Glycerol in South African Table Wines: An Assessment of its Relationship to Wine Quality

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Glycerol is an important by-product of glycolysis and is quantitatively one of the major components of wine. While the physicochemical and sensory characteristics of pure glycerol are well established, the impact of varying levels of glycerol on general wine quality remains a topic of debate. Previous reports have relied on limited numbers of either commercial or experimental wines to assess the role of glycerol, leading to contradictory conclusions. Here we report on a large-scale assessment of the relationship between glycerol concentration and wine quality, based on the analysis of a significant number of commercial South African table wines of adjudged quality. The mean glycerol concentrations of 237 dry red (10.49 g/L), 158 dry white (6.82 g/L), 22 off-dry white (6.55 g/L), 16 special late harvest (8.26 g/L) and 14 noble late harvest wines (15.55 g/L) were found to be associated with considerable variation within each respective style. The final glycerol concentrations were significantly associated with the wine style ($P<0.05$). Shiraz wines had a mean glycerol concentration (10.22 g/L) which was significantly lower than that of Cabernet Sauvignon (10.81 g/L), Pinotage (10.46 g/L) and Merlot (10.62 g/L) wines ($P<0.05$). In both the dry white and off-dry white styles, the mean glycerol concentrations of Sauvignon blanc wines (6.31 and 5.42 g/L, respectively) were significantly lower ($P<0.05$) than those of the Chardonnay wines (7.08 and 7.03 g/L, respectively) and the Chenin blanc wines (6.81 and 6.85 g/L, respectively). No significant association between the final glycerol concentrations in commercial wines and the vintage, geographic origin or yeast strain used in inoculated fermentations could be established ($P>0.05$). The mean glycerol concentrations for South African dry red wines were significantly higher than those of dry white and off-dry white wines. Wine quality could not be significantly associated with glycerol concentrations in the dry red wines ($P>0.05$). For the dry white, off-dry white and late harvest wines this association was significant ($P<0.05$), although the exact nature of the association was somewhat different for the respective styles. Despite this positive statistical association, the observed differences between the mean glycerol concentrations of dry white and off-dry white wines of different quality ratings were too small to be of major practical value. The relationship between glycerol concentration and wine quality is reassessed on the basis of results obtained in this study as well as on recent reports in the literature.

Research in modern enology is focused strongly on the improvement of wine quality through the enhancement of the sensory and flavour attributes of wine. From a scientific perspective this requires the establishment of correlations between the individual components of the wine and its sensory characteristics. Wine, however, is a complex matrix consisting of several hundred components. These are thought to interact in a completely non-linear way to establish the aroma and flavour that are finally perceived (Voilley *et al.*, 1991; Lambrechts *et al.*, 2000). As a result, the contribution of the majority of the individual components to wine quality remains difficult to assess.

Glycerol (sometimes referred to as glycerine) is one of several polyols present in wine and the pure substance is a colourless, odourless, non-volatile sugar alcohol with a slightly sweet taste and a viscous nature. Quantitatively glycerol is a major component of wine and the final levels in table wine are usually 7 to 10% of that of ethanol (Rankine & Bridson, 1971). The glycerol levels of wines from various origins, including several European countries, Australia, Argentina, California and New York State, have been reported in previous studies, and levels ranged from 1.36 to 14.7 g/L (Amerine, 1954; Mattick & Rice, 1970; Rankine & Bridson, 1971; Ough *et al.*, 1972). Exceptionally high glycerol levels of 14.6 to 24.7 g/L were reported for botrytised German Trockenbeerenauslese and French Sauternes wines (Amerine, 1954).

Glycerol found in wine is mainly formed as a by-product of glycolysis by wine yeasts. However, in the case of *Bortrytis cinerea* infected grapes, significant amounts of glycerol can be found in grape must before fermentation, explaining the high levels of glycerol generally found in noble late harvest wines (Ribéreau-Gayon *et al.*, 1998). In yeast glycerol metabolism and glycerol itself play important roles in essential cellular processes, in particular, by maintaining the intracellular $NADH/NAD^+$ balance in conditions of low oxygen availability (Oura, 1977; Costenoble *et al.*, 2000) and by acting as a compatible solute for osmoregulation during hyperosmotic stress (Blomberg & Adler,

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1992; Nevoigt & Stahl, 1997; Scanes *et al.*, 1998). Several parameters, including pH, temperature, the nitrogen source and the yeast strain used in inoculated fermentations, have been shown to influence the final glycerol levels in small-scale laboratory fermentations (Scanes *et al.*, 1998). The ripeness of grapes and microbial flora on the grape berries were also reported to affect glycerol levels (Ribéreau-Gayon *et al.*, 1998).

