THE EFFECTS OF ETHANOL AND GLYCEROL ON THE BODY AND OTHER SENSORY CHARACTERISTICS OF RIESLING WINES

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Abstract

The effect of ethanol and glycerol concentration on the body, sweetness, acidity, aroma and flavour intensity, and perceived viscosity and hotness of three Riesling wines was assessed. The ethanol and glycerol contents of the wines were adjusted by addition to give three realistic levels (5.2, 7.2, 10.2 g/L glycerol and 11.6, 12.6 and 13.6 v/v ethanol). The nine treatment combinations (3 glycerol x 3 ethanol) were rated on the above attributes by a panel of trained tasters. Increased alcohol levels resulted in increased perceived hotness in all wines, and in higher body and perceived viscosity in two of the three wines. The effect of increasing glycerol content was less consistent with only one of each of the three wines showing increased viscosity and body. However, the mean viscosity ratings given to wines with 10 g/L glycerol was higher than at 5 g/L at all alcohol levels and for all wines, suggesting that differences in glycerol concentration typically displayed between dry white table wines can affect their perceived viscosity. Neither alcohol nor glycerol consistently affected sweetness, acidity, aroma or flavour intensity. Higher ratings of the abstract term 'body' were most commonly associated with higher ratings of flavour and/or perceived viscosity, suggesting that for the majority of tasters, these two attributes contributed to their interpretation of the term 'body'. Perceived hotness was not an important component of body, while the role of acidity in body perception was taster dependent.

Keywords: white wine, wine body, glycerol, alcohol level, perceived viscosity, alcohol hotness

Introduction

The terms 'body' and 'fullness' are frequently used to describe the in-mouth impression of both red and white table wines. Wines are routinely categorised as being light, medium or full bodied - presumably as wines of different style appeal to different market segments, and are consumed in different social and culinary contexts. However, despite its widespread use and application, there appears to be a lack of common understanding within the wine trade as to what sensory aspects contribute to wine body.

Beers are also routinely categorised by fullness, and attempts have been made to define body in the context of this beverage. Langstaff et al. (1991a) considered fullness as being one of three primary mouth-feel classes, with viscosity and density being contributing sub-qualities. They defined viscosity as the "degree to which beer resists flow under an applied force in the mouth", and density as "the perceived density or weight of beer in the mouth". Despite these attempts to define and classify fullness in beer, a number of issues remain. Most importantly, there appears to be no agreed position on the necessary conditions for 'fullness' in either beer or wine. That is, what attributes, if missing, would preclude a wine from being full bodied? Despite the apparent lack of agreement on what constitutes body in wine, Gawel

(1997) showed that experienced wine tasters with extensive practical training had an equivalent understanding of 'body' in a group of Chardonnay wines, and considered the feature important in distinguishing between the wines.

It has long been speculated that alcohol strongly contributes to palate fullness in white wine (Amerine and Roessler, 1983). Pickering et al. (1998) were the first to formally test this premise. They found that the perceived density of a de-alcoholised wine generally increased with increasing alcohol over a 14% v/v range, while its perceived viscosity was highest at 10% ethanol. Later work using model wines showed a positive monotonic effect of alcohol content on both perceived viscosity and density over the same alcohol range (Nurgel and Pickering 2005), further supporting the existence of a positive relationship between alcohol content and fullness in white wine.

Glycerol is a major product of yeast fermentation and is reported to range up to 9.9 g/L in Australian white table wines (Rankine and Bidson 1971), and 9.36 g/L in South African dry white wines (Nieuwoudt et al. 2002). In its pure form glycerol is a viscous liquid at room temperature. Therefore it is reasonable to assume that it contributes to the perceived viscosity and fullness of dry white wines. However, Noble and Bursick (1984) estimated that an additional 26g/L of glycerol is required before an increase in white wine viscosity is just noticable. Based on this result, it is unlikely that glycerol concentration influences the perceived viscosity of dry white wine. However, recently Nurgel and Pickering (2005) reported enhanced perceived viscosity of a model wine upon increasing its glycerol concentration from 10 to 25 g/L.

The contribution of ethanol to wine sensory properties extends beyond that of possibly enhancing fullness. Ethanol affects the headspace concentrations of many wine volatiles (Guth and Sies, 2002), and also contributes to sweetness (Scinska et al. 2000). Furthermore, ethanol induced palate warmth and perceived viscosity may indirectly affect both aroma and flavour perception (see Delwiche, 2004 for a review).

This paper investigates the effect of realistic levels of ethanol and glycerol on the body, viscosity, hotness, aroma and taste intensity of dry white table wine. Furthermore, it attempts to explore assessor interpretation of the concept of wine body as distinct from perceived viscosity and density.

Methods

Tasting panel

A panel of 10 volunteer assessors comprising one female and nine male employees of the Australian Wine Research Institute was convened. All but one taster had at least two years general wine tasting experience as part of their profession, but none had participated in previous training specifically relating to wine body.

