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ORIGINAL RESEARCH ARTICLE

Australian red wines made from non-traditional, emerging red grape varieties: distinguishing sensory profiles and consumer perceptions

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ABSTRACT

To sustain the Australian wine sector, it needs to adopt innovative strategies to adapt to rising temperatures brought by climate change. A potential approach is cultivating more drought-resistant emerging grape varieties with diverse flavour profiles to reduce, in part, the current reliance on major varieties. The study aimed to 1) explore sensory profiles of Australian wines made from three emerging red wine grape varieties, 2) determine consumer perceptions and liking of these wines and 3) evaluate whether these three emerging varietal wines display similar sensory characteristics to three major Australian varietal wines. An expert sensory panel (n = 8) performed a sorting task with 38 commercially available Australian wines (10 Montepulciano, 10 Nero d'Avola and 9 Touriga Nacional) and three each produced from Shiraz, Grenache and Cabernet-Sauvignon for exploration of sensory similarity and quality screening purposes, with three wines removed from further study. A Rate-All-That-Apply (RATA) panel of trained wine tasters (n = 36) evaluated the wines to produce sensory profiles and collect preliminary liking. Finally, a subset (n = 9 total) of the emerging wines was selected for consumer trials. Red wine consumers (n = 116) liked all wine samples independent of their knowledge and wine behaviour. Similarity scores indicated that consumers found the most significant similarity between Shiraz and Montepulciano, and Cabernet-Sauvignon and Touriga Nacional wines. The expert and trained tasters also drew similar comparisons between Shiraz and Montepulciano, but also between Grenache and Nero d'Avola wines, yet not towards Cabernet-Sauvignon and Touriga Nacional wines. The findings support the consumer acceptance and perceived similarities between the sensory profile of Shiraz and Montepulciano and Nero d'Avola and Grenache varietal wines, highlighting the potential for producers to adopt these more drought-resistant varieties as alternatives in a warmer future.

KEYWORDS: rate-all-that-apply, expert panel, hedonic, Montepulciano, Nero d'Avola, Touriga Nacional, drought tolerance.

INTRODUCTION

1. Climate change and wine quality

Agricultural production is constantly threatened by temperature rises caused by climate change (Howden *et al.*, 2010) and has already caused production issues for many Australian agricultural products, including wine grapes (Gunasekera *et al.*, 2007; Hannah *et al.*, 2013; Howden *et al.*, 2010), with an irreversibility of effects likely to occur if action is not taken (Venkateswarlu and Shanker, 2009). By the year 2050, Australian temperatures are predicted to increase by approximately 1.2 °C to 2.6 °C on average (Asbridge *et al.*, 2015; Helfer *et al.*, 2012; Webb *et al.*, 2007; Webb *et al.*, 2008) along with a higher frequency and severity of extreme weather events (McDonald, 2021). The bushfires of 2019–20 that resulted in significant agricultural crop losses, including smoke-tainted grape vines, are an example of the high-level impact Australia has already experienced due to climate change (McDonald, 2021). For viticulture, increased temperatures can directly or indirectly affect the phenology of grapes and grapevines, reducing berry quality through excessive sugar accumulation, lowering acidity, anthocyanin and flavonoid production and lowering yields (Mosedale *et al.*, 2016; van Leeuwen and Darriet, 2016; Webb *et al.*, 2007).

To mitigate losses and quality reductions, short-term strategies through increasing water uptake and sun protective means are feasible (Santos *et al.*, 2020) but fail to account for the continuous temperature rises and the costs associated with sourcing increasingly scarce water to satisfy vine demands (Ali and Talukder, 2008; Wang *et al.*, 2016). Longer-term strategies must be considered to provide the wine industry with sustainable adaptations that cope with environmental changes caused by global warming (Fraga *et al.*, 2017).

One solution for Australian viticulture is the adoption of emerging grape varietals displaying characteristics more suited for warmer, drought-prone environments compared to the current major varietal plantings that are more suited for cooler European climates (Albertini and Marconi, 2014; Carvalho *et al.*, 2016; Ferlito *et al.*, 2020; Mezei *et al.*, 2021). Statistics show that 15 % of Australian wine is currently already derived from emerging varietals (Department of Primary Industries and Regional Development Agriculture and Food, 2018), covering an average of less than 150 hectares each in Australia (Wine Australia, 2020).

2. Emerging wine grape varietals in Australia

At the time of writing, no clear definition of what constitutes an emerging wine grape varietal appeared in the literature. Currently, the most used definition for emerging varietals comes from the Australian Alternative Varieties Wine Show (AAVWS), stating that an emerging varietal is a wine made from any variety that is not Cabernet-Sauvignon, Chardonnay, Chenin Blanc, Colombard, Grenache, Merlot, Muscat Gordo, Pinot Gris/Grigio, Pinot Noir, Prosecco, Sauvignon Blanc, Semillon, Shiraz/Syrah, Riesling, Verdelho and White (and Brown) Frontignac (including synonyms) (Australian Alternative Varieites Wine Show, 2021). Previous literature has used this statement to define emerging varieties (Dry, 2010), but that author has indicated that this statement is flawed, as it includes "emerging" varietals that are grown in greater tonnage in Australia than some of the major varietals (Dry, 2010), for example, Petit Verdot and Ruby Cabernet (Wine Australia, 2020). In the present work, emerging varietals will only include varieties that fall into the AAVWS definition and have less than 150 hectares planted in Australia.

Cultivating specific drought and heat-resistant emerging varieties could offer potential environmental benefits, for example, fewer water requirements, rendering many wine-producing regions more sustainable with the flow of social and economic benefits for the community. It also offers a broader wine sensory offering for wine consumers. Nonetheless, consumer acceptance and consumption of wines made from emerging varieties requires consideration since research indicates that consumers explicitly focus on familiarity, in addition to price and reliability, factors that consciously dictate their wine decision choices (Johnson and Bruwer, 2004; Sáenz-Navajas *et al.*, 2013). Additionally, there is a generalised trend globally that markets and consumers are demanding more sustainably produced products (Flint and Golicic, 2009; Flores, 2018).

Given that consumers purchase familiar wines, offering wines with a similar sensory profile will elicit a sense of familiarity. A recent study indicated that Australian wine consumers appreciated the sensory qualities of Australian and international wines from emerging varieties (Mezei *et al.*, 2021). Additionally, sensory profiling demonstrated parallels in the aromas and flavours between wines of the emerging varieties Montepulciano, Nero d'Avola and Touriga Nacional with Australian Shiraz, Grenache and Cabernet-Sauvignon, respectively (Mezei *et al.*, 2021). Very few studies have examined the sensory profiles of single-varietal Australian wines made from these emerging red varieties. There is also a lack of research on whether red wines made from emerging varieties could act as substitutes for consumers of mainstream Australian red wines. The present study aimed to 1) describe sensory profiles of Australian red wines made from three emerging varieties: Montepulciano, Nero d'Avola and Touriga Nacional; 2) evaluate whether Australian wines made from Montepulciano, Touriga Nacional and Nero d'Avola from a wine expert, trained panel and consumer perspective, display similar sensory characteristics to wines made from the mainstream varieties, Shiraz, Cabernet-Sauvignon and Grenache, respectively, and 3) investigate whether Australian consumers like red wines made from emerging varieties.

Findings from this study will assist the wine industry's understanding of the holistic sensory profile of Australian Montepulciano, Nero d'Avola and Touriga Nacional wines, along with consumer behaviour towards them.

MATERIALS AND METHODS

1. Wine samples

A total of 38 commercially available Australian wines were used in this study: 10 Montepulciano, 10 Nero d'Avola and 9 Touriga Nacional wines; 9 wines (3 each) produced from Shiraz, Grenache and Cabernet-Sauvignon. Emerging varietals were chosen based on preliminary studies suggesting Montepulciano, Nero d'Avola and Touriga Nacional shared the greatest perceived similarity in flavour profiles to three of Australia's most predominant red grape varietals, Shiraz, Grenache and Cabernet-Sauvignon, respectively (Mezei *et al.*, 2021). All wines were Australian to mitigate any outliers from emerging varietal wines derived from other countries. Wine code, vintage, variety and provenance details are provided in Supplementary data, Table S1. All wines were utilised for sensory profiling and chemical analysis, with a subset of wines (indicated by an asterisk in Supplementary data, Table S1) additionally used in the consumer preference trial. All wines were bottled under screwcap, with the exception of MON7, which was under cork.

Informed consent was obtained from panellists, and this study was approved by the Human Research Ethics Committee of the University of Adelaide; Approval Number: H-2021-131.