A widely shared opinion among winemakers and other stakeholders in the wine industry suggests that glycerol contributes positively to wine quality, and several reports have reinforced this perception (Rankine & Bridson, 1971; Eustace & Thornton, 1987; Omori *et al.*, 1995; Ciani & Ferraro, 1998). In addition to contributing to sweetness when present in quantities above its threshold taste level of 5.2 g/L in wine (Hinreimer *et al.*, 1955), glycerol has been implicated in mouth-feel sensations by conferring "fullness" (also referred to as "viscosity" or "weight") to wine. Glycerol is also thought to improve the overall balance between alcoholic strength, acidity, astringency and sweetness, and hence is considered to confer a degree of roundness and smoothness on the palate (Hickinbotham & Ryan, 1948). Together with sugars, titratable acids, phenols, lactic acid and other minor components, glycerol is found in the total extract of wine and hence is associated with the characteristic full-bodied nature of wines with high extract values (Ribéreau-Gayon *et al.*, 2000).

To date no firm correlation has been established between glycerol and the adjudged wine quality due to insufficient experimental data. Based on the widespread perception that the quality of wines could be improved by increasing the glycerol levels, several attempts aimed at establishing procedures to increase the final levels in wine have been undertaken. These include the manipulation of fermentation conditions (Radler & Schütz, 1982; Gardner e*t al.*, 1993), the breeding of new wine yeast strains (Eustace & Thornton, 1987; Rainieri *et al.*, 1999; Prior *et al.*, 1999), the use of *Candida stellata* as fermentation starter cultures (Ciani & Ferraro, 1998) and re-directing carbon flux during wine yeast glycolysis using recombinant DNA techniques (Michnick *et al.*, 1997; Remize *et al.*, 1999; De Barros Lopes *et al.*, 2000). However, the impact of higher glycerol levels on the sensory evaluation of experimental wines has only been reported in a limited number of studies, and the wines containing increased glycerol levels were frequently judged less favourably than the control wines (Prior *et al.*, 2000; De Barros Lopes *al.*, 2000). Furthermore, the validity of extrapolating the conclusions of studies involving small-scale experimental wines to large-scale, commercially produced wines has not been established.

The relationship between glycerol concentrations and wine quality clearly needs to be reassessed. Here we report on the analysis of glycerol in a large number of commercial wines of adjudged quality. The data for the first time allow for statistically significant conclusions to be drawn regarding: (i) the distribution of glycerol levels in South African (SA) table wines (about which very little information has been published); (ii) the relationship between the glycerol levels and wine style, geographic origin, vintage, cultivar and the yeast strain used; (iii) the relationship between glycerol levels and adjudged wine quality; and (iv) the possibility of using the data of the glycerol analysis as a predictor of wine quality.

MATERIALS AND METHODS

Wine sample collection

Samples of 447 commercial SA wines were collected. Of these, 414 wines were entered for the SA Veritas competitions of 1999 (101 wines) and 2000 (313 wines). Each wine was judged by 7 judges and rated out of a possible total of 20. All the Veritas competition wines used in this study were medal-awarded. The respective medals were allocated based on the following scoring system: Bronze, a median of 13 or 14; Silver, a median of 15 or 16, or a median of 14 and three judges scoring the wine 15 or more; Gold, a median of 17, or a median of 16 and three judges scoring the wine 17 or more; Double-gold, 17 points or more allocated by 5 of the 7 judges.

In addition, 33 wines (23 red, 2 dry white, 3 off-dry white, 2 special late harvest and 3 noble late harvest wines) that had not been entered for the Veritas competition and were of ordinary quality were included. Where possible, samples from diverse winemaking regions in SA were selected. Wine samples were collected in sterile vials. Samples of the Veritas 1999 competition wines were obtained directly from wineries. The Veritas 2000 competition wines were sampled on the same day that the bottles were opened for judging. Commercial wines not entered for the Veritas competition were obtained from retail outlets and, in a limited number of instances, directly from the winemakers.

Wine sample storage

Samples were stored at 4°C until analysed. Aliquots of a selection of samples were assayed for their glycerol content within 48 h of sampling. These values were used for reference purposes to monitor the effect of long-term storage of the samples on the glycerol concentrations.

Data collection procedures

Data from the routine chemical analyses for ethanol, residual sugar, titratable acidity and pH of the Veritas competition wines were obtained by means of a questionnaire sent to the winemakers of the respective wine cellars. Routine chemical analyses were conducted according to accepted reference methods (Amerine & Ough, 1980) and the values provided were those officially approved by the South African Wine and Spirit Board upon final certification of the wines. For a number of wines (n = 181), the information regarding the yeast strain used in inoculated fermentations was also obtained by means of the questionnaire.