Assessor training

Training consisted of three, forty minute sessions per week over four weeks. The purpose of training was to 1) accommodate assessor views on which attributes influence body in white wine, 2) ensure that there was no redundancy in the selected attributes, 3) arrive at a broad definition of wine body and definitions of the attributes contributing to body, and 4) select and refine an appropriate scale.

Initial training consisted of presenting sets of four or five young commercial Australian and New Zealand dry white table wines of varieties Riesling, Viognier, Chardonnay, Semillon, Sauvignon Blanc and Pinot Gris. The assessors discussed and justified whether the wines were light, medium or full bodied. These discussions gave rise to a list of attributes which were thought by the assessors to affect perceived fullness in white table wines.

In later sessions, assessors were randomly presented with pairs of Riesling wines, one being a control and the other the same wine adjusted by either 1) addition of 10% (v/v), or 2) ethanol addition of 1.0, 1.5% or 2.0% (v/v), or 3) glycerol addition of 2, 4 or 5 g/L, or 4) combinations of glycerol and ethanol given in (2) and (3). On one occasion, a commercial wine that had previously been identified as full bodied was blended (50:50 v/v) with another that had previously been identified as light bodied. This blend was either presented with the light bodied or the full bodied component of the blend. In all cases assessors were asked to rate the fullness of each wine of the pair on a nine point category scale with word anchors on every second scale point. They also rated the intensity of the previously selected attributes (viscosity, hotness, acidity, sweetness, aroma and flavour intensity) using the same scale. In addition, assessors were asked to select which wine of each pair they considered to be fuller in body. Immediately following each tasting the panelists discussed their results. The panel moderator used these discussions to consolidate a common understanding of each of the attributes excluding body. Assessors were given overall panel feed-back in the form of a written report giving collated results at the following session. While the feed-back included the identity of the wines, the panel moderator intentionally avoided making any suggestions as to any possible effects of the chemical modifications to the wines. To illustrate the concept of viscosity, a control white wine was compared with the same wine to which a commercially available food grade thickener was added. Only opinions as to perceived viscosity were discussed during this session.

Formal assessment

Three commercial South Australian Riesling wines were selected on the basis of their low alcohol (< 12% v/v) content (Table 1). Alcohol level was measured using NIR (AWRI Analytical Services) and glycerol concentration was determined enzymatically as previously described (Nieuwoudt et al. 2002). Each wine was either diluted with mineral water or fortified with food grade 96% v/v ethanol (Tarac Technologies, SA) to 11.6, 12.6 and 13.6% v/v, and glycerol (Symex, Vic) from a 50% w/v stock solution in water to 5.2, 7.2 and 10.2 g/L. These additions resulted in nine (three ethanol x three glycerol) treatment combinations for each of the three wines. Flavour dilution effects were likely to be insignificant as the maximum additions of water and ethanol were 0.3% and 1.8% respectively.

The formal assessment was conducted in tasting booths with 30 mL of each sample being presented at a constant room temperature in black ISO wine tasting glasses. During each session, all nine treatment combinations of a particular wine were presented in a completely randomised order to each assessor. The assessors rated the intensity of aroma, body and acidity using a nine point category scale developed on the advice of the assessors during training. Word anchors were applied to the odd numbered categories. For the body attribute, these were light, light-medium, medium, medium-full and full. For all other attributes the word anchors describing intensity were low, low-medium, medium, medium-high and high. After surrendering their ballots and waiting between one and three minutes, the assessors re-tasted the wines and rated viscosity, hotness, flavour and sweetness using the same scale. This protocol was subsequently repeated, three times a week over three weeks. In total, data for the nine treatments by three wines by three tasting replicates was collected.

Directional difference tests were also employed to enable direct comparison of the fullness of wines with increased alcohol and glycerol levels. These tests were conducted 6 months after the rating sessions described above. The panel consisted of 12 assessors, five of whom had previously participated in the body/fullness test described above. During the recruitment process potential assessors were asked if they were familiar with the term body and would be confident of their ability to use this term in a sensory test. All samples were prepared on the morning of the tasting with the exception of day two, where wines from day one were used. In this instance wines from day one were blanketed with nitrogen gas and kept at 4 °C overnight. The treatments were: wine A or wine B with a) ethanol addition of 2%, b) glycerol addition of 5 g/L or c) ethanol addition of 2% and glycerol addition of 5 g/L. Each of these treatments were paired with their respective base wine (i.e. either wine A or wine B) in a directional difference test protocol.

Wine (30 mL) was presented to the assessors under the conditions described above. Replicate tastings were conducted over three consecutive days, whereby six pairs of wines were presented in a randomised order balanced across the twelve assessors. Tasters were required to taste the pairs of samples in the order in which they were presented and indicate which of the pair was fullest in body. Consistent with the previous trial, a definition of fullness/body was not provided. The assessors were also asked to indicate how confident they were in their selection using a five point category scale with the following verbal descriptors on each point: 1. not at all confident, 2. a low degree of confidence, 3. moderately confident, 4. a high degree of confidence, 5. a very high degree of confidence. Assessors were asked to rinse their mouth with water and were forced to wait 30 seconds before tasting the next set.