2. Wine chemical composition measurements

Basic wine chemical analyses were performed on all wines in duplicate (Supplementary data, Table S2), including pH, titratable acidity (TA) through titration to 8.2 using an Autotitrator, residual sugar (RS), volatile acidity (VA) as acetic acid, Free and Total SO_2 measured using ChemWell (Awareness Technology, United States) with D-Glucose & D-Fructose, Acetic Acid Enzyme and Free and Total Sulphur Dioxide kits from Vintessential Laboratories (Orange, Australia). Wine colour hue and intensity were determined using CIELAB (Horiba, Japan), and ethanol content (% ABV) and density (g/cm^3) were obtained using an Alcolyzer (Anton Parr, Austria).

3. Expert sensory sorting task

3.1. Objectives

An expert panel was used to ensure no wine used in the experiments contained faults or obvious quality issues and for the panel to undertake a sorting trial to examine whether the experts could perceive any similarities between the mainstream and emerging varietal wines and provide an initial sensory profile of the wines.

3.2. Participants

An expert panel composed of eight individuals (three females, five males) was assembled. All panellists had 5+ years wine industry employment and experience with the varietals under study and were either winemakers, oenology and sensory academics, or wine professionals (Parr *et al.*, 2002).

Previous studies have utilised between 9 and 15 experts to conduct sorting tasks to obtain wine sensory maps (Bécue-Bertaut and Lê, 2011; Cartier *et al.*, 2006) and indicate that the more expertise plus type of product set can reduce the number of evaluations required to ensure the stability of the sensory space (Blancher *et al.*, 2012).

3.3. Procedure

Experts evaluated the wines at individual benches in an open-plan focus group room. The 38 wines (30 ml each) were presented to the experts in a randomised order (Torgerson and Torgerson, 2003) in clear International Standards Organisation (ISO) approved 215 ml wine glasses coded with 4-digit codes and covered with a petri dish. Experts were asked to sort the wines, based on wine aroma and flavour similarity, into as many groups as they deemed appropriate, disregarding colour. The use of black glasses to disregard colour was not possible due to the number of available glasses and transport issues with black glasses to Australia. Experts allocated wines into their groups noted on large pieces of white paper, which were inputted manually into a computer per expert for future analysis. The experts next completed a variant of the RATA methodology (group-RATA) to obtain the sensory aroma and flavour profiles of their groups. The experts selected from a supplied list only those attributes that applied to each group and rated the intensity on a 5-point scale ranging from "Low" to "High". Sensory attributes were chosen from the red wine lexicon used in other studies (Danner *et al.*, 2018; Ferrero-del-Teso *et al.*, 2020; Kontkanen *et al.*, 2005) with additional attributes that have been shown to be prevalent in these specific emerging varieties (Bonello *et al.*, 2018; Cravero *et al.*, 2012; Falqué *et al.*, 2004; Mezei *et al.*, 2021). Sensory attributes consisted of 29 for aroma and flavour, three for taste and eight for mouthfeel (Supplementary data, Table S3). Descriptors were presented to experts as combined flavours and aromas due to time constraints, and the panel had previously been trained on mouthfeel attributes.

This sorting task assisted in identifying three faulty wines that were subsequently removed from the remainder of the study.

4. Sensory Rate-All-That-Apply (RATA) and preliminary hedonic liking using trained tasters

4.1. Objectives

Trained RATA panellists were required to generate detailed wine sensory profiles, along with a preliminary hedonic liking "score" for the individual wines, to both examine similarity amongst wines and facilitate the selection of a subset of wines for the consumer trial.

4.2. Participants

A RATA panel (n = 36) was assembled consisting of wine sensory panellists formally trained in wine sensory evaluation, including aroma, taste, flavour and mouthfeel and who had sat on numerous wine RATA panels. RATA participants included wine science staff members and higher degree students recruited from the University campus wine science department.

4.3. Procedure

The RATA trials took place over three weeks and consisted of three sessions of approximately one hour. Participants were required to attend each session and evaluate the same wines used in the expert trial but with the three faulty wines removed: 35 wines in total, with 12, 12 and 11 wines in sessions one, two and three, respectively. Sessions took place in the sensory laboratory in individual booths under fluorescent lighting at a constant temperature (21 °C).

With the exception of the 15 panellists in session one, panellists were presented with each wine monadically. All tasters had an enforced 1-minute break between samples and a 10-minute break between wines six and seven. Samples (30 ml) were presented randomly in clear, covered ISO-approved wine glasses labelled with 4-digit codes.

For each wine, participants were first asked to rate their liking on a 9-point hedonic scale (ranging from "dislike extremely" to "like extremely"). Next, panellists were instructed to rate the intensity of only the sensory attributes that they perceived in the wine, using a 7-point rating scale (ranging from "extremely low" to "extremely high"). The flavour and aroma descriptors used were the same as the experts.

Data was collected through Red Jade software (2016, Redwood City, USA)

5. Consumer preference trials

5.1. Objectives

The consumer trial aimed to assess the participants' preference towards wines made from emerging varietals and whether they deemed the emerging varietal wines similar sensorially to the corresponding major varietal wines.

5.2. Wines

From the trained RATA panel data, two wines were selected from each emerging varietal bracket and one wine from each corresponding major varietal. Each two emerging varietal wines were chosen based on the favourable preliminary hedonic responses and flavour profiles obtained through the trained RATA trial and possessed similarities to the benchmarked major varietals chosen yet were different to each other (Supplementary data, Table S1).

5.3. Participants

The consumer panel consisted of 116 participants recruited via email from the University of Adelaide's wine consumer database and through social media. To participate, consumers were required to have consumed red wine in the last month, be over the age of 18, and not have any formal wine qualifications or wine industry experience.

5.4. Procedure

These trials took place over three weeks, taking approximately one hour to complete. Participants were seated in individual sensory booths and undertook an online questionnaire consisting of demographic questions and completed the Fine Wine Instrument (FWI) (Johnson and Bastian, 2015), which is a psychographic segmentation approach used to group wine consumers into clusters based on wine knowledge, engagement with wine and fine wine behaviour. The FWI has uncovered consumer clusters with different wine-associated behaviours, knowledge and wine taste preferences and emotions (Danner *et al.*, 2020). Consumers then had to indicate their liking of the wines and their perception of the similarity between emerging varietal wines and their corresponding major varietals.

Wines were presented two at a time, one emerging variety and its purported corresponding major varietal (Montepulciano with Shiraz, Nero d'Avola with Grenache, Touriga Nacional with Cabernet-Sauvignon). Consumers were asked to rate their liking of each on a 9-point hedonic scale and were then asked to rate how similar the two wines were on a 100-mm line scale with 7-word anchors from No Difference (10 %) to Moderate Difference (50 %) to Extremely Large Difference (90 %). This was repeated six times, one for each emerging varietal. Wines were assigned random 4-digit codes, and the order of wines presented was randomised both between and within each emerging and major varietal pairing. A break of one minute was enforced between each pair of wines.

Data was collected through Red Jade software (2016, Redwood City, USA)

6. Statistical analyses

All statistical analysis was performed using XLSTAT – Sensory Version 2021.2 (Addinsoft SARL, France), except where indicated, and sensory data was collected through Red Jade software (2016, Redwood City, USA), with chemical analysis added as supplementary data (S2).

Expert sorting task data was used to form a similarity matrix subjected to an Agglomerative Hierarchical Cluster (AHC) analysis, using unweighted pair-group averaging to generate several potential solutions. The sensory data were analysed using a two-way mixed model ANOVA with wine samples as fixed factors and panellists as random factors using the means of the sensory attributes (Intensity = Assessor + Sample + Assessor*Sample + Error), with Fisher's LSD post-hoc test with a p-value < 0.15 deemed significant. The mean sensory attribute intensity generated by the expert group RATA data generated for the 38 wines that were significantly different between samples underwent Principal Component Analysis (PCA) to generate multiple bi-plots.

Data obtained from the trained panel RATA trial were analysed using a two-way ANOVA with panellists as random factor and wine as fixed factor effects. Fisher's LSD post-hoc test was set at ($\alpha \leq 0.05$) for multiple comparisons (Intensity = Assessor + Sample + Assessor*Sample + Error). Sensory attributes that were significantly different between samples based on ANOVA ($\alpha \leq 0.05$) underwent a correlation PCA with liking as supplementary data.

Hedonic data for both the RATA and consumer panel responses to the wines were subjected to a one-way ANOVA (Liking = Assessor + Sample + Error) and Fisher's LSD ($\alpha \leq 0.05$). RATA data obtained from both the expert and trained RATA panel underwent Multiple Factor Analysis to examine the associations between the two data sets of the same wines.

