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Investigating the effect of glycerol and selected additives on the taste, mouthfeel, and perceived quality of de-alcoholised wine

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ABSTRACT

The de-alcoholised wine category has undergone substantial growth in recent years, with consumers increasingly moderating their alcohol intake. The growing preference for products with reduced alcohol content reflects a broader shift toward health, wellness, and social responsibility. However, consumer acceptance of de-alcoholised wines remains limited by the perception of their inferior sensory quality compared to traditional wine, particularly with respect to mouthfeel, body, and balance. This study investigated the impact of glycerol, gum Arabic, and mannoproteins on the taste, mouthfeel, and overall quality of de-alcoholised wine across two experiments. In Experiment 1, four glycerol treatments were applied to de-alcoholised Sauvignon blanc to achieve final concentrations of 0, 20, 34, and 57 g/L. Sensory evaluation was conducted by a panel of nine industry experts using free listing (FL) methodology and a 20-point overall quality scoring system. Results revealed that increasing glycerol concentration from 7 to 34 g/L significantly enhanced perceived quality, mouthfeel, balance, and complexity, with 34 g/L identified as the optimum concentration. In Experiment 2, a reduced treatment combination design was used to evaluate de-alcoholised Chenin blanc and Shiraz wines containing different combinations of glycerol (no glycerol addition and a final glycerol concentration of ± 38 g/L), mannoproteins (0, 50, and 150 mL/hL), and gum Arabic (0, 200, and 350 mL/hL). Fifteen industry experts evaluated seven mouthfeel attributes using a modified rate-all-that-apply (RATA) methodology. Treatment combinations containing higher glycerol concentrations were associated with increased ratings for body, length, balance, and sweetness in both wine styles, while no clear sensory differences were observed among treatments containing varying concentrations of mannoproteins and gum Arabic. Overall, these findings demonstrate that glycerol addition is an effective tool for improving the sensory properties of de-alcoholised wine and may help guide global regulatory frameworks governing de-alcoholised wine production.

KEYWORDS: mouthfeel, taste, de-alcoholised wine, glycerol, body, quality

INTRODUCTION

The global non-alcoholic wine market is expected to grow at a compound annual growth rate of 7.9 % from 2024 to 2030, reaching up to $3.78 billion (Grand View Research, 2024). This rapidly increasing segment reflects changing consumer preferences toward healthier lifestyles and mindful consumption (Deroover *et al.*, 2021; Kumar *et al.*, 2024). However, despite these positive market trends, consumer acceptance of de-alcoholised wines remains limited by the perception of their inferior sensory quality compared to traditional wine.

De-alcoholised wine is often characterised by reduced balance, body, and mouthfeel due to the loss of ethanol and its impact on other non-volatile compounds (Mangindaan *et al.*, 2018). Ethanol plays a significant role in the sensory properties of wine by eliciting hotness, viscosity, body, and sweetness perceptions (Ickes & Cadwallader, 2017). Furthermore, the removal of ethanol is typically accompanied by a reduction of approximately 15 to 20 % of the wine's final volume, which can increase the concentration of non-volatile compounds (Schmitt *et al.*, 2023a; Afonso *et al.*, 2025). This often results in increased acidity and astringency perception, culminating in unbalanced sensory profiles (Ma *et al.*, 2022). For example, De-La-fuente-blanco *et al.* (2024) found that alcohol reduction in both white and red model wines below 5 % *v/v* resulted in considerable unbalanced sensory profiles, characterised by excessive sourness. This effect becomes even more pronounced when aiming for less than 0.5 % *v/v* alcohol in de-alcoholised wine, significantly hindering consumer acceptance in this category.

As a result, de-alcoholised wine producers have turned their attention to the use of additives to restore the sensory properties lost by alcohol removal. To mitigate the increased acidity commonly associated with de-alcoholised wine, sugar is frequently added to enhance and regain balance, subsequently improving the overall sensory profile (Schmitt *et al.*, 2023b). Sweetening in de-alcoholised wine can either be done using fructose, sucrose, or grape must, depending on regulatory limits and the desired sensory outcome. According to Podworny *et al.* (2024), sweetening de-alcoholised Chardonnay with 40 g/L rectified grape must concentrate significantly increased consumer liking and acceptability, compared to samples that received lower additions. Additionally, the use of mannoproteins and gum Arabic has been shown to reduce astringency and soften harsh tannins in red wine, while improving body and overall mouthfeel (Rinaldi *et al.*, 2021). Furthermore, the strategic addition of oenological grape- and wood-derived tannins can enhance mouthfeel, offering increased body and complexity in wine (Ben Aziz *et al.*, 2024). The loss of mouthfeel and body, caused by the removal of ethanol, can be counterbalanced using glycerol. In South Africa, glycerol addition is a widely used tool to compensate for the sensory deficits associated with alcohol removal. Glycerol is usually present in table wines at concentrations ranging from 4 to 12 g/L (Nieuwoudt, 2002; Goold *et al.*, 2017). From a sensory perspective, glycerol contributes to body, viscosity, and sweetness perception in wines, especially when levels are increased beyond those normally found in wine (Paissoni *et al.*, 2023). According to Zhao *et al.* (2015), in full-strength wine, glycerol concentrations greater than 5.2 g/L result in an increase in perceived sweetness, whereas glycerol concentrations above 25 g/L increase perceptible viscosity. However, at the glycerol concentrations typically found in commercial full-strength wines, the practical contribution of glycerol to perceived viscosity and overall wine quality is limited (Noble & Bursick, 1984; Nieuwoudt, 2002). The sensory impact of glycerol is therefore likely more pronounced in de-alcoholised wine, where ethanol, which normally masks or modulates glycerol's sensory contribution, is largely absent. That said, the sensory impact of glycerol is matrix-dependent, varying according to the chemical composition of each wine (Zhao *et al.*, 2015). While the use of additives shows promising results for improving the overall sensory acceptability in de-alcoholised wine, tailored additive strategies and specific interaction effects between additives remain relatively unexplored in current literature. This is particularly evident with regard to the addition of glycerol to de-alcoholised wines.

Since glycerol is a potentially valuable tool to improve the taste and mouthfeel of de-alcoholised wines, it is essential to investigate the extent of its contribution to the overall sensory perception of these wines. With this background, this study aimed to explore the impact of glycerol addition on the taste and mouthfeel of de-alcoholised wine.

MATERIALS AND METHODS

1. General materials and methods

This section outlines the materials and methods that were consistent across all experiments. Experiment-specific details, including wine types, chemical analyses, sensory panel composition, sensory evaluation, and additive treatments, are discussed thereafter.