Statistical analysis

Category scales were used to collect attribute intensity and body ratings. As such the data generated were considered to be ordinal scale variables. For this reason, non-parametric statistical analysis methods were chosen in favour of parametric methods such as analysis of variance (ANOVA) and multiple regression. The attribute ratings were modeled on alcohol and glycerol content using ordinal logistic regression using a logit function as the integrator. The data were summarised as mean ratings, with rating variability represented as standard errors. Correlations between body and the predictor variables were determined using Spearmans rank correlation coefficient, and individual judge ratings of body were modeled on the predictor variables of viscosity, flavour, acidity, hotness and sweetness using ordinal logistic regression. To assist in the interpretation of the individual models, points on the nine point category scale for body were combined into three categories, 1-3 being categorised as light bodied, 4-6 as medium bodied and 7-9 as full bodied. All analysis was performed using MINITAB Release 14.13 (Minitab Inc). Directional difference test data with pooled replicates was analysed using tables derived from the binomial distribution. As overall confidence in completing a task is known to be highly individualistic, the confidence ratings provided by each assessor were normalised by subtracting the grand mean confidence rating of that individual from each of their confidence ratings. Due to the inherent variability in sensory ratings, a significance level of 10% was considered appropriate and used throughout.

Results

Attribute selection and definition

The commercial wines used for training were selected on the basis of expected differences in body resulting from variations in grape variety, alcohol content and oak treatment. After tasting these wines and discussing their perceptions, the assessors agreed on the following concepts and definitions. 1) Body was defined as “the overall impression of weight or substantiveness of the wine in the mouth”, 2) the terms ‘body’ and ‘fullness’ were synonyms, 3) viscosity was defined as “the amount of force that must be applied to move the wine around in the mouth”, 4) viscosity was deemed to be a single physical property of the liquid phase of the wine equating to its ‘thinness/thickness’ and 5) aroma and flavour were defined as the wine’s fruitiness perceived orthonasally and retronasally, respectively.

The assessors also agreed that wine body was an abstract concept rather than a single sensory attribute. The consensus was that wine body may be influenced by the attributes of flavour intensity, viscosity, sweetness, acidity and heat, so these were included in the study. Overall aroma intensity was included to investigate the effect of alcohol and glycerol level on perceived aroma rather than on wine body per se.

Effect of alcohol and glycerol

Alcohol level had a significant positive effect on the body of wines B and C (Table 2 and Figure 1). Wine A showed some evidence of increasing body with alcohol content at the highest glycerol concentration (Figure 1). Directional difference tests also showed that enhanced levels of alcohol increased the body of wine B, as did combined higher levels of alcohol and glycerol in wine A (Table 3).

The effect of glycerol concentration on body was also wine dependent. The body of wine B was positively affected by glycerol content, as was wine A at the highest alcohol level (Table 2, Figure 1). When compared directly, higher glycerol in wine B was seen to have increased the body of that wine, but in wine A, a combination of higher alcohol and glycerol was most suggestive of increased body (Table 3). It is noteworthy that despite the observed differences, the assessors indicated a general lack of confidence in their responses. This, together with the fact that the glycerol content did not affect the fullness of wine C at any alcohol level (Figure 1), suggests that the effect of glycerol on wine body in the range used in this study was, at best, subtle.

The effect of alcohol on perceived viscosity was not statistically significant for any of the three wines (Table 2). However, there was a consistent increase in perceived viscosity with increasing alcohol in wine B and C (Figure 2). For both wines, 13.6% v/v alcohol resulted in significantly higher viscosity than 11.6% v/v but only at the highest glycerol concentration.

Higher glycerol concentrations favoured perceived viscosity in wine A (Table 2 and Figure 2). At the highest alcohol level, the perceived viscosity of wine B with 10.2 g/L glycerol was higher than at either 5.2 or 7.2 g/L. No clear trend in viscosity with glycerol was seen in wine C.

A robust effect of in-mouth heat with increasing alcohol was seen for all three wines. As the effects were independent of wine, the pooled results are given in Figure 3. In contrast, glycerol content did not have a consistent or significant effect on the heat elicited by any of the wines. However, at the lowest alcohol level, glycerol seemed to have a slight depressive effect on alcohol elicited palate heat. Neither sweetness, aroma or flavour intensity were affected by the addition of either glycerol or ethanol (Table 2).

Assessor interpretation of body

Table 4 shows the level of significance of the regression coefficients when body category ratings (light, medium and full bodied) were modeled on the ratings for potential predictor variables for individual assessors. The models provided a good fit between wine body and the predictor variables of flavour, viscosity, hotness, acidity and sweetness for all assessors. The coefficients for viscosity and flavour were significant for five of the ten assessors who indicated a positive relationship between these two attributes and overall body. Viscosity and flavour also displayed the strongest correlations with body (Table 5). For two assessors, higher acidity was also positively associated with fullness, however a negative association was observed between body and acidity for four of the assessors. Hotness was not associated with fullness in any instance, and a minority of judges provided evidence for a positive association between fullness and sweetness.