Consumer similarity data were evaluated using a one-way ANOVA. A k-means cluster analysis of the Fine Wine Instrument (FWI) data determined the Fine Wine Segments (FWS). FWS were cross-analysed with the hedonic and similarity data using a one-way ANOVA (Similarity = Assessor + Sample + Error). SPSS was used to determine the consumer panel statistics across gender, age, education and income.

RESULTS

1. Red wine sensory profiles and similarities according to experts

The AHC differentiated the wines into three distinct clusters based on the similarity of the wines to each other. The 3-cluster solution was chosen as it more clearly described how the wines cluster together, compared to a 4- and 5-cluster solution (Figure 1). The first cluster (blue) consisted of 14 wines: 7 of the 10 Nero d'Avola, all 3 Grenache, 2 Montepulciano, 1 Shiraz and 1 Cabernet-Sauvignon. Cluster 2 (orange) comprised 10 samples: 4 of the 10 Montepulciano, 2 of the 3 Shiraz, 2 Cabernet-Sauvignon, 1 Nero d'Avola and 1 Touriga Nacional. Cluster 3 (green) comprised 14 samples: 8 of the 9 Touriga Nacional, 4 Montepulciano and 2 Nero d'Avola.

PCA was performed on the 13 statistically significant sensory attributes ($\alpha < 0.15$), identified through two-way ANOVA (DF = 44; F = 3.93; Pr > F < 0.0001, where F equals product effect) of the expert group RATA responses. Of the variation in the data, 57.67 % was explained in the first two principal components (PC), with a further 13.73 % explained in the third dimension. Biplots of the wines from the PCA for both PC1 and PC2 and PC1 and PC3 are displayed in Figure 2.

The first principal component (PC1) contributed 40.88 % of the variation in the data (Figure 2a). PC1 distinguished wine samples on the left-hand side of the plot as primarily floral, whilst the right-hand side highlighted wines that had greater mouthfeel attributes of body and alcohol/heat. PC1 in Figure 2b yielded similar results to Figure 2a, with the addition of dark fruit aroma and flavour, viscosity and puckering and grippy mouthfeel.

The second principal component (PC2) contributed 16.78 % to the variation in the sensory data and differentiated wines on the top half as showing greater bitterness, leathery and dried fruit flavours, as opposed to wines in the bottom half that displayed more dark and red fruit, spice and eucalyptus aromas and flavours.

The third principal component (PC3) differentiated wines in the top half of the plot, possessing more dried fruit and eucalypt aromas and flavours, with the bottom half containing wines that were more bitter.

The first cluster (blue), which primarily consists of Nero d'Avola (7 of 10) and all three Grenache wines, plus two Montepulciano, one Shiraz and one Cabernet-Sauvignon, dominated the two left quadrants demonstrating floral, red fruit and spice aroma and flavour. Figure 2b, showing PC3, further emphasises floral as a driving attribute but indicates that red fruit is also predominant within this cluster. Spice additionally shows a positive correlation for this cluster, with eucalypt also showing predominance in a few wines in the upper left-hand quadrant (CABS2, SHZ1, NERO2).

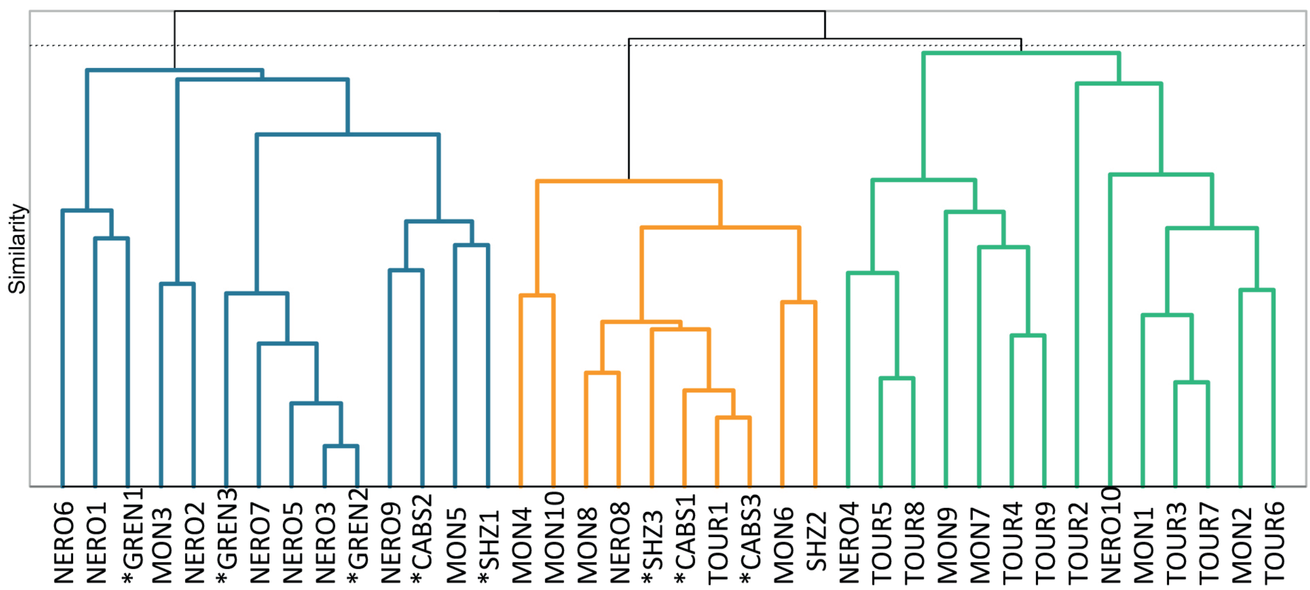

FIGURE 1. Agglomerative Hierarchical Cluster (AHC) dendrogram of 38 red wines of emerging and major varietal wines from sensory similarity data generated by an expert sorting panel. Cluster 1 in blue, cluster 2 in orange, cluster 3 in green. Asterisks indicate mainstream wines.