Glycerol analyses

Glycerol in wine was determined by the enzymatic method (Roche, kit no. 0148270). A total reaction volume of 100 µL was used in microtiter plates. Absorbance at 340 nm was read with a Universal Microplate Spectrophotometer (µQuant model, Bio-Tek Instruments, USA). The relative standard deviation (also referred to as the coefficient of variation, CV) of duplicate determinations was < 3.5%. The accuracy of the enzymatic analyses was evaluated by means of a validation set of 35 wines of which the glycerol concentrations were also tested, with duplicate determination, using high-performance liquid chromatography (HPLC). A Dionex DX 500 system consisting of a Carbopac MA1 analytical column connected to a guard column (Dionex P/N 46122) was used, with 125 mM NaOH as eluent and a flow rate of 0.25 mL/min. For each sample in the validation set, the differences between mean values obtained using the enzymatic method and HPLC analyses were < 0.2 g/L. For the purposes of the statistical analyses only the data obtained with the enzymatic method were used.

Statistical Analyses

Using the analytical data obtained by the enzymatic method, one-way analysis of variance of glycerol concentration was performed to compare the wine styles. For significance tests a critical level of 5% was used and 95% confidence intervals were calculated, using a General Linear Model output by the MINITAB program (MINITAB Reference Manual, 1995). To assess the association between glycerol concentration and wine style together with the Veritas rating, two-way analysis of variance, applying the same model, was used. A variance stabilising transformation was applied to the data prior to analysis by taking the natural logarithms of the glycerol concentrations. The significance of the differences between the means of the $\log_e$(glycerol concentration) values was evaluated on the basis of Fisher intervals calculated by pair-wise comparisons of the respective means (Snedecor, 1967). Discriminant analysis, using the reference data for concentrations of glycerol, ethanol, reducing sugar, titratable acidity and the pH levels as predictors of wine quality, was done using a logistic regression model (Snedecor, 1967).

RESULTS AND DISCUSSION

Relationship between glycerol levels and wine style

Large differences between the mean glycerol levels of dry red (10.49 g/L), white (dry and off-dry wines, 6.82 and 6.55 g/L, respectively), special late harvest (8.26 g/L) and noble late harvest wines (15.55 g/L) were observed (Table 1). Notable was the wider range in glycerol levels, as reflected by the larger standard deviations, in the categories with greater means and the application of a variance stabilising transformation was considered necessary. One-way analysis of variance, using $\log_e$(glycerol concentration), showed a significant association between the mean glycerol concentrations and the wine style ($F = 285.82$; $P<0.005$, Table 1). Pair-wise comparisons of the means using $\log_e$(glycerol concentration) showed that the difference between the means of the dry white and off-dry white wines was not significant. However, the differences between the means of the dry red wines and both the dry white and off-dry white wines respectively were significant. Similarly, the differences between the means of the special late harvest wines and the noble late harvest wines were significant. The differences in the means of both types of late harvest wines and the means of both the dry white and off-dry wines respectively, were significant. No statistically significant association was found between the vintage and the glycerol levels (data not shown). For the purposes of the Veritas competition the white cultivars Chardonnay, Sauvignon blanc and Chenin blanc were entered in various sub-classes. These sub-classes distinguish between wines that have been matured in wood, unwooded wines and delicate-styled or full-bodied wines. No significant differences in the mean glycerol concentrations of the respective sub-classes were found (results not shown).

Relationship between glycerol levels and grape cultivar

The relationships between the mean $\log_e$(glycerol concentrations) and the Chardonnay, Chenin blanc and Sauvignon blanc cultivars within both the dry white ($F = 112.30$; $P<0.005$) and off-dry white wine styles ($F = 7.18$; $P = 0.006$) were significant (Table 2). In the case of the dry red wines the P-value was quite small ($F = 2.48$; $P = 0.062$), but slightly greater than the critical value of 0.05. The relationship between the mean glycerol levels and the cultivars of the dry red style, was therefore not significant. Pair-wise comparisons of the differences between the means of the respective cultivars showed that the Sauvignon blanc cultivar had a significantly lower mean glycerol level than those of either the Chardonnay or

TABLE 1

Glycerol levels in a selection of commercial South African table wines of various styles (vintage 1995 to 2000).

Style	No. wines	Glycerol g/L			$\log_e$(Glycerol concentration)	
		Mean	SD[(a)]	Range	Mean	SD[(a)]
Dry white (maximum sugar 4 g/L)[(b)]	158	6.82	0.91	5.21 – 9.36	1.911	0.130
Off-dry white (sugar 4.1-12 g/L)[(b)]	22	6.55	0.97	4.72 – 8.44	1.869	0.151
Dry red (maximum sugar 4 g/L)[(b)]	237	10.49	1.38	6.67 – 14.24	2.341	0.135
Special late harvest (maximum sugar 50 g/L)[(b)]	16	8.26	1.79	6.05 – 12.20	2.683	0.267
Noble late harvest (minimum sugar 50 g/L)[(b)]	14	15.55	3.39	9.81 – 20.21	2.091	0.205
$F(4, 442) = 285.82$; $P<0.0005$						

[(a)]Standard deviation.