Discussion

The term 'fullness' is a commonly used term to indicate the style of wine. However there appears to be little agreement on an appropriate definition of 'fullness'. In particular, different schools of thought exist as to whether fullness is a single sensory attribute or whether it is more abstract in nature. Langstaff et al. (1991a) have suggested that viscosity and density are components of fullness in beer, a classification later extended to wine (Pickering et al. 1998, Nurgel and Pickering, 2005). Viscosity was defined by Langstaff et al. (1991a) as "the degree to which the beer resists flow under an applied force in the mouth", while 'density' was defined as the "perceived density or weight of beer in the mouth". However, various observations suggest that there is some redundancy in these terms. Using these definitions, Langstaff et al. (1991b) found that the perceived viscosity and density of beer was highly correlated to physical viscosity, and also to each other. Nurgel and Pickering (2005) applied the Langstaff et al (1991a) definitions of density and viscosity to model wine solutions with varying alcohol and glycerol levels. Their results indicated that the perceived changes in the intensity of these attributes were also highly correlated. It is also noteworthy that they used the same sensory standard to represent both viscosity and density further suggesting a lack of orthogonality between these attributes. However, this probable lack of orthogonality does not necessarily imply that palate density and viscosity are completely synonymous. Another possibility is that high viscosity is a necessary condition for denseness in wine, but that other sensory attributes such as flavour also contribute to it.

The term 'density' (Langstaff et al. 1991a) is equivalent to the broad definition of 'body' decided upon by the assessors in this study. A question arises. Is 'body', a concrete or an abstract sensory attribute? A concrete sensory attribute has been defined as one that can be clearly illustrated using a single reference standard, while abstract attributes cannot be adequately illustrated by any single or set of reference standards due to their multidimensional nature (Gawel 1997). The assessors used in this study agreed that body was not singular in nature. Langstaff et al. (1991a) found that the 'taste' standards that best illustrated the different mouthfeel sensations in beer including palate density were different stylistic examples of beers themselves. This outcome also suggests that body is an abstract rather than concrete sensory attribute.

Clapperton (1973) considered 'body' in beer to include 'flavour fullness'. This notion equates well with the views of assessors used in this study regarding the nature of white wine body. During the initial discussion session they suggested that flavour intensity was an important feature of wine body. This assertion was vindicated in part by the observed moderate but significant association between body and flavour (Table 5), and the low odds ratios of the flavour coefficient when it was regressed against body ratings (Table 4).

The assessors agreed upon a definition of viscosity which was effectively identical to that of Langstaff et al. (1991a) for beer. Initial discussions indicated that most of the assessors considered viscosity to be a singular sensory attribute and one of the components of white wine body. The highest observed correlation with body ratings were with those of perceived viscosity (Table 5) which was consistent with the views expressed in the initial discussions. Other researchers have also found strong correlations between perceived density and viscosity in beer (Langstaff et al. 1991b), white wine (Pickering et al. 1998) and model wine (Nurgel and Pickering, 2005).

Effect of alcohol and glycerol

The increased body with increasing alcohol levels seen in two of the three wines (Table 3 and Figure 1, wines B and C) is consistent with the long held premise that body in white wine is influenced by alcohol content. Nurgel and Pickering (2005) also reported increases in density (a term equivalent to the term body used here) with increased alcohol content over the same range of alcohol levels. However, as was observed here, commercially significant differences in alcohol content produced relatively small changes in density when white wine was used as a base and flavour effects were removed (Pickering et al. 1998). Here, the differences in mean ratings of body resulting from a 2% alcohol increase were around a third of a point on a nine point scale. This suggests that within the range of 11.7 to 13.7% v/v, alcohol alone only has a small effect on white wine body. This seems to contradict the commonly held view that alcohol level is important to fullness of white wine. Wines with high alcohol levels are often more flavoursome, possibly a result of them being produced from riper grapes. It is conceivable therefore that perceptions regarding the role of alcohol may have been influenced by the more intense flavours typically found in wines of higher alcoholic strength. Langstaff et al. (1991b) also noted that the fullness of commercial beers were only moderately correlated with their alcohol content suggesting that factors other than alcohol were likely to have influenced beer fullness.

The main effect of alcohol on perceived viscosity was not statistically significant for any of the three wines (Table 2). However, Figure 2 shows a consistent increase in perceived viscosity with increasing alcohol for wines B and C. Nurgel and Pickering (2005) reported monotonic increases in perceived viscosity of model wine with increasing alcohol level over the alcohol range of 0 to 15%. A positive effect of alcohol on the perceived viscosity of white wine in the range of 7-14% v/v has also been reported (Pickering et al. 1998).

Figure 2 shows that at 13.6% v/v ethanol, increasing glycerol concentration from 5.2 to 10.2 g/L produced a small but significant increase in perceived viscosity in two of the three wines. Noble and Bursick (1984) estimated that a glycerol addition in the order of 26 g/L is required to elicit a just perceptible increase in the viscosity of a light bodied dry wine containing 4.8 g/L glycerol. Using the Weber fraction calculated from the results of Noble and Bursick (1984), the difference threshold for perceived viscosity in the Riesling wines in the present study with a base concentration of 5.2 g/L should be in the order of 28 g/L. The greatest difference in glycerol concentrations in the present study was 5 g/L. Therefore, the data of Noble and Bursick (1984) would suggest that any viscosity differences resulting from the addition of glycerol should be undetectable in these wines. One possible reason for this apparent discrepancy is that the addition of glycerol made the Riesling wines perceptively sweeter, which some assessors may have associated with viscosity. However as the differences in sweetness produced by glycerol addition were insignificant (Table 2), and sweetness and perceived viscosity were uncorrelated (Table 5), it is unlikely that the differences in perceived viscosity were due to confounding with sweetness.