1.1. Wine sourcing and de-alcoholisation process

All base wines used in this study were obtained from BevZero (Paarl, South Africa), a commercial de-alcoholisation company. Although each experiment used different base wines available at the time, all wines were de-alcoholised using a Flavourtech Spinning Cone Column (SCC) (Flavourtech Pty Ltd, Griffith, New South Wales, Australia) installed and operated by BevZero. The SCC had a maximum nominal capacity of 10,000 L/h and operated under vacuum at temperatures ranging from 30 to 40 °C (Flavourtech, 2024). The system was fully automated, ensuring reproducibility and control.

1.2. Chemical analysis methods

1.2.1. pH and titratable acidity (TA)

For pH and titratable acidity (TA) analysis, a 50 mL wine sample was titrated using a 702 SM Metrohm auto-titrator combined with a 760-sample changer and a 722 stirrer (Metrohm SA (Pty) Ltd, Johannesburg, South Africa). The sample was titrated to pH 7 using 0.33 N sodium hydroxide (NaOH, KIMIX, Cape Town, South Africa) as a titration standard. Subsequently, the volume of NaOH used to titrate the wine was used to calculate pH and TA. All samples were analysed in duplicate (n = 2).

1.2.2. Alcohol, glycerol, sugar, and organic acid analysis

Ethanol, glycerol, sugars, and organic acids were analysed using high-performance liquid chromatography (HPLC, Agilent Technologies, Waldbronn, Germany), following the method described by Eyéghé-Bickong *et al.* (2012), with modifications to sample preparation and standard handling. A glycerol standard solution was prepared by dissolving 0.5 g of food-grade glycerol (Merck Life Science, Johannesburg, South Africa) in 25 mL of deionised water (dH_2O). For sample preparation, 400 µL of sample was diluted with 600 µL of deionised water and 1 mL of a single mixed internal standard solution containing ribitol and adipic acid at a combined concentration of 4 g/L (2 g/L of each compound). The final volume of 2 mL resulted in a 5 × dilution of the original sample and final concentrations of 1 g/L ribitol and 1 g/L adipic acid. Ribitol was used as the internal standard for ethanol, glycerol, and sugars detected by refractive index detection, whereas adipic acid was used as the internal standard for organic acids detected at 210 nm. Both standards were chromatographically resolved from the target analytes and were used to normalise the measured analyte concentrations (Eyéghé-Bickong *et al.*, 2012). Samples were centrifuged at 8400 g for 5 min to ensure proper separation. Following centrifugation, 1 mL of the supernatant was transferred into HPLC vials and crimp-sealed prior to analysis. Samples were analysed in triplicate or as specified to confirm whether required treatment concentrations were achieved.

The HPLC was performed using an Agilent 1100 Series HPLC system (Agilent Technologies, Waldbronn, Germany) equipped with a diode array detector (DAD) and a refractive index detector (RID). Separation was achieved using a Bio-Rad Aminex HPX-87H ion exchange column (300 mm × 7.8 mm, 3.5 µm particle size), protected by a Bio-Rad Aminex guard cartridge (23 mm × 10 mm, 3.5 µm). The mobile phase consisted of 5 mM sulfuric acid (H_2SO_4) in water, run isocratically at a flow rate of 0.5 mL/min for 39 minutes. Column temperature was maintained at 55 °C, and the injection volume was 10 µL (Eyéghé-Bickong *et al.*, 2012). Organic acids were monitored using UV detection at 210 nm, while sugars and alcohols were detected using RID. Peak integration and calibration were performed manually using the prepared standards, with data acquisition and processing carried out using ChemStation Rev. A.10.02 software (Agilent Technologies©).

1.3. Sensory panel and evaluation

Sensory evaluations were conducted using panels of industry experts, with panel composition and specific protocols detailed under each experiment. Each panellist was seated in an individual sensory booth to minimise bias and ensure consistent evaluation conditions. Wine samples were served at room temperature (20 ± 2 °C) in 25 mL portions using standard ISO tasting glasses (ISO 3591, 1977). To prevent positional bias, the presentation order of the samples was randomised for each panellist by means of a William–Latin square design, and a 10 to 15 min break was provided between flights to reduce sensory fatigue. Each treatment was evaluated in duplicate to enhance the reliability and reproducibility of the sensory data. For sample identification, each wine was assigned a unique three-letter code, ensuring blind tasting conditions. Ethical clearance was obtained from the REC: Social, Behavioural and Education Research Ethics Committee at Stellenbosch University (FESCAGRI-2025-3007).

1.4. Statistical analysis

The sensory data were collected using Compusense® cloud software (Compusense, Guelph, Canada) and exported to Microsoft Excel 2023 (Microsoft Corporation, Redmond, Washington, USA). Univariate and multivariate statistical analysis was conducted using TIBCO Statistica™ Software 14.0.0.15 (TIBCO Software Inc., Palo Alto, California, USA). Mixed model analysis of variance (ANOVA) type III was performed with "judge" as a random effect and "treatments" and "replicates" as fixed effects. To account for mixed effects, the Kenward–Roger test was used to adjust the degrees of freedom (Luke, 2017). Fisher's LSD *post-hoc* test was used to compute pairwise comparisons between the least squares (LS) means of the treatments with $p \leq 0.05$.

2. Experiment 1: impact of glycerol on the mouthfeel of de-alcoholised wine

2.1. Wine sourcing

The wines used in this experiment were sourced from BevZero (Paarl, South Africa), a commercial de-alcoholisation facility. The trial aimed to investigate whether glycerol addition has a perceivable and positive impact on the mouthfeel of de-alcoholised wine. Two fractions of Sauvignon blanc were obtained, including the full-strength (FS) wine prior to de-alcoholisation, as well as the de-alcoholised wine fraction containing essence. Table 1 summarises the wine parameters of the Sauvignon blanc before and after de-alcoholisation.

2.2. Wine treatments and glycerol adjustments

To assess the impact of glycerol on mouthfeel, the de-alcoholised wine fraction underwent four treatments with varying glycerol concentrations. Due to the typically high acidity and low residual sugar (RS) levels found in de-alcoholised wine, a standard addition of 30 g/L crystal grape must (Naturalia Ingredients, Mazara del Vallo, Italy)

was made to each sample prior to glycerol (Glycerin Food Grade, Pound Chemicals, Paarl, South Africa) adjustments. Glycerol additions were prepared at 0, 1, 2, and 4 % *v/v*, corresponding to target final glycerol concentrations.

The following target glycerol concentrations were applied:

- Treatment 1: No glycerol addition
- Treatment 2: Final glycerol concentration of 20 g/L
- Treatment 3: Final glycerol concentration of 35 g/L
- Treatment 4: Final glycerol concentration of 57 g/L

TABLE 1. Sauvignon blanc wine parameters before and after de-alcoholisation.

