while 14/17 differed for Wine 2. Fig. 1 shows the factor loadings and scores from the PCA.

Factors 1 and 2 explain 76% of the variation in the data. Factor 1 is positively loaded with pucker, grippy/adhesive and unripe and negatively loaded with fleshy. Factor 2 is positively loaded with bitterness and aggressive and negatively loaded with silk/satin. Most 0% ethanol wines are separated from other samples along Factor 1 based on their higher scores on this dimension. The three 3.2/0% wines group together here and are further characterized by greater ratings for overall astringency, acidity and mouthcoat intensity. In contrast, the 15% wines group loosely
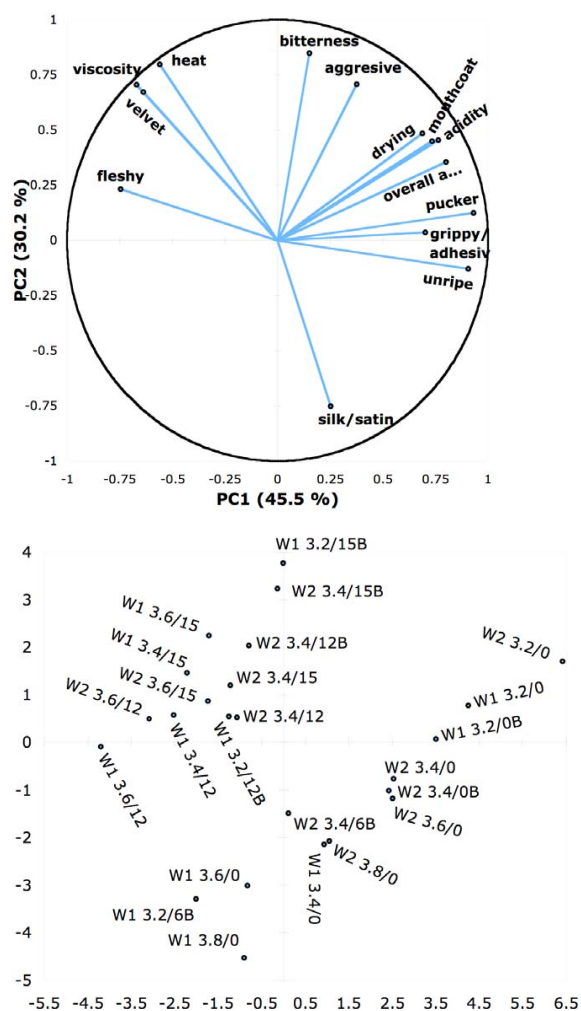
Figure 1. Factor loadings and scores from principal component analysis of oral sensation scores elicited by de-alcoholised red wines varying in pH (3.2-3.6) and ethanol (0-15% v/v) (each data point [bottom figure] represents the factor score from the ratings of 9 judges and duplicate assessments; W1 = 1999 Ariel Vineyards Cabernet Sauvignon; W2 = NV Carl Jung Carignane/Grenache/Merlot blend; only sensory attributes that differed between wines (p(F)<0.05) included in analysis).

together on Factor 2 based on positive scores for this dimension, and the 15% wines at the higher pH (3.4, 3.6) form a sub-group based on their similar high ratings for heat, viscosity and velvet intensities. Most 12% wines are located along Factor 1 to the left of the origin, reflecting their lower scores for the unripe descriptor.

Interestingly, the differences in overall astringency between samples was relatively small, as summarized in Fig. 2a, with the higher intensities of the 0% wines at pH 3.2 compared to others the only noteworthy result. However, when the sub-qualities of astringency are examined, more differences are apparent. Irrespective of pH, 12 and 15% wines show substantially higher scores for velvet (Fig. 2b). Silk/satin scores are much higher for 6% wines, especially at pH 3.2 (Fig. 2c). Wines of 6% had lower intensities ratings for grippy/adhesive than other alcohol concentrations regardless of pH (Fig. 2d). Finally, pucker intensity changes with ethanol concentration, although this is mediated to some extent by pH (Fig. 2e). Geddes *et al.* [6] observed greater

intensity of 'harsher' attributes in higher ethanol wines, while Vidal *et al.* [10] found that the intensities of chalky, adhesive and overall astringency decreased with increasing ethanol in model wines containing 11, 13 and 15% v/v ethanol. Viscosity and heat are two other non-taste oral sensation, and both increased with ethanol concentration at all pH levels (Figs 2f and 2g) consistent with previous findings on heat [28] and viscosity [29,30]. Bitterness intensity tends to increase inversely with pH, consistent with the previously reported influence of acid in accentuating bitterness[21], although overall our wines scored low for this attribute.