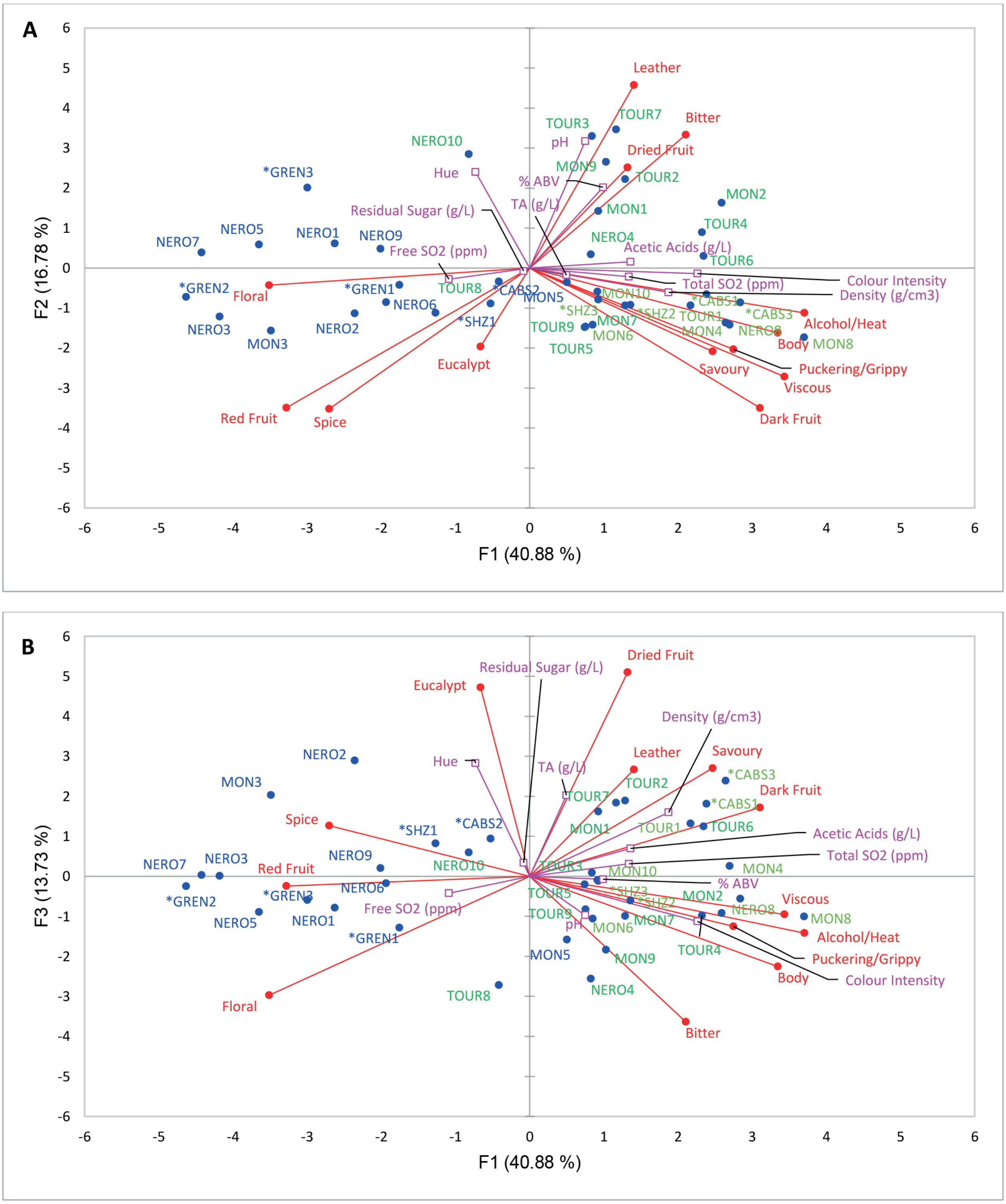

FIGURE 2. Principal Component Analysis showing (A) PC1 and PC2, and (B) PC1 and PC3 of the significant aroma/flavour attributes ($\alpha < 0.15$) distinguishing the 38 wines sorted by the expert panel and evaluated through group-RATA. Label colours for the wine samples represent the same clusters demonstrated by the AHC in Figure 1: cluster 1 in blue, cluster 2 in orange and cluster 3 in green. Asterisks indicate mainstream wines.

The second cluster (orange) in Figure 2a was exclusively located in the bottom right quadrant. These wines displayed attributes of savoury and dark fruit notes, with increased mouthfeel viscosity, puckering/grippy, body and alcohol heat. MON6, MON10 and SHZ3 were closer to the origin, indicating they encompassed more average attributes across the PCA. Figure 2b yielded very similar results, with the second cluster being present on both right quadrants. Attributes remained the same, with a few wines (CABS1, CABS3 and TOUR1) showing dried fruit and leather attributes.

The third cluster (green), in Figure 2a, was predominant in the two right-hand quadrants and displayed attributes of leather and dried fruit, with bitter taste and a few wines (TOUR5, TOUR9 and MON7) showing dark fruit, savoury, viscous and puckering attributes. Wines were more evenly spread across the right-hand side in Figure 2b, with the same attributes as Figure 2a, with the addition of body and alcohol. NERO10 and TOUR8 remained the outliers for these groups, being more strongly correlated to attributes describing the blue cluster.

Experts agreed that three of the wines showed undesirable characteristics: MON7 showed 2,4,6-trichloroanisole (TCA) taint, which may explain why it was relatively low in intensity for all sensory aromas; TOUR2 was described as possessing Brettanomyces off odours and it was strongly leathery; and GREN3 was found to be mousey. All three wines were removed from the rest of the study.

2. RATA sensory profiling and preliminary hedonic liking

2.1. Preliminary hedonic results

Prior to RATA sensory profiling, the 36 participants were asked to rate their hedonic responses to the wines. One-way ANOVA (Supplementary data, Table S4) demonstrated that all wines, except for MON2 (mean liking score 4.89), scored greater than 5 on a 9-point scale, indicating participants moderately liked all wines. TOUR8 (mean liking score 6.47) from the Riverland was the most liked wine and was liked significantly more than 17 other wines.

2.2. Trained RATA panel sensory results

To examine the sensory attribute similarities and differences between individual wines from a trained RATA panel perspective, ANOVA was conducted on the RATA profiling intensity ratings, and a PCA was performed using the statistically significant attributes that differentiated the 35 wines ($DF = 68$; $F = 8.522$; $Pr > F < 0.0001$). Of the 67 RATA attributes used, 46 significantly differentiated the wines at a 95 % confidence interval ($P < 0.05$). The biplot of the PCA with the preliminary hedonic response overlaid as supplementary data is presented in Figure 3.

In the first and second-dimension biplot (Figure 3a), PC1 contributed to 31.62 % of the variance in the data. Wines were distinguished as showing aromas and flavours of red fruits, floral, blue flowers and confectionery on the left-hand side, with wines on the right-hand side showcasing aromas and flavours of leather, savoury, earthy, meaty/salami, pepper and tobacco, flavours of dried fruits and greater mouthfeel alcohol/heat and longer aftertaste.

PC2 contributed 12.37 % to the variance of the data. Wines in the upper half possessed aromas of vegetal, herbaceous, green, mint, dried herbs and eucalypt, and vegetal, minty, cooked vegetables and green flavours. Wines in the bottom half had greater jammy, sweet oak and chocolate aromas, flavours of caramel/butterscotch and sweet oak, and were perceived as tasting sweet.

PC3 contributes 11.80 % to the variation of the wines in the sensory space. Wines present in the upper half were more predominant in dark fruit, minty, eucalypt and dark fruit flavours and aromas, with a positive correlation towards blue flower/violet aromas. Wines were also perceived as having greater astringency and body than most other wines. Wines in the lower half contained aromas and flavours of caramel/butterscotch, earthy, meaty/salami attributes and sweet taste.

Figure 3a indicated primarily Grenache (GREN1, GREN2) and Nero d'Avola (NERO1, NERO3, NERO4, NERO5, NERO6, NERO8 and NERO9) showing greater red fruit, floral and confectionary attributes, similar to what was described by the expert panel (Figure 2). The upper right quadrant of Figure 3a housed primarily green, dried herbs, cooked vegetables and herbaceous aroma and flavour attributes associated with the three Cabernet-Sauvignon wines.

The Touriga Nacional wines were relatively evenly dispersed across the sensory space occurring in each quadrant, thus reflecting that numerous wine styles made from this variety were apparent in this sample set. However, TOUR3 and TOUR7 saw the strongest positive correlation towards green and herbaceous characteristics compared with other Touriga Nacional samples in the first and second dimension biplot (Figure 3a) yet were not as strong as Cabernet-Sauvignon was towards these attributes. The first and third-dimension biplot (Figure 3b) indicated a greater positive correlation towards green and herbaceous characteristics for more Touriga Nacional replicates (TOUR1, TOUR4 and TOUR6), indicating that there may indeed be some similarities between these varieties.

The three Shiraz wines (SHZ1, SHZ2 and SHZ3) plus MON8, MON4 and MON6, TOUR1, TOUR4 and TOUR6 appear in the bottom right-hand quadrant in Figure 3a, associated with increased body and longer aftertaste, dark fruit aromas and flavours plus oak, sweet oak and chocolate oak aromas and flavours, plus pepper flavour and more bitter and sweet taste. Along PC3, SHZ2 and 3, plus MON6, 5, 4, 8, 1, 2 and 9 are more associated with dark fruits and eucalyptus, minty, blue flowers and more astringent styles of wine versus SHZ2, MON1, 2 and 9, which were more savoury, dried fruit, earthy, meaty/salami and caramel butterscotch styles.

Figure 3a in the first and second dimensions highlighted that preliminary liking was primarily driven by confectionary and blue flower flavours and aromas, with floral, red fruit,