It is shown here that the effect of glycerol on viscosity is dependent on the wine to which it was added. The effect of glycerol addition was greater in wine C than of either wine A or B (Figure 2). All the wines had similar sugar content and identical alcohol levels (Table 1), so the differential effects of glycerol addition on the wines remains unexplained.

Alcohol level significantly increased the palate heat of all three wines (Table 2). While the palate warming effect of alcohol is well known, it appears that little research has been conducted into the chemesthetic aspect of alcohol. Clapperton (1974) reported that his subjects described alcoholic solutions as both drying and warming. However the ability of assessors to detect different levels of hotness due to alcohol was not tested.

There was some evidence that glycerol suppressed the alcoholic heat at the lower alcohol level (Figure 3). Berg et al. (1955b) also noted that sucrose sweetness tended to raise the alcohol difference thresholds in water, indicating a form of sweetness suppression on alcohol perception. However, these authors did not indicate what specific aspect of alcohol perception was affected by sweetness. Alcohol elicited sweetness would be more difficult to detect in the presence of sucrose, while alcohol elicited bitterness would be suppressed by the sweetness of sucrose. Both explain the raised alcohol detection threshold. However, a suppressive effect of carbohydrate viscosity on palate heat is also plausible as it is known that they partly share the same somatosensory pathway (Rolls et al. 2003). Further work needs to be done to elucidate the effect of both tastes and textures on alcohol induced hotness in wine.

Adding the sweet tasting alcohol and glycerol (Scinska et al. 2000) did not increase the perceived sweetness of any wine. It is plausible that the contribution to sweetness by these substances was effectively suppressed by the high acidity of these wines. Similarly, neither aroma nor flavour intensity was consistently affected by either glycerol or ethanol level. Across a wider concentration range than used here, ethanol was shown to suppress the perceived aroma and flavour intensity of wine volatiles (Guth and Sies 2002). However, consistent with the result here, ethanol levels slightly above those used here did not affect headspace volatilities (Conner et al. 1998, Escalona et al. 1999).

Assessor Interpretation of Body

Table 4 shows that for half the assessors, both flavour and perceived viscosity were positively associated with body. The small odds ratios imply large increases in the probability of a wine being rated in a higher body class with each unit increase in perceived flavour or viscosity (Table 4). That is, for half the assessors, perceived viscosity and flavour were important components of body. It is worth noting that any differences in flavour perception was due to the influence of the addition of alcohol and glycerol as the concentrations of wine volatiles was the same across all treatments. The role of flavour in fullness perception was evaluated by Clapperton (1974). He found that the addition of the buttery compound, diacetyl increased the body of ale, but decreased the body of lager beer. He attributed this to the fact that the characteristic flavour of ale was retained more strongly than that of lager following the addition. This suggests that the type of flavour may be important in fullness evaluation. That is, the presence of typical or expected flavours may increase fullness, while a greater intensity of an atypical flavour may not.

While perceived viscosity and flavour intensity appeared to be the most consistent predictors of body, other contributors to fullness perception were idiosyncratic. Higher acidity ratings by four assessors were associated with lower body, while for another two assessors, increased acidity was associated with higher body. A possible reason for these assessor differences is that some may have interpreted high acidity as contributing to a varietal citrus flavour and hence body, or that the positive role of acidity on body may have simply been a previously learned response.

Higher sweetness appeared to be a factor in the perception of body by two assessors. Although sweetness differences in the wines would be expected to be small because the differences in the wine's sugar and glycerol levels were sub-threshold (Berg et al. 1955a, Noble and Bursick 1984), it is also possible that they had an additive effect on overall sweetness perception. The apparent relationship between sweetness and body could conceivably have resulted from these assessors perceptually associating sweetness perceived in the wines with fullness. This association could result from the assessors previous experiences of sweeter beverages being more physically viscous due to their sugar content. Some assessors may also have associated sweetness with flavour. Hort and Hollowood (2004) found that for all but their most experienced assessors, sucrose sweetness was a key driver of fruit flavour intensity of flavoured aqueous solutions. Presumably this association derives from our common experiences of concurrently experiencing fruit flavours and sweetness when consuming ripe fruits. There is some evidence of this association, with small increases in mean flavour intensity being noted with increasing glycerol concentration at all alcohol levels (data not shown). In fact, some winemakers believe that residual sweetness in white wine can enhance the impression of its fruitiness and fullness. While experienced and trained tasters can easily separate flavour sweetness from sugar sweetness, many naive tasters do not.