Parameter	Before de-alcoholisation	After de-alcoholisation
pH	3.82	3.73
TA (g/L)	5.94	6.42
VA (g/L)	0.40	0.60
Glycerol (g/L)	5.26	7.23
RS (g/L)	3.02	2.10
Alcohol (% *v/v*)	12.64	0.44

2.3. Sensory panel

A panel of nine de-alcoholised wine and production specialists (six male and three female), aged 32–59 years and with previous experience evaluating de-alcoholised wines, were invited via email to participate in the sensory evaluation.

2.4. Sensory evaluation

Sensory evaluations assessed mouthfeel, taste, and overall quality differences between de-alcoholised Sauvignon blanc wines subjected to different glycerol treatments. Each wine sample was evaluated in duplicate for free listing (FL) and quality scoring to ensure repeatable, consistent responses.

2.4.1. Free listing (FL) methodology

The free listing (FL) methodology was used to assess the sensory profile of each glycerol treatment (Vieira *et al.*, 2020). Panellists were instructed to describe the taste and mouthfeel attributes they perceived for each wine sample using a blank sheet of paper. There were no restrictions on the number or type of descriptors to be provided. Following the sensory evaluation, the handwritten responses were manually transcribed and exported to Microsoft® Excel 2023 (Microsoft Corporation, Redmond, Washington, USA) for data processing. When no descriptors were recorded for a modality, the term "no comment" was noted to maintain consistency in the dataset. To prepare the data for analysis, the dataset was first screened for Afrikaans descriptors and translated into English equivalents. Spelling and grammatical errors were then corrected to ensure accurate interpretation of responses. Finally, descriptors with overlapping or synonymous meanings were standardised to a single term to reduce redundancy and ensure consistency across panellists and replicates (Campo *et al.*, 2008). Table 2 provides an overview of how we standardised the original mouthfeel descriptors.

TABLE 2. Example of standardised taste descriptors from the original free listing (FL) text data.

Original mouthfeel descriptors	Standardised mouthfeel descriptors
lean, but fresh, falls a bit short and lacks mid-palate	poor mouthfeel, good acidity, low mid-palate, short length
thin, watery	poor mouthfeel
watery, diluted, poor mouthfeel	poor mouthfeel
low body and diluted	poor mouthfeel, low body

Thereafter, the standardised descriptors were grouped into broader sensory categories using a process known as lemmatisation. Lemmatisation reduces words to their base or root form and clusters similar terms (McLaughlin *et al.*, 2022). In the present study, descriptors considered synonymous or representative of the same sensory concept were assigned to a common sensory subcategory. For example, "watery", "thin", and "diluted" were grouped under "poor mouthfeel", as these terms indicated an overall negative perception of insufficient palate weight and mouthfeel intensity. We retained "low body" as a separate subcategory for descriptors that explicitly refer to body or closely related sensations, such as "light palate". When a response contained more than one distinct sensory concept, we retained each concept separately. Each descriptor was classified as positive, neutral, or negative, based on its evaluative contribution to the sensory profile (Campo *et al.*, 2008; Valentin *et al.*, 2021). The lemmatisation and classification were performed independently by two researchers. Differences were discussed until consensus was reached, and the agreed coding framework was then applied consistently across all panellists, treatments and replicates. This framework enabled a structured interpretation of the data and facilitated the identification of favourable and unfavourable attributes across treatments. Examples of sensory categories used and classifications are outlined in Table 3.

Not all descriptors were included in the lemmatisation and subsequent statistical analysis. Descriptors were excluded on two grounds. First, comparative descriptors that lacked standalone sensory meaning and were dependent on other samples, such as "sweeter than 160" or "more vegetal", were removed as they could not be interpreted in isolation. Second, entries consisting of illegible handwriting that could not be confidently transcribed were excluded.

2.4.2. Quality scoring

Each wine sample was evaluated using the overall 20-point quality scoring system, which is commonly applied in wine sensory analysis (Brand *et al.*, 2018). Panellists were instructed to assign scores for each sensory modality as follows: three points for appearance, seven points for aroma, and ten points for palate. All quality scores were recorded electronically using Compusense® Cloud Software (Guelph, Canada) and subsequently exported to Microsoft® Excel 2023 (Microsoft Corporation, Redmond, Washington, USA).

2.5. Statistical analysis

Sensory data were collected using Compusense® cloud software (Compusense, Guelph, Canada), exported to Microsoft Excel 2023, and analysed using TIBCO Statistica™ Software (version 14.0.0.15). Numerical quality comparison scores were analysed using mixed-model ANOVA type III. Glycerol treatment and replicate were specified as fixed effects, while panellist was included as a random effect to account for repeated evaluations. Denominator degrees of freedom were estimated using the Kenward–Roger approximation (Luke, 2017). When the ANOVA indicated a significant treatment effect, Fisher's least significant difference test was used for pairwise comparisons between treatment least squares means at $p \leq 0.05$. Results were presented as least squares means with 95 % confidence intervals.

The original free listing responses were summarised as citation frequencies before correspondence analysis. Correspondence analysis (CA) was performed using a 4 × 13 frequency table, in which the four rows represented the glycerol treatments and the 13 columns represented the sensory descriptor categories obtained after standardisation and lemmatisation. Each cell contained the total number of citations of a descriptor category for a particular treatment across panellists and replicates. The first two dimensions accounted for 78.92 % and 13.41 % of the total inertia, respectively, representing 92.33 % of the overall variation in the descriptor frequency data. CA was used as an exploratory technique to visualise associations between glycerol treatments and sensory descriptors.

3. Experiment 2: comparison of glycerol, gum Arabic, and mannoproteins

3.1. Wine sourcing and treatments

To investigate the effects of glycerol (Merck Life Science, Johannesburg, South Africa), mannoproteins (MANNOFEEL®, Laffort, Paarl, South Africa), and gum Arabic (STAVIN® SP, Laffort, South Africa) on the mouthfeel of de-alcoholised Chenin blanc and Shiraz wines, a reduced treatment combination design was used. Selected combinations of the three additives were evaluated at industry-relevant concentrations. The number of combinations was limited to reduce sensory fatigue and support reliable sensory evaluation. Each formulation was treated as a separate treatment, and the design was not used to estimate the independent main effects or statistical interactions of the three additives.