[(b)]Specified according to Veritas classification.

Chenin blanc cultivars in both the dry white and off-dry white styles (Table 2). In the dry red style, Shiraz wines had a significantly lower mean glycerol level than the Cabernet Sauvignon, Pinotage or Merlot wines.

Taking the complexity of the factors that determine the final glycerol levels in wine into account, the data presented here are insufficient to establish the relationship between the glycerol levels and the wine cultivars *per se.* The association of lower glycerol levels with both Shiraz and Sauvignon blanc cultivars is nevertheless significant. In a set of 15 experimental Australian wines made from six grape cultivars, no clear relationship could be established between the cultivar and the glycerol content (Rankine & Bridson, 1971). Data on the relationships between glycerol levels and cultivars in commercial and experimental wines were found to be very limited in the literature and, to our knowledge, the data obtained by this research are the result of one of the first large-scale studies to report on this aspect.

Relationship between yeast strain and glycerol levels in commercial SA wines

Although the impact of the yeast strain on final glycerol levels in laboratory fermentations and experimental wines has been documented in several studies (Scanes *et al.*, 1998; Prior *et al.*, 1999; Remize *et al.*, 2000), very little information has been published on possible relationships between the yeast strain used in inoculated industrial wine fermentations and the final glycerol levels in commercial wines. In this study data on the yeast strains used for inoculation were obtained by means of a questionnaire sent to the respective winemakers of an arbitrary set (n = 450) of 1999 Veritas competition wines. A relatively large proportion of these wines (24%) was produced by blending separate lots of must fermented by different yeast strains to obtain the required final style. Thirty different yeast strains were used in the production of the wines represented by this sample set, of which at least 20 different strains were used for the production of white wines (data not shown). These practices are in line with the worldwide trend towards increased diversity in white wine styles (Ribéreau-Gayon *et al.,* 2000). Commercial yeast strains represented at the highest frequencies (in wines inoculated with a single yeast strain) were WE372 (30%), WE14 (5%), VIN13 (14%) and Lalvin D47 (6%).

Due to the somewhat uneven representation of some of the yeast strains (notably WE14 and Lalvin D47) in this sample set, only conditional conclusions could be drawn about the possible relationship between the inoculated yeast strain and the final glycerol levels in the commercial wines. Nevertheless, in the case of the wine yeasts WE14 and WE372 used for red wine production, no significant relationship between the yeast strain and the mean glycerol concentration, using $\log_e$(glycerol concentrations), was found (F = 2.20; P = 0.14, Table 3). The difference between the mean glycerol levels associated with the yeast strains was also not significant. Similarly, for the wine yeasts VIN13 and Lalvin D47 used for white wine production, no significant relationship between the yeast strain and the mean glycerol concentrations associated with these yeast strains was found (F = 2.73; P = 0.11). The difference between the mean glycerol levels was also not significant. A striking observation, however, was the relatively large range of glycerol levels in wines produced by particularly WE372 (7.10 to 14.24 g/L) and VIN13 (5.30 to 9.32 g/L). In comparison, small-scale laboratory fermentations in synthetic must (20% glucose, 25°C) yielded final glycerol concentrations of 4.80 ± 0.42

TABLE 2

Glycerol levels in a selection of commercial South African table wines of various cultivars (vintage 1995-2000).

Style/Cultivar	No. wines	Glycerol g/L			$\log_e$(Glycerol concentration)	
		Mean	SD[(a)]	Range	Mean	SD[(a)]
Dry white						
Chardonnay	88	7.08	0.94	5.31 – 9.36	1.949	0.131
Sauvignon blanc	44	6.31	0.65	5.21 – 8.20	1.837	0.098
Chenin blanc	26	6.81	0.86	5.20 – 8.17	1.910	0.130
F(2 , 155) = 112.30; P<0.005						
Off-dry white						
Chardonnay	4	7.03	0.75	6.39 – 7.86	1.946	0.107
Sauvignon blanc	5	5.42	0.51	4.72 – 6.10	1.686	0.095
Chenin blanc	10	6.85	0.92	5.18 – 8.44	1.917	0.136
F(2 , 16) = 7.18; P = 0.006						
Dry red						
Pinotage	53	10.46	1.28	7.25 – 13.37	2.339	0.124
Merlot	24	10.62	1.46	7.47 – 14.24	2.354	0.135
Cabernet Sauvignon	79	10.81	1.24	7.47 – 14.00	2.374	0.115
Shiraz	58	10.22	1.51	6.67 – 13.65	2.313	0.154
F(3 , 210) = 2.48; P = 0.062						

[(a)]Standard deviation.

g/L (n = 3) for strain VIN13 and 5.11 ± 0.39 g/L (n = 3) for strain WE372 (manuscript in preparation). This observation highlights some of the possible difficulties in attempts to manipulate the final levels of glycerol in large-scale fermentations. It is also evident that care should be taken when extrapolating data obtained from controlled laboratory fermentations to those of industrial fermentations. The fairly high upper glycerol levels reported in the fermentations represented in Table 3 should also be taken into consideration in studies aimed at the development of yeast strains that produce elevated levels of glycerol.