Overall, Wines 1 and 2 elicited similar responses, despite their differences in variety and phenolic composition, suggesting that the effects of ethanol and pH on these oral sensations may be relatively robust for red wine.

Relationship between the variables: As suggested by the common angles of some of the eigenvectors in Fig. 1, some of the sensory attributes are correlated. Overall astringency is most closely associated with mouthcoat (r = 0.805), drying (r = 0.784), pucker (r = 0.734) and grippy/adhesive (r = 0.719). Gawel *et al.* [4] categorized velvet and silk as 'surface smoothness' descriptors, and in our study they were negatively correlated (r = -0.708) indicating they were being used correctly to delineate different characteristics of this dimension. Interestingly, these attributes are generally not correlated with other astringency sub-qualities (perpendicularity of eigenvectors [Fig. 1] and low r values [data not shown]), suggesting that surface smoothness has independent value in describing oral sensations. Pucker and grippy sit within the 'dynamic' tier of the red wine mouthfeel wheel [4] and have a moderate, positive association in this study (r = 0.604).

The composite term fleshy was not strongly correlated with any other attribute, indicating it is not redundant and also has value in profiling and differentiating these wines. Aggressive was strongly and positively correlated with bitterness (0.852), which is not surprising given the incorporation of bitterness in the definition of aggressive (Table 2). The inclusion of composite terms such as these in describing multiple percepts can be problematic in regard to consistency of use and a common understanding by the panel, although as 'integrated' concepts they may better reflect the actual experience of tasting wine under 'normal' (vis-à-vis laboratory) conditions.

Mechanistic considerations: A possible mechanism for some of the mouthfeel effects observed could be the direct inhibition by ethanol of binding between salivary proteins and polyphenolic constituents of the wines, speculation supported by the results of Serafini *et al.* [31] and Hagerman *et al.* [32]. Matrix viscosity has also been shown to affect total astringency intensity [33-35] and may be implicated in our results, given the different physical viscosities of the samples. Further research could explore the possible role of interactions between ethanol and the polysaccharide fractions of wine, particularly given some interesting and unexpected effects on tactile sensations noted in model wines by Vidal *et al.* [10].