Glycerol was evaluated at two levels, namely no addition and a final addition of approximately 35 g/L. Mannoproteins (0, 50, and 150 mL/hL) and gum Arabic (0, 200, and 350 mL/hL) were evaluated at three levels. The levels for mannoproteins and gum Arabic were selected to represent no addition, an industry-recommended dosage, and a maximum dosage based on supplier guidelines. Glycerol dosages used for this experiment were determined based on findings from Experiment 1. A complete factorial design would have included 18 additive combinations. However, only 14 combinations were selected to limit the number of samples presented to panellists and reduce sensory fatigue. Each selected treatment was applied to both de-alcoholised Chenin blanc and Shiraz wines, with a standard addition of 30 g/L crystal grape must.

3.2. Sensory panel

Fifteen de-alcoholised wine and production specialists (10 male and 5 female), aged 27 to 50, participated in the sensory evaluation.

3.3. Sensory evaluation

A modified Rate-All-That-Apply (RATA) methodology was used to assess seven predefined taste and mouthfeel attributes: sweetness, sourness, bitterness, astringency, length, body, and balance (Vidal *et al.*, 2018). All attributes were presented for each sample, and panellists were required to provide a response for every attribute. A score of 0 indicated that the attribute was not perceived, while perceived attributes were rated on a five-point intensity

TABLE 3. Example of lemmatisation of the standardised mouthfeel text data and sensory categories used to group the text data.

Modality	Classification	Sensory subcategory	Free listing descriptors
Acidity	Positive	Good acidity	Tart; balanced TA/RS; good decent acidity
Acidity	Negative	Low acidity	Balance needs a bit of acidity
Balance	Positive	Good balance	Balanced TA/RS; ok acid balance; well balanced; good balance and concentration; balanced body
Balance	Negative	Unbalanced	No real balance; too rich and round; balance needs a bit of acidity
Body	Positive	Good body	Broad; broad palate; balanced body; softer and rounder; broad mouthfeel
Body	Neutral	Medium body	Some roundness and gentle body; medium body and roundness
Body	Negative	Low body	Low body; light palate
Complexity	Negative	Lacks complexity	Lacks complexity
Complexity	Positive	Complexity	Broad palate; broad

scale (1 = low, 3 = medium, and 5 = extremely intense), with scores of 2 and 4 representing intermediate intensity levels. The 0 response option distinguished attributes that were not perceived from unanswered items and ensured complete data capture. Each de-alcoholised wine sample was evaluated in duplicate.

3.4. Statistical analysis

A linear mixed model analysis of variance (ANOVA) with Type III sums of squares was performed for each sensory response. Treatment and replicate were included as fixed effects, while panellist was included as a random effect. Each panellist evaluated every treatment on two occasions, and both scores were retained as individual observations rather than averaged. Evaluation occasion was included to account for possible systematic differences between the first and second assessments, while the random panellist effect accounted for repeated observations from the same individual. The Kenward–Roger approximation was applied when testing the fixed effects in the mixed model (Luke, 2017). Fisher's least significant difference test was used for pairwise comparisons between treatment least squares means at $p \leq 0.05$.

To complement the mixed model ANOVA, principal component analyses (PCA) were performed for the de-alcoholised Chenin blanc and Shiraz wines using the correlation matrix. For each wine, the input matrix consisted of 14 rows representing the additive combinations and 7 columns representing the mean intensity scores for sweetness, sourness, bitterness, astringency, length, body, and balance. PCA biplots were used to explore relationships among the sensory attributes and to visualise similarities and differences in the sensory profiles of the additive combinations. For Chenin blanc, the first two principal components explained 74 % and 10 % of the total variance, respectively, representing 84 % cumulatively. For Shiraz, the first two principal components explained 76 % and 9 % of the total variance, respectively, representing 85 % cumulatively.

4. Experiment 1: impact of glycerol on the mouthfeel of de-alcoholised wine

The de-alcoholised Sauvignon blanc wine (2024) had a pH of 3.56 ± 0.25 and TA of 6.42 ± 0.00 g/L (n = 2). Prior to sensory analysis, glycerol and total sugar levels were measured to confirm the concentrations corresponding to each treatment. The measured glycerol concentrations shown in Table 4 were in close agreement with the target values. The slightly lower concentration observed in Treatment 3 is likely attributable to the high viscosity of glycerol, which can reduce precision during spiking. Additionally, slight deviations from the target sugar level of 30 g/L were observed, likely due to inaccurate handling during sample preparation. The measured alcohol concentrations confirmed that the de-alcoholised Sauvignon blanc wine adhered to South African de-alcoholised wine regulations as described by SAWIS (2020), containing less than 0.5 % *v/v* alcohol.

The correspondence analysis plot (Figure 1) illustrates the free-listing results of mouthfeel attributes from different glycerol additions in de-alcoholised Sauvignon blanc. The sample containing no glycerol addition (7 g/L) was positively associated with poor mouthfeel and good acidity, whereas increasing glycerol to a final concentration of 20 g/L was positively associated with medium mouthfeel. Further increases to a final concentration of 34 g/L were positively associated with good mouthfeel and increased complexity, while a final concentration of 57 g/L was positively associated with "good body" and increased perceived sweetness.

The ANOVA LS means graph (Figure 2) depicts the 20-point quality score sensory evaluation results. There was a significant difference in perceived quality between samples containing no glycerol (7 g/L) and a final glycerol concentration of 34 g/L. However, no significant differences were observed between samples containing a final glycerol concentration of 20 g/L, 34 g/L, and 57 g/L.

5. Experiment 2: impact of glycerol, gum Arabic, and mannoproteins on the mouthfeel of de-alcoholised wine

The de-alcoholised Chenin blanc base wine had a pH of 3.39 ± 0.04 and TA of 6.16 ± 0.14 g/L (n = 2), whereas the de-alcoholised Shiraz base wine had a pH of 3.68 ± 0.06 and TA of 6.44 ± 0.24 g/L (n = 2). Table 5 shows the measured concentrations of glycerol, total sugar, and alcohol, confirming that target concentrations were achieved. Measured values of de-alcoholised Chenin blanc for glycerol and total sugar were slightly higher than expected, likely due to spiking and sampling errors during preparation at this small scale. The alcohol levels of both wines were consistent with those typically reported in the literature, reflecting alcohol content of less than 0.5 % *v/v* (Schmitt *et al.*, 2023a).

For the de-alcoholised Chenin blanc, mixed-model ANOVA identified significant differences among treatment combinations for sweetness, body, and length ($p \leq 0.05$; Table 6). Perceived sweetness was significantly higher

TABLE 4. HPLC analysis results of de-alcoholised Sauvignon blanc wine used in Experiment 1.