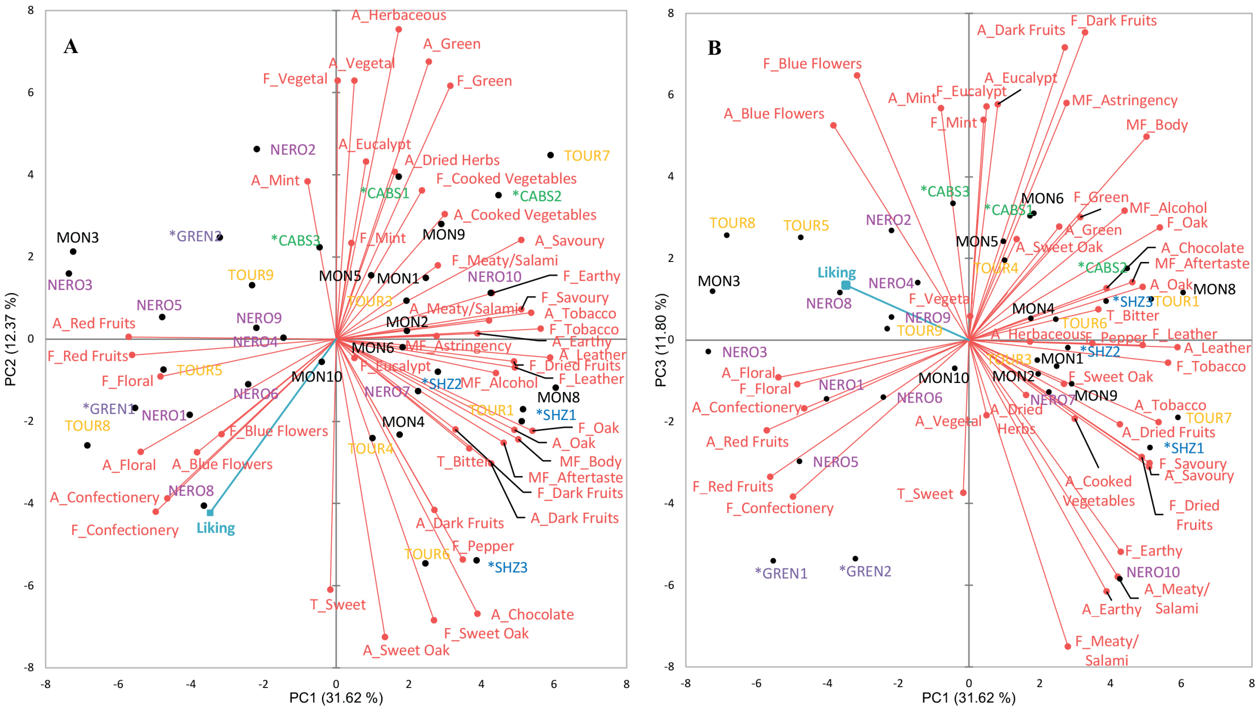

FIGURE 3. Principal component analysis of the significantly different (α ≤ 0.05) aroma and flavour attributes used to profile the 35 wines by RATA panellists using preliminary liking as supplementary data with A) displaying PC1 and PC2 and B) displaying PC1 and PC3. Asterisks indicate mainstream wines.

caramel/butterscotch, sweet oak and sweet taste also driving liking. Figure 3b in the first and third dimensions similarly showed that liking was driven by floral, blue flowers and confectionary aromas and flavours. The most liked wine in the tasting, TOUR8, was shown to be strongly correlated with these flavour attributes. Conversely, wines that were least liked (MON2, TOUR3, TOUR7) were associated with savoury, meaty/salami and cooked vegetable attributes.

Wines analysed by the trained RATA panel showed similar flavour and sensory profiles to those described by the expert panel. The MFA analysis indicated that there was a significant ($P < 0.001$) relationship between the RATA data generated by the two panels, returning a RV coefficient value of 0.448. This suggests that the expert and trained RATA panels, despite undertaking different tasks (sorting followed by group-RATA in an open plan sensory lab and monadic wine sample RATA in individual booths), were describing the wines in a relatively similar way and provided confidence when summarising the generic sensory profiles of the wines made from the distinct varietals.

Wines were colour-coded into groups based on results obtained from the expert AHC (Figure 1). Figure 3a closely resembled the group separation denoted in Figure 2.

The basic chemistry measurements (Supplementary data, Table S2) were overlayed on the sensory results in Supplementary Figure S6. Basic chemistry attributes of alcohol (% ABV) and residual sugar (RS) were in line with sensory attributes. Mouthfeel body was strongly correlated with % ABV, whilst sweeter attributes of taste and caramel correlated with RS.

2.3. Consumer liking scores and similarity responses

The consumer panel was a convenience sample of South Australian red wine drinkers. Females comprised 55 % of the consumer panel, with 44 % male and 1 % non-identified, 50.8 % of whom were over the age of 55, with the remainder below. 79.3 % of the consumers held tertiary education qualifications, and 52 % had an annual household income of over AUD$100,000. Most individuals consumed red wine frequently, with 81 % of consumers drinking wine at least once a week and 70 % purchasing their wine for $25 or less per bottle (Supplementary data, Table S5). Each of the two emerging varietals chosen were based on the favourable hedonic responses and flavour profiles obtained through the trained RATA trial (hedonic scores of 5.5–6.47), and possessed a broad range of flavour profiles (including wines higher in leather, tobacco, oak and alcohol; wines with more intense red fruit, confection, blue flower, minty, herbaceous and vegetal attributes with low to moderate astringency; and wines with more dark fruit, jammy, pepper, chocolate and sweet oak characters, with more prominent astringency and fuller-bodied), as well as possessing similarities to the benchmarked major varietal chosen, yet were different to each other (Supplementary Table S1) from multiple (5) regions across South Australia.

Considering these factors, the following wines were chosen for the consumer trial: GREN1, CABS3, SHZ3, MON1, MON8, NERO5, NERO8, TOUR6 and TOUR8 (Supplementary data, Table S1).

Table 1 presents the consumer liking data and overall similarity scores for the nine wines in the trial

(Hedonic one-way ANOVA; DF = 11; F = 1.69; Pr > F < 0.07). Liking was assessed using a 9-point liking scale, with all wines scoring above 5, indicating consumers liked all wines equally (Table 1).

Consumers were also asked to indicate their perceived similarity (Similarity one-way ANOVA; DF = 5; F = 12.575; Pr > F < 0.0001) of wine style between the emerging variety and its corresponding major varietal. There was no information as to what the consumers were tasting. Consumer results indicated that one pairing, NERO8 and GREN1, was perceived as significantly more dissimilar than all other pairings, including NERO5 and GREN1. The remaining pairings were considered as having moderate to slight differences, indicating perceived similarity. MON8 and, to a slightly lesser extent, MON1 showed the greatest amount of similarity with their proposed counterpart wine, SHZ3.

TABLE 1. Consumer mean hedonic responses and similarity score for emerging varietals compared to their corresponding traditional varietal counterpart.

Wine Variety	Consumer Liking (n = 116)
SHZ3	6.54
TOUR6	6.48
MON1	6.38
TOUR8	6.38
NERO8	6.31
MON8	6.17
NERO5	6.17
CABS3	6.17
GREN1	5.93
Varietal Pairing	Wine Similarity
MON8 to SHZ3	42.89d
MON1 to SHZ3	44.53cd
TOUR8 to CABS3	46.78bcd
TOUR6 to CABS3	48.54bc
NERO5 to GREN1	49.66b
NERO8 to GREN1	60.27a

Post-hoc tests were performed using Fishers LSD α < 0.05; wines sharing letters are not significantly different. Lower values for similarity score (< 50) indicate greater perceived similarity.

2.4. Psychographic influences on consumers' liking

Following the protocol outlined in Johnson and Bastian (2015), the FWI was used to segment the consumer panel into three segments: Wine Enthusiasts (WE), Aspirants (ASP) and No Frills (NF) based on their wine involvement, knowledge and wine connoisseur behaviour. Demographic information on the segments is displayed in Supplementary data, Figure S5.

Table 2 indicates the overall FWI segment's hedonic response towards the wines, highlighting no statistical differences in wine liking between the WEs and the ASPs. NF consumers liked MON8 and TOUR6 significantly less than the other segments. Table 2 also demonstrates that all segments reported NERO8 and GREN1 to be the most dissimilar pairing. Significant differences were only observed for the perceived similarity of the NERO5 and GREN1 pairing, with the WEs finding this pairing significantly more dissimilar than the other segments.

Correlation analysis of the FWI consumer segment hedonic scores and trained taster RATA sensory attributes are displayed in a correlation coefficient graph (Figure 4). Absolute values of > 0.4 were used to determine the importance of attributes driving segment wine liking or disliking (Mezei *et al*., 2021). Thirty attributes were significant in driving wine liking or disliking for consumer segments. Dark fruit, dried fruit, chocolate, sweet oak and oak aromas, dark fruit, dried fruit, jammy, blue flower and sweet oak flavours, bitter taste, fuller body, longer aftertaste and more intense alcohol mouthfeel characteristics contributed to WEs liking of wine; whilst aromas of red fruit and earthy drove their wine disliking (Figure 4). For the ASPs, dark fruit, dried fruit, meaty/salami, tobacco, leather, chocolate, sweet oak and oak aroma; dark fruit, dried fruit, jammy, savoury, tobacco, leather, sweet oak and oak flavours, bitter taste, fuller body and higher alcohol and longer aftertaste mouthfeel were the attributes that drove their liking of the wines. Aromas of red fruit and floral, and flavours of red fruits, confectionary, floral and barnyard/horsey drove their dislike of the wines (Figure 4). Finally, the NF consumers saw aromas of savoury, tobacco, leather, chocolate and oak, flavours of tobacco, leather and oak and more body, higher astringency and alcohol, plus longer aftertaste as drivers of their dislike towards the wines (Figure 4).

DISCUSSION

Adapting to climate change to ensure a more sustainable Australian viniculture sector may be achieved by utilising more drought and heat-tolerant planting material. Studies on the use of emerging wine grape varieties that may possess these characteristics in Australia are limited, but in recent years, they have begun to appear (Copper *et al.*, 2020; Mezei *et al.*, 2021). Preliminary studies on sensory profiles and Australian consumer preferences for a small number of Australian and international red wines made from purportedly drought-tolerant varieties were described by Mezei *et al*. (2021). The current study expands on their data by exploring more examples of fewer varieties of only Australian-produced red wines using expert, trained and consumer panels, and in addition, an examination of these wines' similarity to exemplar wines produced from three mainstream red wine varieties.