Relationship between the winemaking region and glycerol levels

Wine estates (n = 52), private cellars (n = 61) and co-operative cellars (n = 28) were included in this selection. Results indicated that the winemaking region was not significantly associated with the mean log_e(glycerol concentrations) in either the dry and off-dry white wines (F = 0.10; P = 0.96, Table 4) or the dry red wines (F = 0.59; P = 0.62). Pair-wise comparisons of the means showed no significant differences between the mean glycerol concentrations of the wines of the various winemaking regions for both the white wine styles and the dry red style. Very small sample sets of red and white table wines from diverse winemaking regions such as Cederberg, Benede-Oranje, Tulbagh, Overberg and Jacobsdal were also analysed for their glycerol levels (data not shown). Mean glycerol levels in wines from these areas were similar to the values reported for the respective styles produced in the areas listed in Table 4.

Relationship between wine quality and glycerol levels

Table 5 shows the range of the glycerol levels for the gold- (including double-gold), silver- and bronze categories of the Veritas ratings within the major wine styles. Relatively few wines of the various wine styles received gold- or double-gold awards and the ratings of these two groups were combined. Two-way analysis of variance derived from a General Linear Model, with

TABLE 3

Relationship between yeast strain and glycerol levels in commercial South African wines.

Wine style	Yeast strain	No. wines	Glycerol g/L			loge(Glycerol concentration)	
			Mean	SD[(a)]	Range	Mean	SD[(a)]
Dry red	WE372[(b)]	56	10.45	1.36	7.10 – 14.24	2.338	0.131
	WE14[(b)]	9	11.07	0.43	10.48 – 11.60	2.403	0.039
F(1 , 63) = 2.20; P = 0.14							
Dry and off-dry white	Lalvin D47[(c)]	10	7.36	0.71	6.28 – 8.38	1.991	0.098
	VIN13[(b)]	26	6.81	1.04	5.30 – 9.32	1.907	0.148
F(1 , 34) = 2.73; P = 0.11							

[(a)]Standard deviation.

[(b)]Commercial active dry yeast produced by Anchor Yeast.

[(c)]Commercial active dry yeast produced by Lallemand.

TABLE 4

Distribution of glycerol levels in 1999 and 2000 Veritas competition wines from different winemaking districts.

Wine style (number of wines)	Glycerol g/L			log_e(Glycerol concentration)	
Dry and off-dry white	**Mean**	**SD[(a)]**	**Range**	**Mean**	**SD[(a)]**
Robertson (n = 27)	6.78	0.86	5.42 – 8.80	1.907	0.124
Paarl/Franschoek/Wellington (n = 46)	6.23	0.62	4.82 – 6.91	1.909	0.148
Stellenbosch/Helderberg (n = 69)	6.86	0.86	5.21 – 8.90	1.918	0.127
Coastal (n = 14)[(b)]	6.92	0.89	5.42 – 8.23	1.927	0.133
F(3 , 152) = 0.10; P = 0.96					
Dry red					
Robertson (n = 14)	10.89	0.89	9.84 – 12.67	2.385	0.080
Paarl/Franschoek/Wellington (n = 61)	10.48	1.39	6.98 – 14.24	2.340	0.135
Stellenbosch/Helderberg (n = 102)	10.43	1.38	6.62 – 13.65	2.335	0.137
Coastal (n = 10)[(b)]	10.46	1.34	8.87 – 13.64	2.340	0.120
F(3 , 183) = 0.59; P = 0.62					

[(a)]Standard deviation.

[(b)]Producing cellars in the Constantia, Tokai, Cape Point and Hermanus areas are included.