Glycerol treatment	Glycerol (g/L)	Total sugars (g/L)	Alcohol (% *v/v*)
1. No glycerol addition	7.23 ± 0.11	28.81 ± 0.79	0.44 ± 0.03
2. Final concentration of 20 g/L	19.87 ± 0.05	28.35 ± 0.31	0.43 ± 0.02
3. Final concentration of 35 g/L	33.57 ± 0.05	28.50 ± 0.12	0.43 ± 0.01
4. Final concentration: 57 g/L	57.01 ± 0.72	27.61 ± 0.67	0.44 ± 0.02

Values are represented as mean ± standard deviation (n = 3).

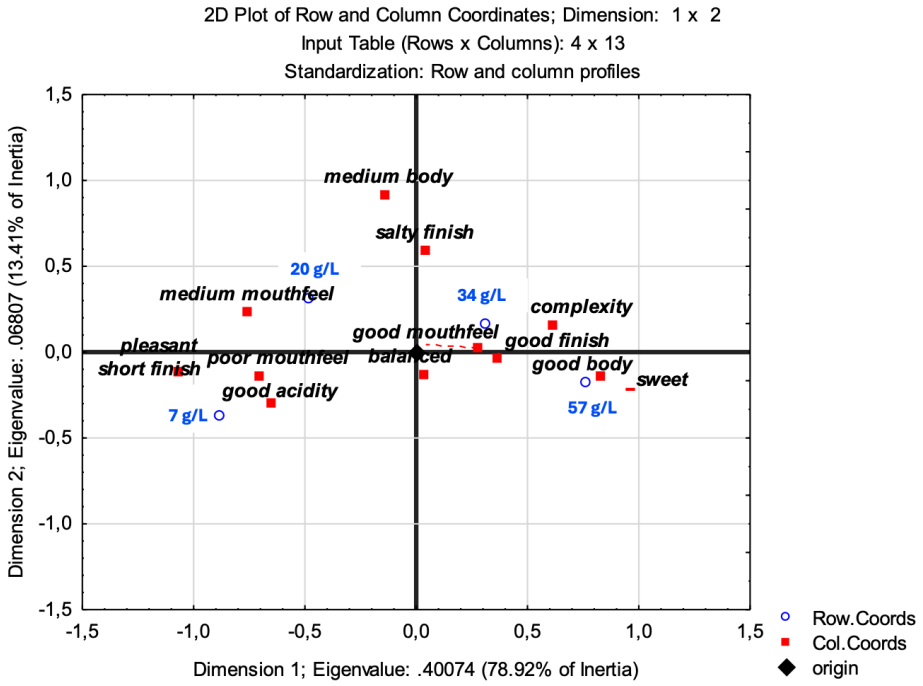


FIGURE 1. Correspondence Analysis plot for mouthfeel attributes and glycerol additions from the sensory analysis using free listing (obtained from TIBCO Statistica 14.01).

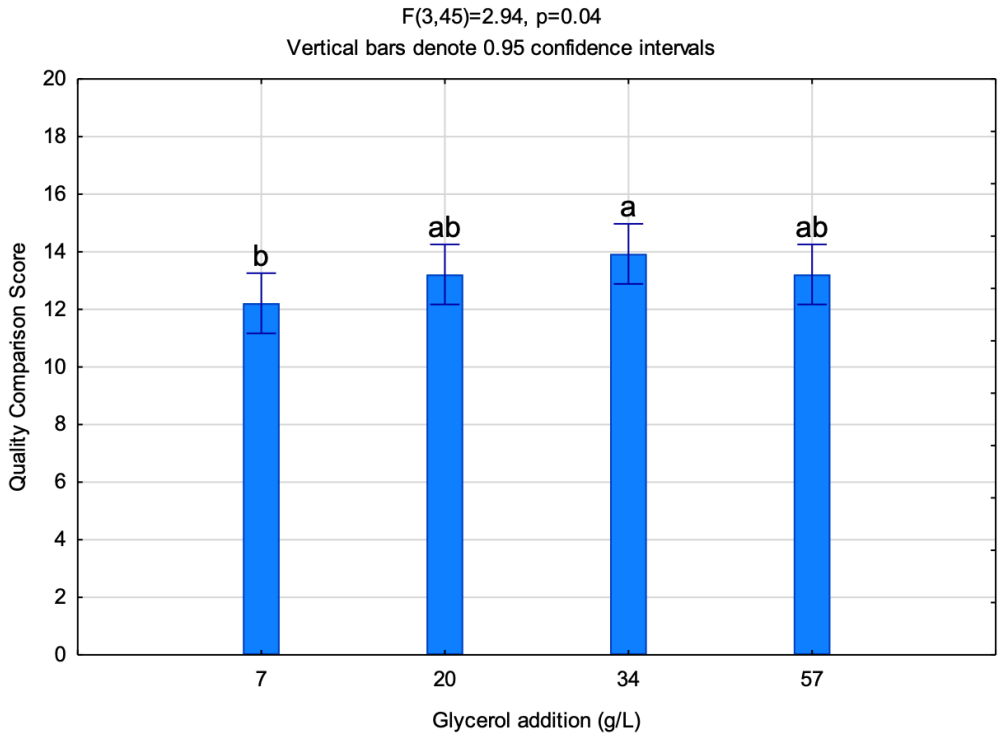


FIGURE 2. ANOVA LS means graph for quality comparison scores at different glycerol concentrations (obtained from TIBCO Statistica 14.01). Bars sharing letters are not significantly different (Fisher's LSD *post hoc* test, $p \leq 0.05$).

TABLE 5. HPLC analysis results of de-alcoholised Chenin blanc and Shiraz wines used in Experiment 2.

De-alcoholised wine type	Glycerol treatment	Glycerol (g/L)	Total sugars (g/L)	Alcohol (% *v/v*)
Chenin blanc	No glycerol addition	6.59 ± 0.12	35.34 ± 0.73	0.34 ± 0.01
	Final concentration of 35 g/L	39.33 ± 0.65	35.49 ± 0.58	0.33 ± 0.01
Shiraz	No glycerol addition	13.59 ± 0.13	29.05 ± 0.32	0.30 ± 0.01
	Final concentration of 35 g/L	38.70 ± 1.75	28.76 ± 0.60	0.29 ± 0.01

Values represent mean ± standard deviation (n = 8).