1. Sensory profiles of Australian wines produced from emerging red grape varieties

Sensory profiles of the wines under study were developed during the expert sorting and trained taster RATA trial, with the latter identifying 46 statistically significant attributes differentiating the wines.

The expert and trained tasters' data described the three Shiraz wines as displaying red and dark fruit, dried fruit, leather and oak-driven flavours and aroma while showing

TABLE 2. FWI segments' mean hedonic responses and similarity score for emerging varietals compared to their corresponding traditional varietal counterpart.

	Wine Enthusiast (n = 56)	Aspirants (n = 42)	No Frills (n = 18)	F	Pr > F
Wine Variety		Hedonic Liking			
MON1	6.39	6.31	6.50	0.076	0.927
MON8	**6.23a**	**6.60a**	**5.00b**	**4.901**	**0.009**
SHZ3	6.69	6.56	6.03	1.279	0.282
TOUR6	**6.68a**	**6.67a**	**5.44b**	**3.363**	**0.038**
TOUR8	6.59	6.26	6.00	0.984	0.377
CABS3	6.38	6.14	5.58	2.372	0.098
NERO5	6.36	5.98	6.06	0.585	0.559
NERO8	6.30	6.29	6.39	0.020	0.980
GREN1	5.88	6.07	5.78	0.315	0.730
Varietal Pairing		Wine Similarity			
MON1 to SHZ3	45.14	46.12	38.94	0.917	0.403
MON8 to SHZ3	42.88	43.02	42.61	0.003	0.997
TOUR6 to CABS3	45.25	51.43	52.06	1.578	0.211
TOUR8 to CABS3	46.77	46.36	47.78	0.031	0.970
NERO5 to GREN1	**53.70a**	**47.05b**	**43.17b**	**3.718**	**0.027**
NERO8 to GREN1	61.59	58.83	59.50	0.331	0.719

Post-hoc tests were performed using Fishers LSD $\alpha < 0.05$; wines sharing letters in the same row are not significantly different (significant differences between segments in bold).

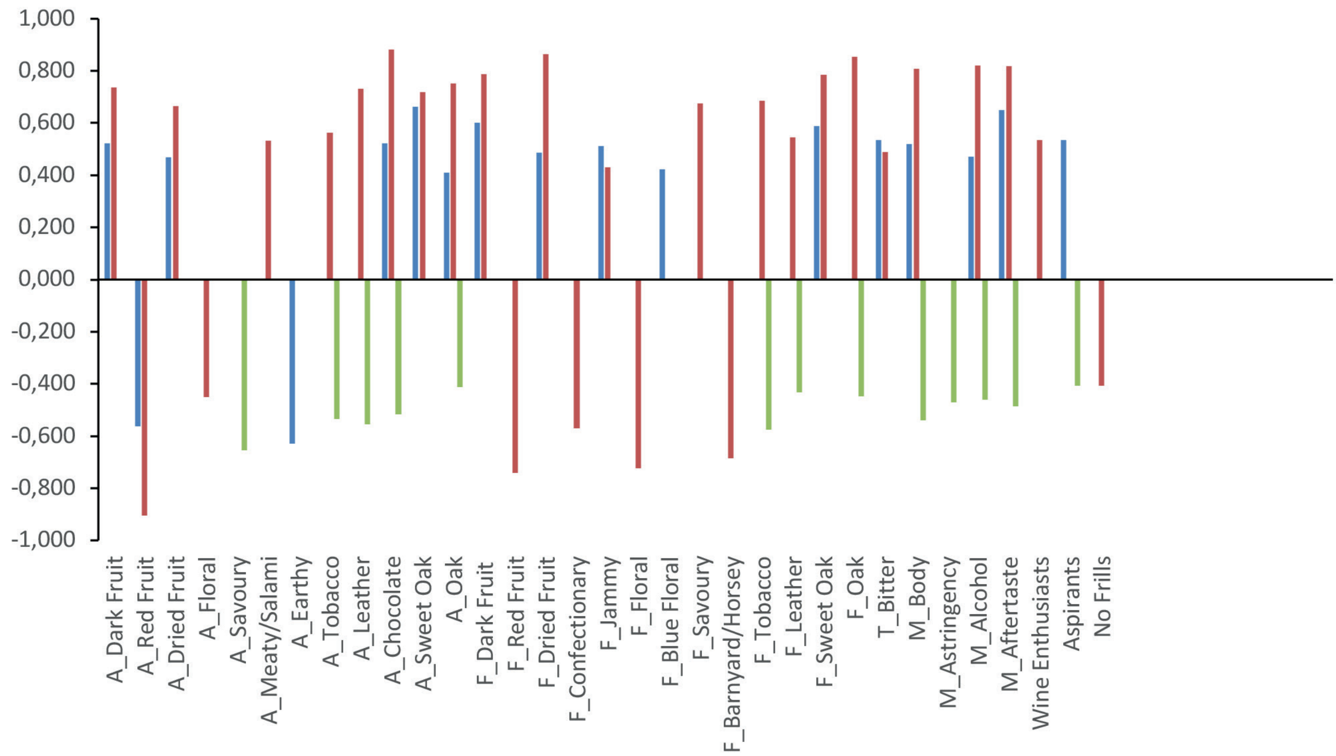

FIGURE 4. Sensory Attributes with an absolute correlation coefficient that indicates sensory drivers of consumer liking for the FWI Segments.

Blue bars represent Wine Enthusiasts, red Aspirants, and green No Frills. A = Aroma, F = Flavour, M = Mouthfeel, T = Taste.

greater alcohol mouthfeel. SHZ3, chosen for the consumer trial, displayed primarily dried and dark fruit, chocolate, caramel, oak and pepper aromas and flavours, which is consistent with Australian Shiraz (Bastian *et al.*, 2010; Herderich *et al.*, 2012; Robinson *et al.*, 2013). Montepulciano has been described as showing dark fruit, cherry and earthiness attributes (Kalleske, 2016; Suzzi *et al.*, 2012). Australian-made Montepulciano wines used in the current study had characteristics of savoury, earth, dried and dark fruits, leather, oak, and meaty/salami, which is consistent with the current literature. MON1 and MON8 did show some deviation from SHZ3 in flavour and aromatics in Figure 3a but were closer in the third dimension (Figure 3b), displaying more chocolate, savoury and oak attributes akin to SHZ3.

Grenache and Nero d'Avola were shown to be consistent in flavour by both experts and trained tasters (Figures 1, 2a,b, 3a,b), confirming previous literature (Mezei *et al.*, 2021). Grenache displayed predominantly floral, blue flower, red fruit and confectionary aromas and flavours, with literature indicating the typicity of these attributes in Grenache (Alegre *et al.*, 2020). Nero d'Avola had nearly identical attributes to Grenache across the ten wines. Both the experts and trained tasters indicated that Nero d'Avola showcased floral and red fruit characteristics predominately, with the addition of confectionery. In terms of Nero d'Avola mouthfeel, most wines showed a negative correlation towards body and astringency, indicating they were lighter-bodied and less astringent. Nero d'Avola wines used in the consumer trial showed different intensities of certain attributes, with NERO5 being greater in red fruit and NERO8 in confectionery. The literature highlights Nero d'Avola as showing plum, cherry, raspberry, chocolate, and perfume attributes (Avellone *et al.*, 2018; Hickey, 2012; Robinson *et al.*, 2013), consistent with this study's findings.

Much of the current research on Nero d'Avola focuses on an Old-World understanding of this variety, showing that Nero d'Avola naturally has higher levels of flavans (Rinaldi and Moio, 2018), which evoke astringency compared to other native Italian varieties and also remains rich in these phenolic compounds as the wine ages, indicating higher astringent tendency within the varietal (Rinaldi and Moio, 2018). Other research shows Nero d'Avola as predominantly a fuller-bodied variety, yet can also show finesse and elegance (Avellone *et al.*, 2018). Whilst mouthfeel attributes noted in this study contradict those in the literature, it must be re-emphasised that the varieties used in this study are all derived from Australia and are therefore made differently than more traditional, Old-World styles. Clonal variation may also play a role in this difference in mouthfeel (Duchêne *et al.*, 2009). However, this study did not consider clonal variety nor the studies discussing Sicilian Nero d'Avola astringency and body (Avellone *et al.*, 2018; Rinaldi and Moio, 2018). Therefore, this may be the first study to look at New-World Nero d'Avola as displaying predominately lighter-bodied and less astringent profiles. Further research is required to investigate the flavour chemistry and phenolics to validate these claims, as well as the effects of clonal influence.