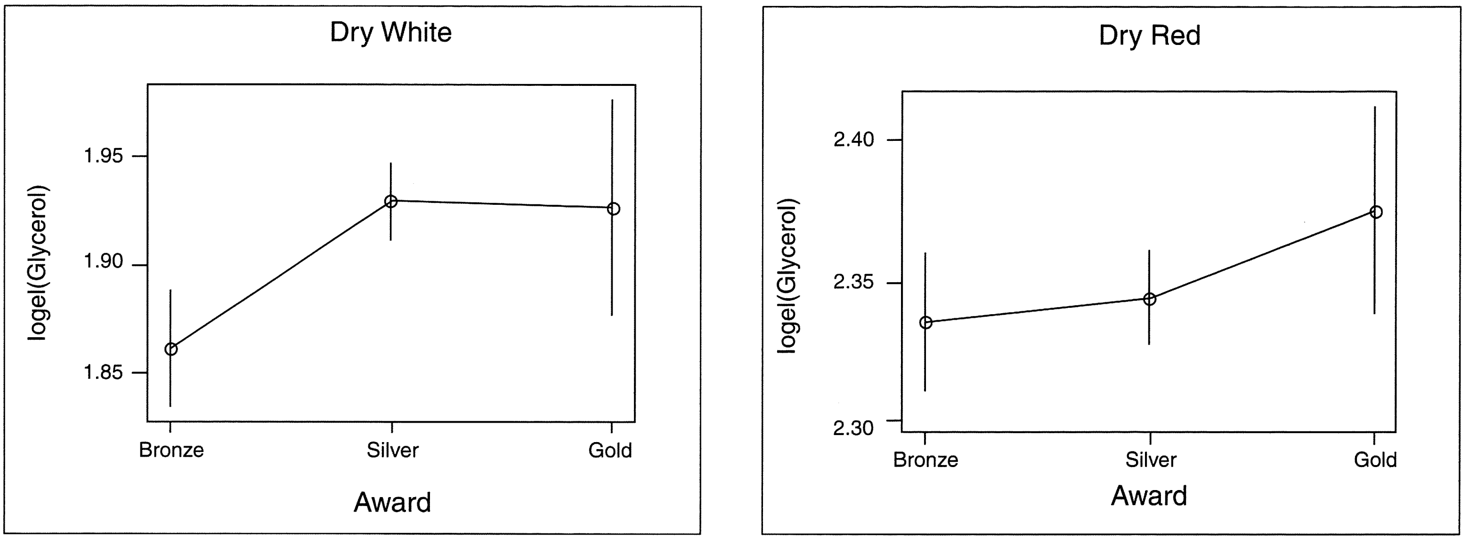

FIGURE 1

Significance of the relationship between the Veritas rating and glycerol levels.

interaction between the Veritas rating and the wine style, showed a significant relationship between the mean $\log_e$(glycerol concentration) and both the Veritas rating and the wine style, but the interaction effect, however, was not significant (Table 6A). A repeat of the analysis using the same model with no interaction confirmed the significant relationship between glycerol levels and both wine style and Veritas rating (Table 6B). The significance of the differences between the means of $\log_e$(glycerol concentrations) of the bronze-, silver- and gold ratings in the respective styles was evaluated on the basis of t-statistics obtained through

TABLE 5

Relationship between glycerol concentration and adjudged wine quality in a selection of 1999 and 2000 commercial South African wines.

Style	Veritas rating	No. wines	Glycerol g/L			$\log_e$(Glycerol g/L)	
			Mean	SD[a]	Range	Mean	SD[a]
Dry white	Bronze	44	6.47	0.72	5.21 – 8.17	1.879	0.111
	Silver	99	6.95	0.93	5.20 – 9.36	1.919	0.134
	Gold[b]	13	6.93	0.96	5.77 – 9.32	1.948	0.139
	Not entered	2	7.48	1.87	6.16 – 8.80	n.a.	n.a.
Off-dry white	Bronze	12	6.32	1.11	4.72 – 8.44	1.846	0.176
	Silver	6	6.78	0.85	5.46 – 7.86	1.886	0.125
	Gold[b]	1	7.24	n.a.	n.a.	1.915	n.a.
	Not entered	3	6.77	0.65	6.06 – 7.34	n.a.	n.a.
Dry red	Bronze	59	10.44	1.40	6.67 – 14.24	2.100	0.133
	Silver	129	10.53	1.40	6.67 – 13.84	2.140	0.133
	Gold[b]	26	10.82	1.15	8.04 – 13.47	2.169	0.106
	Not entered	23	9.90	1.47	6.78 – 12.65	n.a.	n.a.
Special late harvest	Bronze	7	7.64	0.85	6.08 – 8.48	2.644	0.111
	Silver	6	8.94	2.03	6.98 – 12.20	2.684	0.227
	Gold[b]	1	10.93	n.a.	n.a.	2.713	n.a.
	Not entered	2	6.40	0.50	6.05 – 6.76	n.a.	n.a.
Noble late harvest	Bronze	3	14.86	4.50	11.68 – 18.04	2.314	0.302
	Silver	4	15.62	2.14	13.39 – 18.43	2.354	0.137
	Gold[b]	4	16.37	4.57	9.81 – 20.21	2.383	0.279
	Not entered	3	14.84	4.25	10.11 – 18.32	n.a.	n.a.