Lastly, the association between sweetness and body may be the result of a common response. That is, sweetness and body may have responded to changes in some other variable. Sweetness was significantly correlated with hotness (Table 5), a character which was almost certainly due to alcohol (Figure 3). As ethanol is itself sweet (Scinska et al. 2000), it is likely that increased ethanol was the cause of the positive relationship between body and sweetness.

Conclusion

Ethanol and glycerol levels in realistic ranges had a small but inconsistent positive effect on the body and viscosity of Riesling wines. The perceived hotness of the wines was strongly influenced by alcohol level, while sweetness, flavour and aroma intensity were relatively unaffected by either glycerol or alcohol. Assessors given a broad definition of wine fullness were idiosyncratic with regard to what features of the wine contributed to its fullness. However, flavour and perceived viscosity were most frequently and most strongly correlated with the fullness of these wines.

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Acknowledgements

This project was supported by Australia's grapegrowers and winemakers through their investment body, the Grape and Wine Research and Development Corporation, with matching funds from the Federal Government, and by the Cooperative Research Centre for Viticulture. We also thank the tasters for contributing their time and skill, and Dr Mark Sefton and Dr Leigh Francis for critically reviewing the manuscript.

Table 1. Composition of the base wines.

Wine	Alcohol (% v/v)	Glycerol (g/L)	Fermentable sugars (g/L)	pH	Titratable Acidity (g/L)
A	11.9	5.1	1.1	2.96	7.3
B	11.7	5.3	2.5	3.07	6.0
C	11.9	5.3	1.3	3.24	6.9

Table 2. Significance of the Effect of Ethanol and Glycerol Concentration on Intensity of Sensory Attributes (*P* values)

Wine	Body		Viscosity		Flavour		Hotness		Acidity	
	Ethanol	Glycerol	Ethanol	Glycerol	Ethanol	Glycerol	Ethanol	Glycerol	Ethanol	Glycerol
A	0.81	0.44	0.78	0.06	0.41	0.67	0.01	0.14	0.59	0.61
B	0.09	0.07	0.12	0.46	0.81	0.40	0.01	0.70	0.06	0.86
C	0.10	0.51	0.18	0.94	0.38	0.20	0.01	0.76	0.41	0.50

Table 3. Perceived differences in the body of Riesling wines with varying levels of alcohol and glycerol

Treatment	Wine A			Wine A			Wine A		
	Control	+ 2% Ethanol	P	Control	+ 5 g/L Glycerol	P	Control	+ 2 % Ethanol + 5 g/L Glycerol	P
Number selected as higher in body	16	20	0.309	18	18	0.566	14	22	0.121
Assessor confidence*	0.174	0.024		-0.057	-0.320		-0.586	0.294	

Treatment	Wine B			Wine B			Wine B		
	Control	+ 2% Ethanol	P	Control	+ 5 g/L Glycerol	P	Control	+ 2 % Ethanol + 5 g/L Glycerol	P
Number selected as higher in body	13	23	0.066	13	23	0.066	15	21	0.203
Assessor confidence*	0.045	0.073		-0.178	-0.149		0.295	0.040	

* Overall degree of assessor confidence in their evaluation of the relative body of Riesling wines which vary in alcohol and glycerol concentration. A positive (negative) value indicates that on average the assessors were more (less) confident in their choice of the fullest bodied wine.

Table 4. Weightings of predictor variables of white wine "body" by assessor.

Assessor	1	2	3	4	5	6	7	8	9	10
Perceived viscosity		+ + + (0.37)		+ (0.65)	+ + + (0.44)	+			+ (0.58)	
Flavour	++ (0.49)		++ (0.40)	+ (0.62)	+++ (0.52)					++ (0.57)
Perceived hotness										
Acidity	+++ (0.15)				- (1.87)	- - (1.68)	- (1.21)	- - (2.06)		+++ (0.49)
Sweetness						++ (0.32)				+++ (0.54)
P (model fit)	0.000	0.057	0.016	0.006	0.000	0.027	0.060	0.072	0.061	0.023

+ + + , + + , + indicates significant positive impact on body at the 1, 5 and 10% level respectively
- - , - indicates significant negative impact on body at the 5 and 10% level respectively.
Odds ratio of rating as low bodied compared with rating medium or high bodied are given in brackets.

Table 5. Spearman rank correlation coefficients between attributes for all wines.

	Body	Acidity	Flavour	Hotness	Viscosity	Sweetness
Body	1.00					
Acidity	0.12 ns	1.00				
Flavour	0.28 **	0.11 ns	1.00			
Hotness	0.15 #	0.01 ns	0.16 #	1.00		
Viscosity	0.42 ***	0.09 ns	0.25 **	0.40 ***	1.00	
Sweetness	-0.07 ns	-0.28 **	0.10 ns	0.33 ***	0.01 ns	1.00

#, *, **, *** indicates significance at 10%, 5%, 1% and 0.1% respectively, ns= not significant.