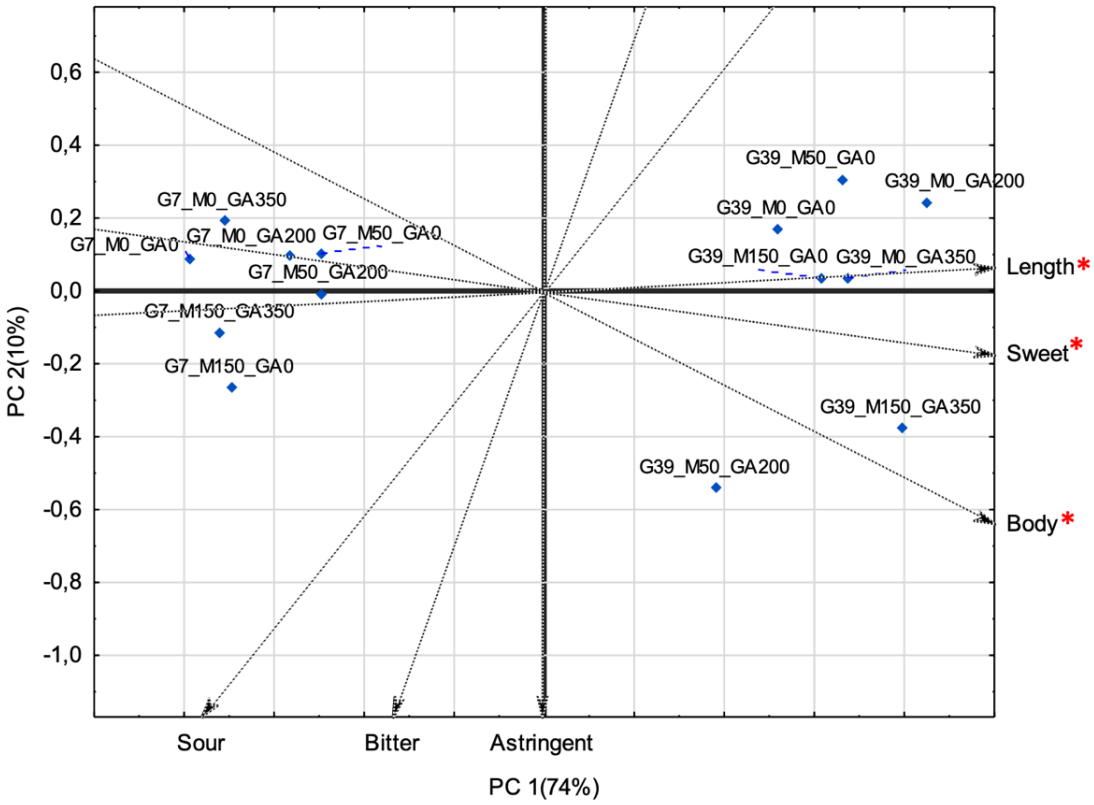


FIGURE 3. PCA biplot of the impact of different additive combinations on the mouthfeel attributes of de-alcoholised Chenin blanc 2024 (obtained from TIBCO Statistica 14.01).

Sample codes are structured as follows: the first letter indicates the glycerol level (G), the second letter indicates mannoproteins (M), and the third letter indicates gum Arabic (GA). Mouthfeel attributes marked with an asterisk (*) showed a significant treatment effect according to the mixed model ANOVA ($p \leq 0.05$).

TABLE 6. LS means (± SD) for significant mouthfeel attributes of de-alcoholised Chenin blanc across treatment combinations (Experiment 2).

Glycerol (g/L)	Mannoproteins (mL/hL)	Gum Arabic (mL/hL)	Sweet	Sour	Body	Length
			Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
6.59 ± 0.12	0	0	2.22 ± 0.72^{b}	2.94 ± 1.12 ns	2.25 ± 0.69^{cde}	2.28 ± 0.97^{cd}
	0	200	2.44 ± 0.86^{b}	2.72 ± 0.75 ns	2.28 ± 0.89^{cde}	2.44 ± 0.92^{bcd}
	0	350	2.28 ± 0.83^{b}	2.89 ± 0.83 ns	2.44 ± 0.51^{bcde}	2.44 ± 0.62^{bcd}
	50	0	2.44 ± 0.92^{b}	2.89 ± 1.08 ns	2.56 ± 0.98^{bcde}	2.53 ± 1.07^{cd}
	50	200	2.61 ± 1.04^{b}	3.06 ± 0.64 ns	2.50 ± 0.62^{cde}	2.44 ± 0.70^{bcd}
	150	0	2.28 ± 0.89^{b}	3.28 ± 0.83 ns	2.44 ± 0.86^{cde}	2.44 ± 0.92^{bcd}
	150	350	2.56 ± 0.62^{b}	3.11 ± 0.96 ns	2.22 ± 0.81^{e}	2.00 ± 0.97^{e}
39.33 ± 0.65	0	0	3.44 ± 1.03^{a}	2.72 ± 0.88 ns	2.69 ± 0.67^{abc}	2.81 ± 0.67^{ab}
	0	200	3.56 ± 0.86^{a}	2.39 ± 0.70 ns	2.94 ± 0.80^{ab}	2.78 ± 0.94^{abc}
	0	350	3.50 ± 0.86^{a}	2.67 ± 0.69 ns	2.72 ± 0.83^{abcd}	2.61 ± 0.85^{abc}
	50	0	3.56 ± 0.78^{a}	2.72 ± 0.89 ns	2.56 ± 0.92^{abc}	2.61 ± 0.85^{ab}
	50	200	3.28 ± 1.07^{a}	2.94 ± 1.06 ns	2.78 ± 0.73^{abcd}	2.72 ± 0.83^{abc}
	150	0	3.39 ± 1.09^{a}	2.83 ± 0.92 ns	2.72 ± 0.67^{abc}	3.00 ± 1.03^{abc}
	150	350	3.56 ± 0.92^{a}	2.78 ± 1.00 ns	3.06 ± 0.80^{a}	2.72 ± 1.07^{a}

Means sharing the same letter are not significantly different (Fisher's LSD, $p \leq 0.05$). ns = not significant.

in all treatment combinations containing a final glycerol concentration of approximately 39 g/L. In the PCA biplot (Figure 3), these treatment combinations were positioned on the positive side of PC1 and were more closely associated with sweetness, length, and body. Treatment combinations without added glycerol were positioned on the negative side of PC1 and were more closely associated with sourness, bitterness, and astringency. However, no significant differences were observed among treatment combinations for sourness, bitterness, or astringency ($p > 0.05$). Furthermore, no clear trends were observed among treatments containing different concentrations of mannoproteins and gum Arabic.