[a]Standard deviation.

[b]Gold- and double-gold awarded wines are combined.

TABLE 6A

Analysis of variance for $\log_e$(Glycerol concentration) with a General Linear Model with interaction between Veritas rating and wine style.

Effect	DF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Veritas rating	2	0.911	0.162	0.081	4.22	0.015
Wine style	4	21.238	13.302	3.326	173.54	0.000
Veritas* Style	8	0.191	0.191	0.024	1.25	0.269
Error	399	7.646	7.646	0.019		
Total	413	29.986				

TABLE 6B

Analysis of variance for $\log_e$(Glycerol concentration) with a General Linear Model with no interaction between Veritas rating and wine style.

Effect	DF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Veritas rating	2	0.911	0.195	0.098	5.07	0.007
Wine style	4	21.238	21.238	5.309	275.72	0.000
Error	407	7.837	7.837	0.019		
Total	413	29.986				

pair-wise comparisons of the differences between means. The t-statistics were calculated as the ratios of difference/standard error with 407 degrees of freedom and expressed at level 0.05. These comparisons indicated that, in the case of the dry white and off-dry white wines, the differences in mean glycerol levels between the bronze- and both the silver- and gold rated wines were significant. The differences in mean values for the silver- and gold-rated wines in these two wine styles were, however, not significant. For the dry red wines the differences between mean glycerol levels of the bronze-, silver- and gold-rated wines were not significant. The relationships between the Veritas rating and glycerol concentrations in the dry red and the dry white wines are graphically presented in Fig. 1. Error bars have been calculated so that the non-overlap of any two of them indicates statistical significance at level 0.05. The observation that there was no significant difference in glycerol levels between the wines with either a silver or gold rating in the Sauvignon blanc, Chenin blanc or Chardonnay cultivars does not support the widely held perception that higher levels of glycerol could improve the quality of these wines. In the case of the special late harvest and noble late harvest wines, the differences in means between bronze- and silver-rated wines and that between silver- and gold-rated wines were significant in both cases. In view of the relatively high sugar concentrations of these wines, this result could imply that glycerol plays an indirect role in contributing to the overall quality of these wine styles.

In addition to the wines from the Veritas competition, 33 other commercial wines of ordinary quality were also tested for their glycerol content. Data obtained using this sample set were not subjected to statistical analysis due to the relatively small sample numbers and these wines were considered merely for comparative purposes. No major differences between the observed mean glycerol concentrations of the various styles represented by this group and those of the corresponding styles of the Veritas competition wines were found (Table 5).

TABLE 7

Chemical analyses of Veritas-awarded dry white SA wines.

Veritas rating	No. samples	Component	Mean	Range
			g/L	g/L
Bronze	27	RS[(a)]	2.26 ± 0.69	1.20 – 4.00
		pH	3.37 ± 0.16	3.11 – 3.62
		TA[(b)]	6.20 ± 0.78	4.90 – 8.10
Silver/Gold[(c)]	81	RS[(a)]	2.57 ± 0.79	1.20 – 4.00
		pH	3.41 ± 0.16	3.12 – 3.84
		TA[(b)]	6.27 ± 0.68	4.40 – 8.10

[(a)]Residual sugar.
[(b)]Titratable acidity.
[(c)]Silver-, gold- and double-gold rated wines are pooled.

Discriminant analysis of glycerol as predictor of wine quality

The possibility of using the analytical data for glycerol and the reference values of the routine wine analyses to predict wine quality in the dry white style was tested. For this purpose a sample set of 101 wines was used, and the data for the gold- and silver-rated wines were pooled, based on the finding that the glycerol levels for these two groups did not differ significantly. The application of a mathematical regression, using the glycerol concentration in combination with the levels of either ethanol, titratable acidity, pH, or residual sugar, to predict either a bronze or silver/gold Veritas rating, identified only glycerol in combination with pH as significant predictors of quality in the sample set used. The linear discriminant equation was determined as:

Veritas award = -1.8867 + 0.1105[Glycerol] + 0.5748pH, which could be used to calculate the predicted Veritas award (either bronze or silver/gold) correctly in 78 out of the 101 wines used for this analysis by assigning a "cut-off" value of 0.7118 to "Veritas Rating". This function, however, should be treated with some caution, since the same sample set was used for the determination as well as the validation of the equation. Furthermore, the equation has only been tested for the mentioned components in the concentration ranges specified in Table 7. Clearly the use of an independent validation set, the inclusion of data for more chemical components, particularly the volatile components, as well as a wider concentration range for the components of interest, could add to the future applicability and usefulness of such a discriminant function.