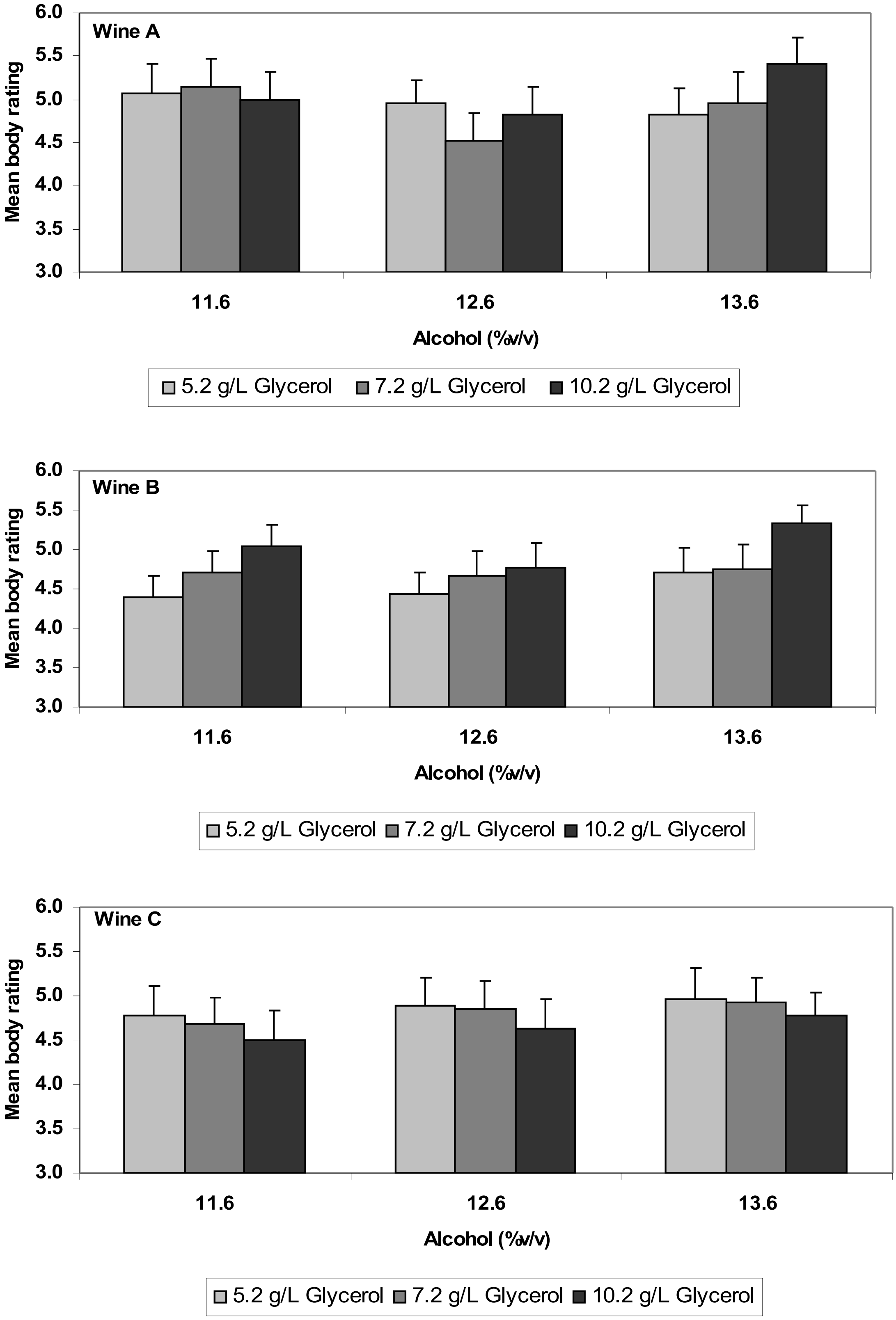

Figure 1: The effect of increasing ethanol and glycerol concentration in Wine A, Wine B or Wine C on the mean body rating. Two standard errors of ratings from three replicates and ten assessors are shown only to illustrate rating variability.