Similar trends were observed for the de-alcoholised Shiraz wines, where mixed model ANOVA identified significant differences among treatment combinations for sweetness, sourness, bitterness, body, and balance ($p \leq 0.05$; Table 7). In the PCA biplot (Figure 4), treatment combinations containing 38 g/L glycerol were positioned on the positive side of PC1 and were more closely correlated with body, length, balance, and sweetness. Treatment combinations that received no glycerol addition were positioned on the negative side of PC1 and were more closely correlated with sour, bitter, and astringent attributes. All treatment combinations containing a final glycerol concentration of approximately 38 g/L received significantly higher sweetness scores than those without additional glycerol. However, only the treatment containing glycerol alone and the treatment containing 38 g/L glycerol with 350 mL/hL gum Arabic received significantly lower sourness scores than the treatments that received no glycerol addition. Although the treatment containing 150 mL/hL mannoproteins and 350 mL/hL gum Arabic without additional glycerol had the highest bitterness score, it did not differ significantly from all treatments containing additional glycerol. Furthermore, no clear trends were observed among treatment combinations with varying concentrations and combinations of mannoproteins and gum Arabic, suggesting that their individual contributions could not be clearly separated within the treatment combinations evaluated.

DISCUSSION

These results are broadly consistent with previous studies, although the relationship between glycerol concentration and perceived body remains controversial in the literature. Gawel *et al*. (2007) reported increased mean viscosity ratings when glycerol concentration in dry Riesling wines increased from 5.2 to 10.2 g/L, while earlier work found that perceptible increases in viscosity only occurred at concentrations above 25.8 g/L (Noble & Bursick, 1984). Both studies evaluated glycerol concentrations substantially lower than those examined in the present study and were conducted in full-strength wines. In the present work, treatment combinations containing higher final glycerol concentrations were generally associated with more pronounced sensory differences, which may have been amplified by the very low ethanol content of the de-alcoholised wine matrix. Collectively, the results suggest that treatment combinations resulting in a final glycerol concentration of 34 g/L were associated with the most favourable sensory responses and improved mouthfeel characteristics in de-alcoholised Sauvignon blanc. Furthermore, treatment combinations with final glycerol concentrations between 20 and 34 g/L were generally associated with enhanced mouthfeel relative to treatments containing lower glycerol concentrations.

Several authors have documented the negative sensory consequences of wine de-alcoholisation, including increased acidity and reduced body, as well as heightened bitterness and astringency (Bellsario-Sánchez *et al.*, 2009; Mangindaan *et al.*, 2018; Pham *et al.*, 2020; Veiga-del-Baño *et al.*, 2024). The influence of phenolic compounds on bitterness and astringency appears to be even more pronounced in the absence of alcohol, which may result in reduced consumer acceptance and unfavourable purchasing behaviour (Chan *et al.*, 2012; Gawel *et al.*, 2013). Schmitt *et al*. (2023b) reported only modest increases in liking following the addition of tannins and mannoproteins to de-alcoholised wines and observed minimal sensory changes with the addition of 10 g/L glycerol, a concentration considerably lower than those evaluated in the present study. Similarly, Podworny *et al*. (2024) reported that sugar additions of up to 40 g/L may be required to improve overall liking in de-alcoholised Chardonnay wines, although such levels may raise concerns regarding excessive sugar intake.

The findings of the present study highlight the potential of glycerol addition as an approach for improving positive mouthfeel attributes and taste perception in de-alcoholised wines. In Experiment 2, treatment combinations with glycerol addition were more consistently associated with sweetness, body, length, and balance. These trends suggest that glycerol addition may improve the mouthfeel of de-alcoholised wine by increasing perceived body and persistence, while the increased sweetness perception from glycerol may modulate sourness and bitterness and contribute to a more balanced sensory profile. However, the relationship between these attributes differed between white and red wine samples. In the de-alcoholised Chenin blanc, body appeared to be positively associated with sweetness and length. In contrast, in de-alcoholised Shiraz, body was more closely associated with a reduction in astringency, suggesting that increased astringency may negatively affect the perception of body. Furthermore, no clear relationship between body and sweetness is observed in the red wines. The higher tannin and phenolic content of red wine may explain this difference, as interactions between tannins and salivary proteins produce drying and puckering sensations that may counteract the perception of fullness and body (Laguna *et al.*, 2019; Kuhlman *et al.*, 2024). These findings suggest that the impact of mouthfeel additives is matrix-dependent and that astringency may contribute more strongly to body perception in de-alcoholised red wines than in de-alcoholised white wines. Additionally, no clear trends were observed across the mannoprotein and gum Arabic concentrations tested. However, because the study compared selected treatment combinations rather than the independent effects of each additive, further research is needed to quantify the individual and combined effects of these additives.