Overall astringency tended to increase inversely with pH in the 0% wines, but the differences are small and no clear pattern was seen at other ethanol concentrations. A general observation of total astringency varying inversely with pH has been observed in earlier studies with acids [17,18], model solutions and white wines[19] and may be due to a lower proportion of charged phenolate ions
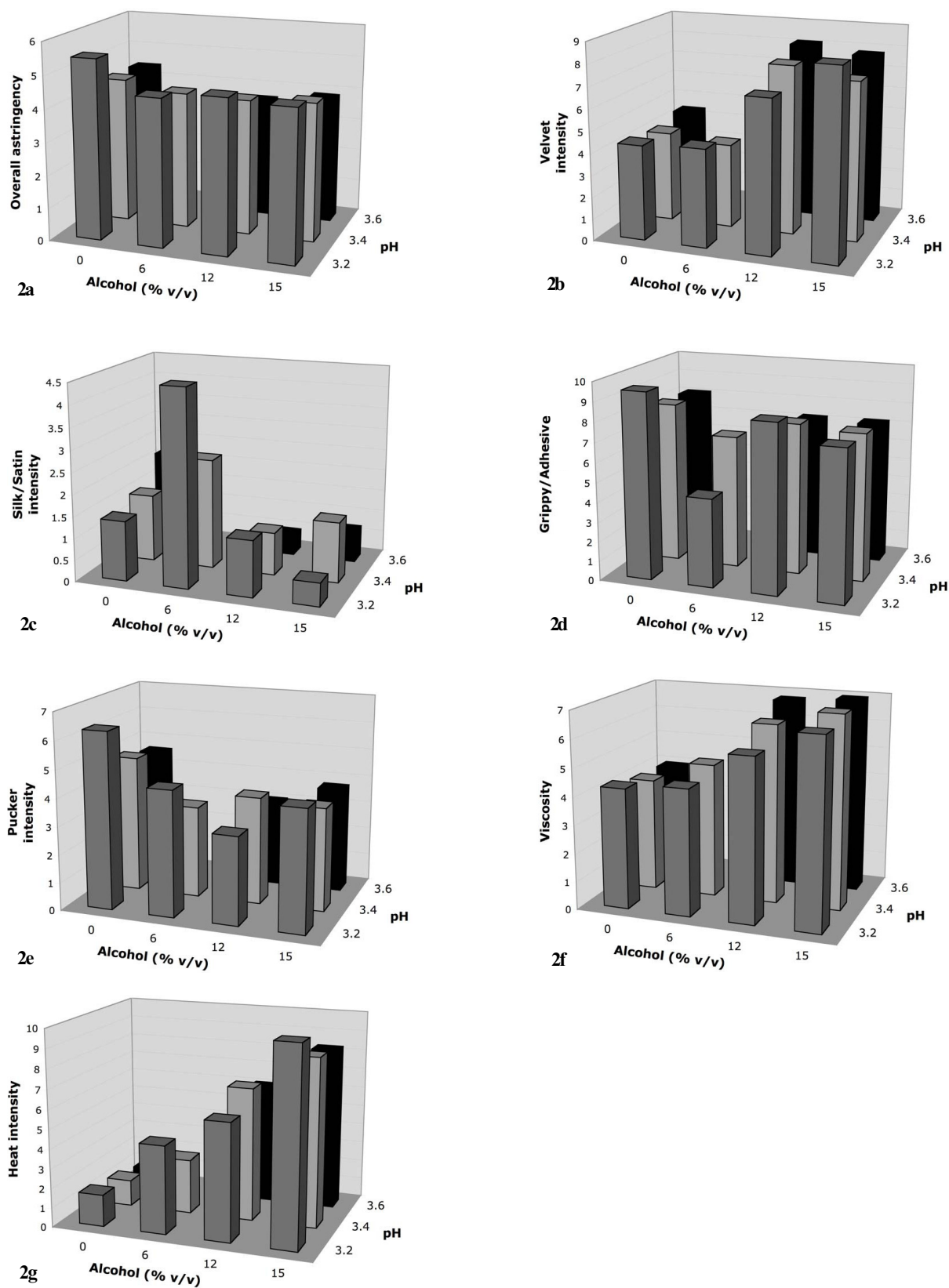
Figure 2. Intensity scores for select oral sensation scores elicited by de-alcoholised red wines varying in pH and ethanol (data represent the average scores of 9 judges and duplicate assessments of 2 wines – a non-vintage Carl Jung red blend (50% Carignane, 40% Grenache, 10% Merlot) and a 1999 Ariel Vineyards Cabernet Sauvignon).

(which are less able to form hydrogen bonds with salivary proteins) at lower pH.

Practical considerations and directions for further research:
Both dealcoholised and reduced alcohol wine products represent a specialized but growing share of the wine market. Our data show that these wines possess taste and mouthfeel characteristics that differentiate them from 'full-strength' wines (such as higher intensity for 'unripe'), although this result is often moderated by pH, with higher pH samples eliciting finer and arguably more desirable oral sensations, such as silk/satin. This may provide some guidance to producers, given the acknowledged challenges in creating acceptable mouthfeel in low- and reduced-alcohol wines [36]. Of interest to producers of traditional table wines (12–15% v/v ethanol), alcohol concentration plays a more dominant role in modifying most oral sensations than does pH. This result may assist winemakers with decisions regarding harvest date and chaptalisation and acid adjustments to their juice/wine.

Interestingly, sweetness was not a taste attribute generated by the panel, despite significant residual sugar in these wines. This may be due to a masking effect from other wine constituents. It remains to be determined if the perception of oral sensations elicited by wines that differ in pH and ethanol will be different in chemically dry red wines, which are more commercially common than those used in this study. It would also be informative and beneficial for producers to examine how pH and ethanol-mediated mouthfeel profiles vary with time (bottle aging) and with other grape varieties and wine styles.

The 'mouthfeel wheel' as a tool for descriptive analysis proved useful in assisting this panel to generate appropriate terms to describe their sensations, develop a common vocabulary and to categorise those sensations. Some limitations and suggestions for improvement were made by the panel, including; (i) removal of the 'flavour' and 'acidity' portions of the wheel (considered inappropriate/confusing in a mouthfeel lexicon), (ii) removal of the texture tier (creamy and syrup were regarded as uncommon descriptors for red wine) and (iii) incorporation of a 'length' tier (to address the time-dependent nature of many of the mouthfeel sensations).

Finally, given that physiological factors such as salivary flow rate [21] and PROP sensitivity [12, 37] influence perception of both bitter and astringent sensations elicited by wine, it would be interesting to investigate the extent to which these physiology-based differences affect responses to pH and ethanol changes in wine. Extending this concept further to include consumer behaviour would be a logical and potentially valuable endeavour.

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