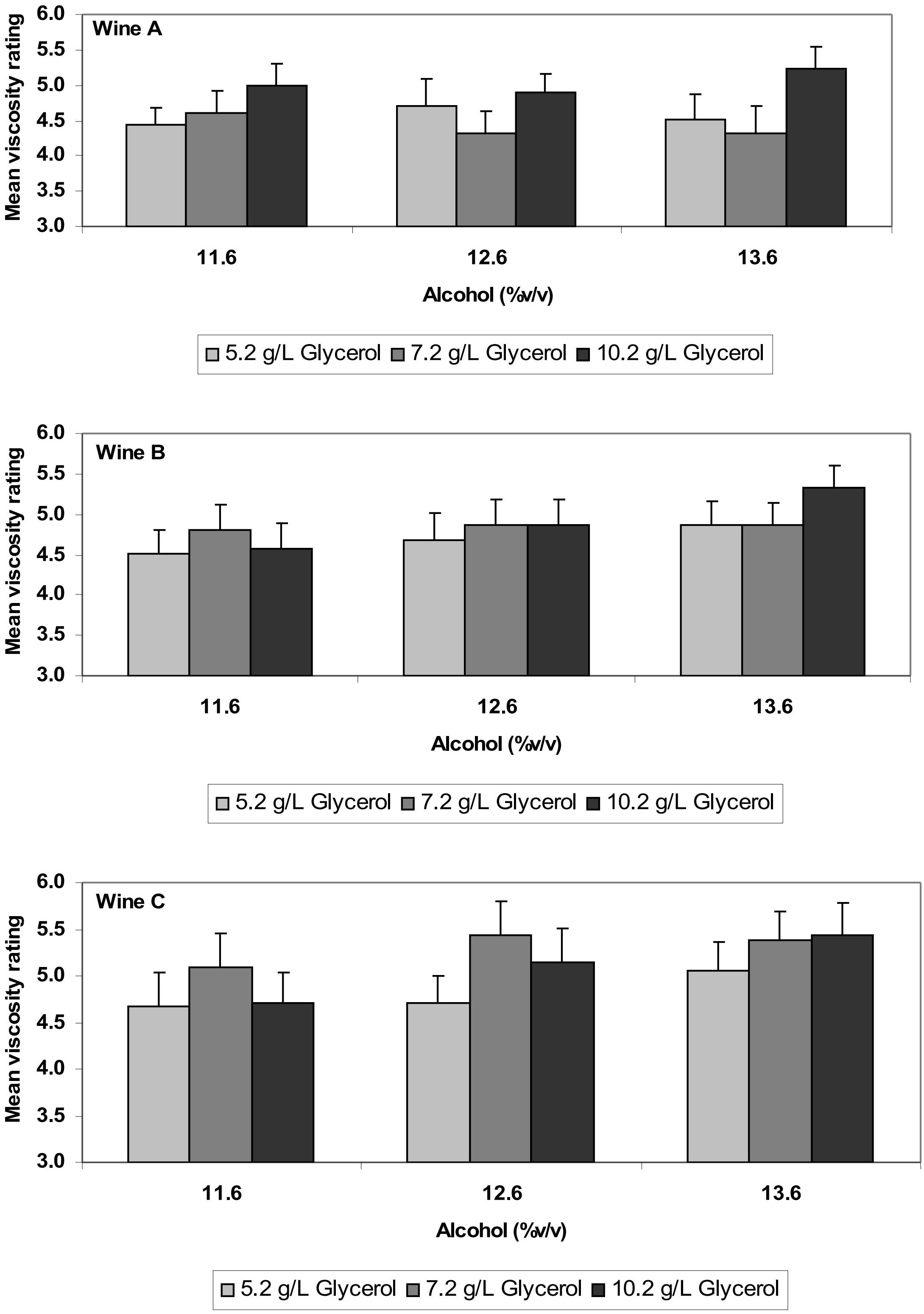

Figure 2: The effect of increasing ethanol and glycerol concentration in Wine A, Wine B or Wine C on the mean perceived viscosity rating. Two standard errors of ratings from three replicates and ten assessors are shown only to illustrate rating variability.

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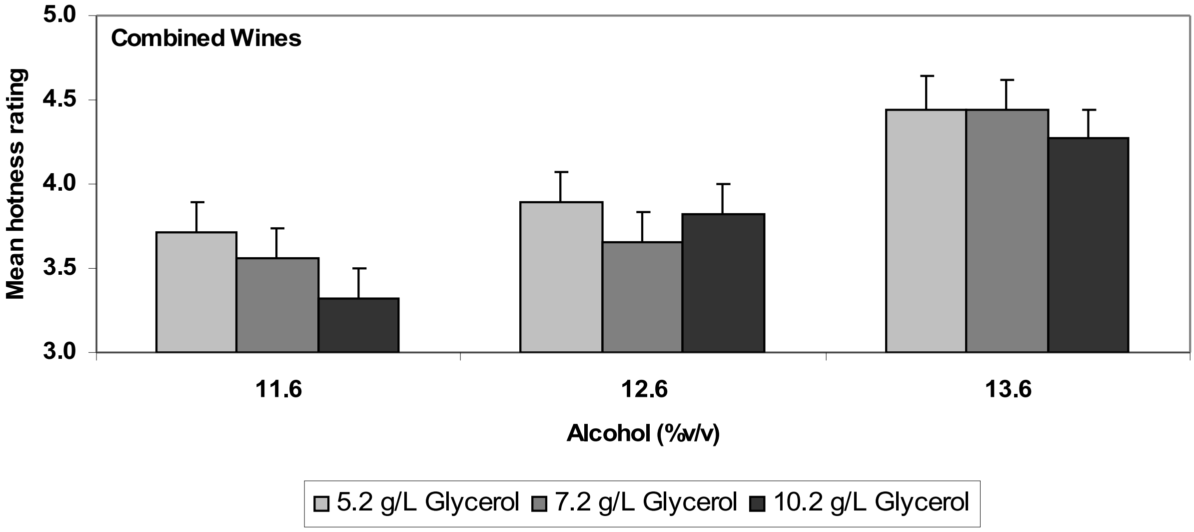

Figure 3: The effect of increasing ethanol and glycerol concentration in all wines on the mean perceived hotness rating. Two standard errors of ratings from three replicates, ten assessors and three wines are shown only to illustrate rating variability.