A preliminary study tentatively linked Cabernet-Sauvignon and Touriga Nacional as having similar flavour profiles (Mezei *et al.*, 2021). Not unexpectedly, Cabernet-Sauvignon was shown to predominantly display minty, eucalypt, herbaceous, green, savoury and cooked vegetable character by the experts and trained tasters, with some correlation towards astringency, fuller body, chocolate, leather and dark fruit attributes consistent with our other studies (Souza-Gonzaga *et al.*, 2019; Souza-Gonzaga *et al.*, 2020) CABS3, used in the consumer trial, retained predominant green and herbaceous characteristics, consistent with the literature (Capone *et al.*, 2018; Hashizume and Samuta, 1997; Robinson *et al.*, 2013). Touriga Nacional wines displayed sweet oak, caramel, red, dark, and dried fruit, tobacco, leather, and savoury attributes with greater body and aftertaste. TOUR6 displayed greater sweet oak, jammy and caramel attributes, with TOUR8 displaying red fruit and floral attributes. The third dimension biplot (Figure 3b) shows a closer correlation between the chosen Touriga Nacional wines and the Cabernet-Sauvignon. Our wines were consistent with the literature, where Touriga Nacional is described as having mulberry, cherry, dark fruit and floral attributes, with greater tannin and body (de Oliveira *et al.*, 2018; Falqué *et al.*, 2004; Robinson *et al.*, 2013). Cabernet-Sauvignon showed no cross-over in clusters with the Touriga Nacional, except for TOUR1 (Figure 1), with the remaining Touriga Nacional grouped together. The lack of herbaceous notes in Touriga Nacional (Falqué *et al.*, 2004) may explain why similarities between Cabernet-Sauvignon and Touriga Nacional were not noted by experts (Figure 1). Flavour and mouthfeel profiles appear more diverse for Touriga Nacional in the RATA panel (Figure 3a), yet they show a weaker correlation towards attributes more strongly correlated to Cabernet-Sauvignon (Figure 3a).

2. Understanding consumer liking towards emerging varieties

Understanding consumer acceptance and preference for wines made from emerging grape varieties in Australia that show promising adaptive abilities in warmer climates (Barbagallo *et al.*, 2021; Carvalho *et al.*, 2016; Kalleske, 2016) will provide assurance or not to wine grape growers and producers to cultivate these varieties within the market (Mezei *et al.*, 2021).

In this study (with the exception of MON2), both the trained panel and consumers scored each wine over five (on a 9-point scale), indicating liking. A previous study identified positive consumer hedonic preferences towards emerging varietal wines (Mezei *et al.*, 2021); however, it did not focus primarily on emerging varietal wines made entirely from Australian fruit.

There appeared to be a trend in consumer liking with Shiraz, Cabernet-Sauvignon, Montepulciano, Nero d'Avola, and both Touriga Nacional wines being preferred over the Grenache. However, this was not significant, and all wines were rated either as 6 or close to, indicating they were all equally well-liked.

Overall, all wines were liked by each consumer segment (WE, ASP and NFs). However, small differences were noted. WEs and ASPs were shown to like TOUR6 and MON8 significantly more than the NFs. Wine complexity is still not equivocal; however, a number of studies have suggested that wine experts and consumers agree it is a multilayered and multidimensional percept and constitutes layers of flavours and textures, but that the dimensions vary depending on the level of wine expertise (Parr *et al.*, 2011; Wang *et al.*, 2021). Wine professionals emphasised the effect of extrinsic factors, including wine production processes and terroir variables, on perceived complexity. Contrastingly, wine consumers focused on intrinsic flavours relating to their own experience and pleasure of tasting the wine (Parr *et al.*, 2011). Thus, these wines appear to meet the current definitions of possessing higher wine complexity and could be linked to different drivers of segment liking. Literature has shown WEs and ASPs preference towards more complex characteristics (Danner *et al.*, 2020; Mezei *et al.*, 2021; Parr *et al.*, 2011; Wang and Spence, 2019). NFs have been previously shown to have a preference towards wines with more simple attributes (Danner *et al.*, 2020; Mezei *et al.*, 2021), with the wines they rated higher (albeit not significantly) in the present study (MON1, NERO8) also being less complex, and more fruit-forward wines.

With WEs preferring wines with more complex attributes than NFs, winemakers and marketers should implement strategies to target these three distinct groups of consumers. By doing so, producers can make varying stylistic choices with their wines to conform to the different market segments and their tastes and needs. Future research is necessary to confirm this, but potentially using this strategy for emerging varietals within Australia may help consumers' acceptance, adoption and regular consumption.

3. Exploring the similarities between emerging and main-stream wine varieties

3.1. Wine expert point of view towards emerging and main-stream wine varieties similarity

A panel of wine experts performed a sensory sorting trial to form groups of similar wines to reveal if any emerging varietal wines were similar to wines made from mainstream varieties. The panel was not informed about the varieties and was told they were Australian dry red table wines. The expert dendrogram (Figure 1, blue cluster) showed that all three Grenache wines were grouped together with seven out of the ten Nero d'Avola wines. Thus, these wines were interpreted to be perceived as similar, as both the expert and trained panel (Figures 2a,b and 4a,b) consistently noted the same flavour and mouthfeel attributes, with both varieties producing wines with floral, red fruit and spice attributes, with lower body and astringency. These findings are consistent with the results of (Mezei *et al.*, 2021).

Extensive overlap of the sensory profiles of Shiraz and Montepulciano wines was also found. Previous literature has highlighted similar flavour profiles of Shiraz (Bastian *et al.*, 2010; Herderich *et al.*, 2012; Robinson *et al.*, 2013) and Montepulciano (Kalleske, 2016; Suzzi *et al.*, 2012). Expert data obtained in this study alludes to an observable similarity between these varieties, indicated by the group clustering of these varietals in the AHC dendrogram (Figure 1, orange cluster). Additionally, the expert AHC dendrogram showcased no clusters containing Cabernet-Sauvignon and Touriga Nacional together. Dendrogram (Figure 1, green cluster) also separated Touriga Nacional from Cabernet-Sauvignon (with the exception of TOUR1 in the orange cluster), contradicting the indication of similarity existing between these varietals. Compared to the literature, this appears representative of wines from this variety in Australia. The difference may have been because the Mezei *et al*. (2021) study used both European (Old World) varieties and fewer examples from each variety compared to the current study.

3.2. Wine consumer similarity response to emerging and main-stream wine variety

The reluctance observed in consumer purchase of unfamiliar wine indicates the hedonistic, non-utilitarian nature of this beverage (Lacey *et al.*, 2009). In other words, consumers are less inclined to take a perceived risk (Johnson and Bruwer, 2004). This orthodoxy may be countered by providing clear, unconfrontational product information to reassure consumers (Manske and Cordua, 2005). This notion is supported by studies determining that passing quality information to consumers through trusted agents, such as retailers and waiting staff, can lessen purchasing uncertainty (Hilger *et al.*, 2011). Since a strategy to grow the emerging varietal wine market may be by educating consumers as to what familiar wines the emerging varietal wines are similar to, one of the purposes of this study was to understand whether consumers perceived similarity between emerging and major varietals. Consumer understanding will enable the promotion of these varietals in the future and reduce fears and anxiety around the consumption of wines made from unfamiliar varieties (Mueller *et al.*, 2009). This could be achieved by communicating to the consumer the similarities in sensory characteristics of emerging wine varieties to the wines they usually consume, increasing their product choice as well.

The study by Mezei *et al.* (2021) concluded that certain emerging varieties could act as replacement varieties in the future. Montepulciano and Shiraz were shown to be similar in their flavour profiles in the Mezei *et al*. (2021) report; AHC (Figure 1) data in the present study supports this. However, the AHC data (Figure 1) for Montepulciano illustrates its potential as a highly versatile grape variety with an ability to make varying wine styles due to its presence across all three clusters, as suggested previously (Dry *et al.*, 2017). Consumer opinions towards the similarity of Montepulciano and Shiraz yielded the strongest perception of similarity in the study. Notably, there was no statistically significant difference in similarity reported between the different FWS, confirming that despite differences in understanding and knowledge of wine, all consumers generally agreed that the Montepulciano sample set appeared to be similar to Shiraz.

Both Montepulciano and Shiraz wines were derived from the Barossa Valley. They were described as fuller-bodied and heavier in style, with an average alcohol reading of 14.5 % v/v across the three wines (Supplementary Table 2). Montepulciano grown in other regions will likely show similarity to Shiraz from the same region, with future research necessary to further support the findings. Montepulciano, made as a full-bodied red wine reminiscent of Shiraz, is liked by consumers in the present study and perceived as being similar and, therefore, may have the potential to act as a substitute varietal.