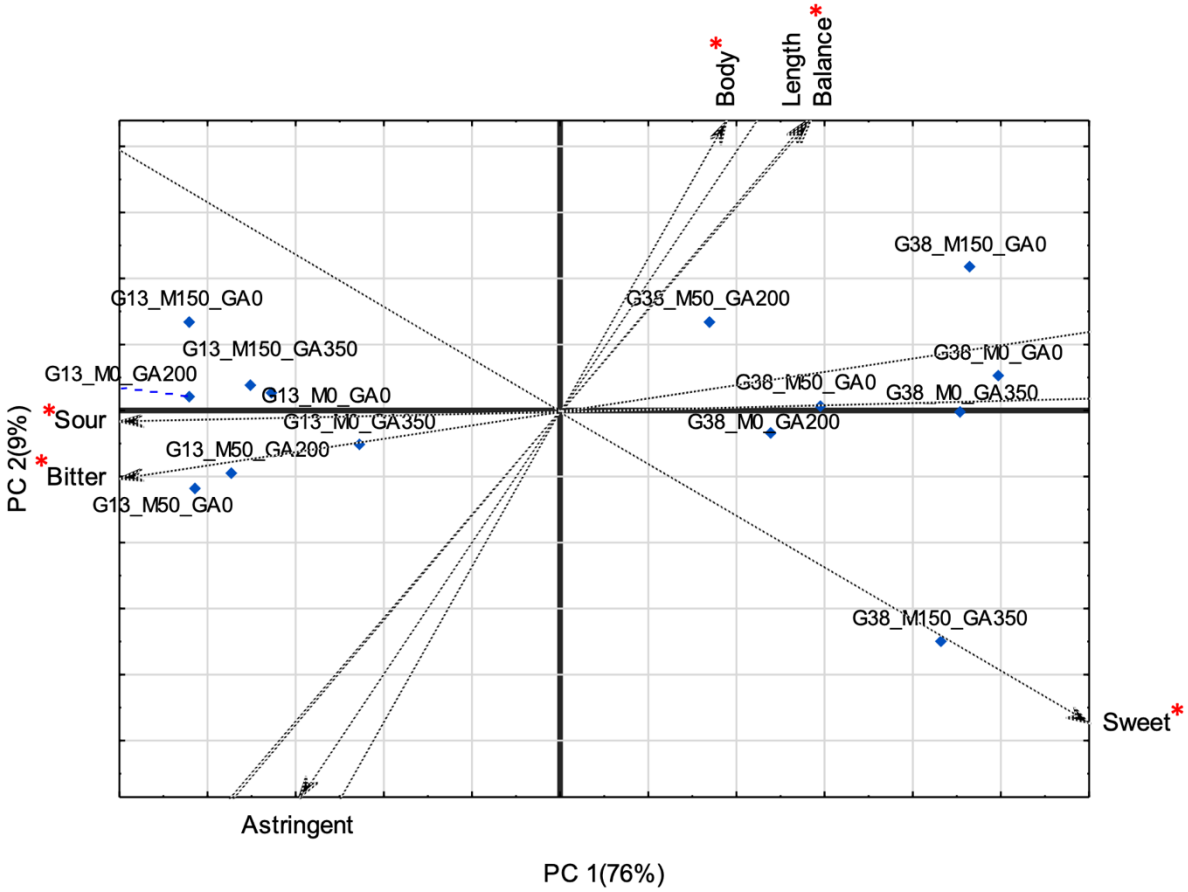


FIGURE 4. PCA biplot of the impact of different additive combinations on the mouthfeel attributes of de-alcoholised Shiraz 2024 (obtained from TIBCO Statistica 14.01).

Sample codes are structured as follows: the first letter indicates the glycerol level (G), the second letter indicates mannoproteins (M), and the third indicates gum Arabic (GA). Mouthfeel attributes marked with an asterisk (*) showed a significant treatment effect according to the mixed model ANOVA ($p \leq 0.05$).

TABLE 7. LS means (± SD) for significant mouthfeel attributes of de-alcoholised Shiraz across treatment combinations (Experiment 2).

Glycerol (g/L)	Mannoproteins (mL/hL)	Gum Arabic (mL/hL)	Sweet	Sour	Bitter	Body	Balance
			Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
13.59 ± 0.13	0	0	1.96 ± 0.84^{c}	3.32 ± 0.94^{a}	2.00 ± 1.31^{abc}	2.54 ± 0.79^{abc}	2.21 ± 0.79^{cd}
	0	200	1.79 ± 0.97^{c}	3.14 ± 1.17^{a}	1.71 ± 1.27^{bcd}	2.21 ± 0.97^{bcd}	1.93 ± 0.73^{d}
	0	350	2.07 ± 0.83^{c}	3.14 ± 1.10^{a}	2.14 ± 1.56^{abcd}	2.29 ± 1.07^{cd}	2.07 ± 0.92^{cd}
	50	0	2.00 ± 1.18^{c}	3.00 ± 1.04^{a}	1.93 ± 1.49^{ab}	2.07 ± 0.83^{cd}	2.00 ± 0.78^{cd}
	50	200	1.86 ± 1.03^{c}	3.14 ± 1.10^{a}	2.14 ± 1.29^{abcd}	2.08 ± 0.86^{cd}	1.93 ± 0.73^{cd}
	150	0	1.79 ± 0.97^{c}	3.00 ± 0.96^{a}	2.00 ± 1.30^{abcd}	2.71 ± 0.83^{abcd}	2.46 ± 1.20^{cd}
	150	350	1.86 ± 1.03^{c}	3.14 ± 1.17^{a}	2.43 ± 1.34^{bcd}	2.57 ± 0.76^{abcd}	2.00 ± 0.55^{cd}
38.70 ± 1.75	0	0	3.11 ± 1.07^{ab}	2.50 ± 1.00^{bc}	1.64 ± 1.39^{bcd}	2.74 ± 0.76^{a}	2.68 ± 1.06^{abcd}
	0	200	2.79 ± 0.80^{b}	2.64 ± 1.01^{abc}	1.64 ± 1.45^{bcd}	2.57 ± 0.76^{ab}	2.43 ± 0.85^{bcd}
	0	350	3.00 ± 1.04^{b}	2.43 ± 0.76^{abc}	1.57 ± 1.40^{bcd}	2.43 ± 0.65^{bcd}	2.71 ± 0.83^{abc}
	50	0	2.93 ± 1.07^{ab}	2.79 ± 0.97^{abc}	1.50 ± 1.40^{cd}	2.29 ± 0.73^{ab}	2.50 ± 0.85^{ab}
	50	200	2.71 ± 1.38^{ab}	2.86 ± 0.95^{abc}	1.50 ± 1.34^{cd}	2.79 ± 0.58^{abc}	2.79 ± 0.89^{abc}
	150	0	3.07 ± 1.21^{ab}	2.71 ± 1.33^{abc}	1.43 ± 1.50^{d}	2.71 ± 0.91^{ab}	3.00 ± 1.18^{a}
	150	350	3.57 ± 0.94^{a}	2.71 ± 1.07^{abc}	1.64 ± 1.22^{bcd}	2.64 ± 0.50^{abc}	2.43 ± 0.65^{bcd}

Means sharing the same letter are not significantly different (Fisher's LSD, $p \leq 0.05$). ns = not significant.

CONCLUSIONS

De-alcoholised wines generally lack body, balance, and mouthfeel due to the loss of ethanol (De-La-fuente-blanco *et al.*, 2024; Kumar *et al.*, 2024). While additives can be used to improve these sensory deficits, tailored additive strategies and specific interaction effects between additives remain relatively unexplored. Findings from Experiment 1 revealed that increasing glycerol concentration from 7 to 34 g/L in de-alcoholised Sauvignon blanc significantly increased perceived quality, with a final glycerol concentration of 34 g/L positively associated with increased body, mouthfeel, complexity, and balance. At the highest concentration tested (57 g/L), glycerol was primarily associated with increased perceived sweetness without further quality improvement.

Experiment 2 showed that treatment combinations containing higher glycerol concentrations were associated with improved body, length, balance, and sweetness in both de-alcoholised Chenin blanc and Shiraz. No significant sensory differences were observed between treatments containing different concentrations of mannoproteins and gum Arabic. This suggests that the sensory differences observed were more strongly associated with variation in glycerol concentration than with variation in mannoprotein or gum Arabic concentration at the levels tested. However, the effects of glycerol cannot be distinguished completely from those of the other additives included in the treatment combinations. Further research is therefore needed to investigate the interactions between glycerol, mannoproteins, and gum Arabic across a wider concentration range in de-alcoholised wine.

Despite the favourable mouthfeel and sensory responses associated with treatment combinations containing higher glycerol concentrations, several limitations should be acknowledged. Only a limited range of de-alcoholised wine varieties and oenological additives was evaluated, which may limit the applicability of the findings to other wine matrices. Furthermore, the experimental design focused on treatment combinations, restricting the ability to distinguish the individual contributions of specific additives. Future research should therefore investigate a wider range of de-alcoholised wine varieties and oenological additives, as well as their individual and interactive effects, to validate these findings across different wine matrices.

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