CONCLUSIONS

In this study a large-scale investigation of the glycerol levels in Veritas-awarded commercial SA wines was undertaken. This approach facilitated the statistical analysis of the range of glycerol concentrations in wines of different styles, as well as the possible relationships between cultivar, geographic origin and the most commonly used yeast strains and the glycerol levels. All judgements on wine quality are necessarily subjective. The large number of wines submitted for the Veritas competition and the relatively constant and consistent tasting conditions provided an opportunity to assess the possible relationships between glycerol concentration and wine quality, and to evaluate the commonly held perceptions regarding glycerol and wine quality against the industrial background of market-ready wines.

Results obtained in this study indicated that the mean glycerol concentrations found for the red table wines were higher than those of the white table wines. A similar trend was found for the respective styles in wines from California (Ough *et al.*, 1972), New York State (Mattick & Rice, 1970) and Australia (Rankine & Bridson, 1971). Mean glycerol levels for SA red wines were comparable to red wines from New York State (9.4 g/L) and California (10.6 g/L), but were considerably higher than those reported for Australian red wines of the Claret type (7.7 g/L) and Burgundy type (8.0 g/L). In the case of white wines the mean values for SA wines were lower than those reported for New York State (7.6 g/L) and German dry table wines (7.7 g/L), but higher than those found in Australian Hock types (5.5 g/L) and Californian white table wines (4.8 g/L). The mean glycerol values found in SA white wines in an earlier limited study (Venter, 1955) were higher than the values reported here for the white wines (7.8 g/L versus 6.8 g/L). A similar situation was observed in Californian white wines (9.6 g/L in 1954 versus 4.8 g/L in 1972). In the SA wine industry glycerol is not routinely determined for the analyses of commercial wines. Wines destined for the export market, however, are increasingly subjected to analysis additional to the standard requirements, including glycerol analysis. This is in line with the growing tendency for governments to adopt maximum and minimum acceptable limits for various constituents to ensure quality control. The data presented here could prove to be valuable in establishing the glycerol concentrations normally associated with the respective styles investigated.

Results obtained established statistically significant relationships between glycerol concentrations and adjudged wine quality for the dry white, off-dry white and special late harvest and noble late harvest wine styles. In both the dry white and off-dry white wines, however, the differences between the mean glycerol concentrations of the wines with a silver rating and wines with a gold or double gold rating were not significant. For these styles, therefore, this result implies that the wine quality of the SA Chardonnay, Chenin blanc or Sauvignon blanc cultivars is unlikely to be improved by increased glycerol levels alone. The observed differences between the mean values of the different quality ratings, however, were small. This observation, together with the relatively large range in glycerol levels found in most styles, could diminish the practical value of the statistical relationship and highlights the difficulties that could be encountered in attempts to control the final glycerol levels in large-scale industrial fermentations. Nevertheless, the sensory profile of each wine is unique and this therefore does not imply that an individual wine could not benefit from increased glycerol levels.

In reassessing the contribution of glycerol to wine quality, several recent reports in the literature on this topic should be mentioned. Some prominent enologists have expressed reservations on the emphasis that should be placed on the organoleptical role of glycerol in wine (Zoecklein, 1995; Ribéreau-Gayon *et al.*, 1998). Factors other than glycerol concentration have been implied in the mouth-feel properties of wine, including the ethanol concentration (Pickering *et al.*, 1998), barrel maturation, yeast autolysis, certain yeast cell wall mannoproteins (Ribéreau-Gayon *et al.*, 1998), and the balanced sensory profile associated with certain yeasts (Delteil & Jarry, 1992). In relating the instrumental measurement of the contribution of glycerol to viscosity in wine, tasters reported that a minimum value of 25.8 g/L was necessary for perception (Noble & Bursick, 1984). The impact of ethanol concentration on the increase in viscosity, however, was not taken into account by these authors. In view of the fact that the glycerol content in wine is only 7 to 10% of that of ethanol in the dry and off-dry table wines (Rankine & Bridson, 1971), the impact of glycerol on perceived viscosity is probably negligible. It should be borne in mind, however, that thresholds are merely statistically determined endpoints that could be influenced by a variety of factors causing fluctuations (Trant and Pangborn, 1983). Therefore predictions made about threshold values for the levels of glycerol required for the optimum perceived contributions to the organoleptic characteristics in wine will be open for debate and should be retested at regular intervals.

Several aspects regarding the contribution of glycerol to wine quality must still be clarified and future work should include the establishment of a workable definition of "body" in wine (which to date does not exist) and the evaluation of glycerol as an impact factor in conferring a smooth mouth-feel. Furthermore, the establishment of the precise nature of the contribution of glycerol to wine quality through descriptive aroma analyses, as well as by means of an investigation into the possible indirect effects of glycerol on wine quality through physical/chemical interactions between glycerol and other flavour constituents in wine, requires further investigation.

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