Based on the data obtained from the expert and trained tasters, Nero d'Avola and Grenache showed the greatest potential for the similarity between varietals. Consumer evaluation, however, varied. Consumers as a cohort found one of the Nero d'Avola wines to be significantly different to the Grenache. However, as individual segments, ASPs and NFs found NERO5 to be significantly more similar to GREN1, whilst WEs did not. WEs' negative response to similarity for NERO5 could potentially be due to their greater skills with wine knowledge and involvement, indicating they may be able to pick up subtle differences indicating dissimilarity; however, this needs to be tested further with more examples.

The observed dissimilarity was likely related to the presence of more blue flower characters in the NERO8 example or the colour of the Nero d'Avola compared with the Grenache. Colour intensity data indicated that the Grenache used was lighter than the Nero d'Avola (Supplementary Table 1). Literature reports that colour influences an individual's perception of wine flavour and aroma (Parr *et al.*, 2003). Whilst consumers were indicated to disregard colour when analysing the similarity between wines, this may have played a role in their decision-making. Black glasses may have negated this issue with consumers; however, consumers normally use clear glasses when drinking wine.

Based on the results from the RATA panel, NERO8 showed a difference in perceivable flavours compared to NERO5 and GREN1. Additionally, NERO5 was derived from the McLaren Vale region, the same region as GREN1, while NERO8 was derived from the Barossa Valley. It appears Nero d'Avola's similarity to Grenache is like that between Montepulciano and Shiraz, where wines derived from the same region may invoke a greater similarity potential and could act as a replacement varietal.

Considering attribute differences between NERO5 and NERO8, it is unsurprising that a negative response to similarity, valued above 50 (Table 2), was associated between NERO8 and GREN1 for the consumer trial. However, it reduces the validity of a consistent, observable similarity between Nero d'Avola and Grenache from a consumer perspective. Future research may wish to examine Nero d'Avola and Grenache further, as the expert data showed a clear similarity in flavour profiles. ASPs and NFs found NERO5 and GREN1 to be significantly more similar than the WEs. NERO5 was noted as displaying increased red fruit attributes, which WEs and ASPs found to negatively affect their liking of the wine, whilst NFs did not find red fruit a driver of dislike towards the wine, but has been shown as a positive driver in previous research (Mezei *et al.*, 2021). Whether consumer hedonic responses influenced perceived similarity needs further investigation.

Confirmation that Nero d'Avola and Grenache display similarity from a consumer's perspective cannot, therefore, be confirmed conclusively from this research and would require a more detailed study. Wines more closely correlated in flavour to NERO5 and GREN1 (such as NERO1, NERO6 and NERO9) may have elicited a different result.

A similarity between wines made from Cabernet-Sauvignon and Touriga Nacional was shown by Mezei *et al.* (2021). Dissimilarity was seen between TOUR6 and CABS3 for both ASPs and NFs, yet the statistical difference between these segments and the WEs, who indicated similarity between this pairing, did not occur. When observing the overall similarity score between TOUR6 and CABS3, the similarity was denoted, indicating that consumer data found the two Touriga Nacional wines somewhat like Cabernet-Sauvignon. Despite this observation, expert AHC (Figure 1) illustrated the observed separation between Cabernet-Sauvignon and Touriga Nacional between groups, except for TOUR1 and CABS1 and CABS3 in group 2 (orange), highlighting divergence in flavour and aroma similarities.

Therefore, we conclude that Touriga Nacional cannot be identified as a clear substitute varietal for Cabernet-Sauvignon. Results indicated that consumers can clearly perceive the similarity between Touriga Nacional and Cabernet-Sauvignon. However, a lack of confidence from wine experts suggests that further research is warranted before accepting similarity.

4. Study limitations and proposed future improvements

This study aimed to add to the findings of Mezei *et al.* (2021) by increasing the sample number of wines assessed to improve the generalised sensory profiles of the wines. Whilst the sensory profiles of the wines yielded useful, indicative profile results, consideration of the wine's clonal variety must be addressed. Selection of different clonal varieties has been shown to be one of the major tools used to improve grapevine performance, such as inferring varietal resistance towards detrimental factors (Atak *et al.*, 2014). Yet, clonal variation has been shown to cause changes in the grape's characterisation and flavour (Duchêne *et al.*, 2009). Future research highlighting the effects clonal variation of these varieties has on consumer perceptions and flavour profiles, to see if the results are consistent with the current research, should be addressed.

Results from the RATA PCA biplots showed that Montepulciano and Touriga Nacional portray an array of sensory profiles. This indicates that the wines have a range of styles, enabling them to cater to differences in consumer preferences. Wines for the study were from several regions across South Australia and provided an indication of the aroma and flavour profiles available.

However, regionality has been shown to cause variations in wine composition and sensory attributes (King *et al.*, 2014; Kustos *et al.*, 2020; Liu *et al.*, 2020) and may be a factor in the wine's perceived flavour. However, the above studies used commercial wines, which avoid considering confounding factors such as different winemaking procedures. Therefore, studies that avoid commercial wines in favour of wines made under controlled conditions may provide a clearer examination of regional differences. Using Shiraz wines (n = 186) produced using identical production methods over three vintages from five subregions of Barossa Valley and Eden Valley, a recent study by Ranaweera *et al*. (2023) proposed that there also may be distinct sensorial differences in Australian wines derived from differing subregions. Nevertheless, regional typicality for emerging Australian varieties has not been explored. Future research could explore the sensory typicity of emerging varieties within different regions across Australia to confirm various claims on regionality. Differences in vintages similarly yield changes in aroma and mouthfeel (Sadras *et al.*, 2013) and should be researched further to indicate its effects on emerging varieties.

Our results indicate and confirm our previous studies that the FWI is a robust tool that reproducibly identifies very clear segment structures within Australian wine consumer data. Although some may think that the accuracy of segmentation analyses can be significantly improved upon increasing the sample size, the current authors believe this effect is stronger for more difficult segmentation tasks, but not in the case of data with a very clear segment structure.

Detailed chemical analysis, encompassing wine volatile and phenolic chemistry, should be assessed. As the study focussed primarily on sensory profiling and hedonic responses, determining the chemical composition will indicate which compounds are associated with each variety and drive consumer liking.

CONCLUSION

This study helps understand the consumer preferences for Australian wines made from emerging grape varieties. Pleasingly, all wines were liked by Australian consumers. The identification of subtle idiosyncratic drivers of liking between FWI segments suggests that more engaged wine consumers prefer different wine styles than less involved consumers. Shiraz was shown to have predominant aromas and flavours of dark and dried fruit, chocolate, caramel, oak and pepper, with higher levels of body and alcohol. Montepulciano yielded similar results, with the addition of savoury, leather and meaty/salami aromas and flavours. Nero d'Avola and Grenache were extremely similar in aroma and flavour, both showcasing red fruit, floral and confectionary notes whilst remaining low in body and tannin. Unsurprisingly, Cabernet-Sauvignon had green, minty, eucalypt, and savoury aromas and flavours, with Touriga Nacional differing in aroma and flavour, showcasing more red, dark, and dried fruit, tobacco, leather oak and sweet oak attributes with greater mouthfeel body and aftertaste.

Initial expert data and trained taster RATA suggested similarity between Grenache and Nero d'Avola, and Shiraz and Montepulciano. The consumer trials confirmed the similarity between Shiraz and Montepulciano, but results between Grenache and Nero d'Avola could not confirm the perceived similarity. Consumer data confirmed similarity between Cabernet-Sauvignon and Touriga Nacional, yet expert data highlighted a negative perception towards similarity, indicating similarity cannot be conclusively stated.

The knowledge obtained from this study has provided an understanding of wines made from purportedly more drought-resistant emerging varieties within Australia and the flavour profiles they provide. It also highlights strong consumer acceptance of these wines in blind taste trials relative to wines from more familiar, mainstream varieties. It also suggests a degree of similarity with mainstream wines. As such, these findings support the potential benefit of importing and cultivating more emerging varieties to sustain the wine industry into the future. As this study indicates that these wines could potentially act as substitutes for consumers of mainstream wines, the knowledge gained from this work will permit wine producers to encourage the consumption of emerging varietals by their consumer base, who typically consume wines made from mainstream varieties, expanding their wine choices and enhancing consumer satisfaction. As global temperatures continue to rise and viniculture becomes more complex, the adoption of emerging, drought-tolerant varieties may be a key piece in sustaining the Australian wine industry.

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