Author/s:
Xynas, B;Barnes, C;Howell, K

Title:
Moderating impacts of water addition in must by the use of Accentuated Cut Edges (ACE) vinification for Vitis vinifera cv. Shiraz winemaking

Date:
2024-06-07

Citation:
Xynas, B., Barnes, C. & Howell, K. (2024). Moderating impacts of water addition in must by the use of Accentuated Cut Edges (ACE) vinification for Vitis vinifera cv. Shiraz winemaking. Oeno One, 58 (2), https://doi.org/10.20870/oeno-one.2024.58.2.7936.

OENO One vine & wine

DOI: https://doi.org/10.20870/oeno-one.2024.58.2.7936

OPEN ACCESS

ORIGINAL RESEARCH ARTICLE

Moderating impacts of water addition in must by the use of Accentuated Cut Edges (ACE) vinification for *Vitis vinifera* cv. Shiraz winemaking

Billy Xynas*, Christopher Barnes and Dr Kate Howell

The University of Melbourne, School of Agriculture, Food and Ecosystem Sciences, Faculty of Science, Parkville, 3010 Victoria, Australia

*correspondence: billy.xynas@unimelb.edu.au

Associate editor: Valeriu Cotea

Received: 07 January 2024

Accepted: 23 April 2024

Published: 07 June 2024

ABSTRACT

In a warming climate, high-quality wine production is challenging due to grapes having higher sugar concentration, with wines being produced with higher alcohol levels, which can negatively impact final wine quality. Australian regulations now permit water treatment of pre-fermentation musts, which can ameliorate these effects, but final wines often lack colour and flavour. Accentuated Cut Edges (ACE) can overcome these drawbacks. ACE mechanically breaks grape skins into small fragments and accelerates phenolic extraction during wine fermentation, yet we do not know to what extent by reference to different applied levels of ACE. Expanding on previous studies, we implement ACE at three grape skin fragmentation levels: 10-second ACE treatment (low), 20-second ACE treatment (moderate (mod)) and 40-second ACE treatment (high), into pre-fermentation 15.5 °Bé musts for *Vitis vinifera* cv. Shiraz, which is then diluted with water to 13.5 °Bé. For chemical compounds, reduced total phenolics (a.u.) in diluted to 13.5 °Bé (no ACE) treatment wine (53.00 a.u.) can be addressed by diluted to 13.5 °Bé high ACE treatment, restoring levels similar to 15.5 °Bé (non-diluted no ACE) treatment wine (54.33 a.u.). Total tannins (%) are restored to a similar level as 15.5 °Bé (non-diluted no ACE) treatment wine (1.19 %) by diluted to 13.5 °Bé high ACE treatment (1.20 %). Sensory analysis for naïve wine consumers shows that diluted to 13.5 °Bé moderate ACE treatment produces wine with the greatest preference for colour intensity and increased preference for odour intensity and dark fruit taste. Further, 13.5 °Bé high ACE treatment produces a wine with the greatest preference for hotness and vegetal smell and an increased preference for dark fruit taste. Both diluted to 13.5 °Bé high ACE and diluted to 13.5 °Bé mod ACE treatment wines demonstrate a statistically significant increase in purchase likelihood when compared to 15.5 °Bé (non-diluted no ACE) and diluted to 13.5 °Bé (no ACE) treatment wines. If and when water treatment of pre-fermentative musts winemaking approaches become more widely accepted globally, it is important that all winemakers are provided with additional mitigation strategies such as ACE, which can further address any consequential impacts on final wine quality outcomes.

KEYWORDS: Accentuated Cut Edges (ACE), water dilution, chemical compounds, sensory parameters, wine quality.

ABBREVIATIONS

ACE: Accentuated Cut Edges

alc/vol: Alcohol by Volume

°Bé: degrees Baumé

Dilution: Water dilution treatment into a grape must pre-fermentation

FSANZ: Food Standards Australia and New Zealand

high ACE: High ACE implementation at 40 seconds

H_2O: Water

JAR: Just About Right

low ACE: Low ACE implementation at 10 seconds

MCP: Methyl Cellulose Precipitable

mod ACE: Moderate ACE implementation at 20 seconds

$Na_2S_2O_5$: Sodium metabisulphite

no ACE: No ACE implementation

PCA: Principle Component Analysis

PEACE: Pressed Early Accentuated Cut Edges

RATA: rate all that apply

SO_2: Sulphur Dioxide

INTRODUCTION

1. Climate Change, wine quality, and water treatment of pre-fermentation grape must

Due to warmer weather across Australia's grape-growing regions, compressed vintages are presenting significant challenges to winemakers (Terral *et al*., 2010; Petrie and Sadras, 2017; Webb *et al*., 2023). Increased atmospheric carbon dioxide can lead to faster growth of wine grapes, resulting in higher sugar concentrations in the berries (Webb *et al*., 2023). These developments can negatively affect the quality of a final wine, where shifts in relative humidity and hotter temperatures can lead to an increase in biomass, an increase in sugar and a decrease in acid levels in wine grapes at harvest, all impacting a final wine's alcohol levels, flavour and aroma (Schultz, 2010). These challenges are also relevant to winemakers globally (Cataldo *et al*., 2023).

Water treatment of pre-fermentative must is one winemaking technique that can be readily implemented to address fermentation issues associated with high sugar musts as well as addressing associated production of unfavourable alcohol levels in a final wine. However, this winemaking approach is currently not universally accepted. Importantly, the introduction of water into pre-fermentation musts is currently limited in the European Union, where water can only be used in those circumstances where it is for a 'specific technical necessity', and it does not modify the characteristics of wine (European Commission Regulation, 2018; Christmann, 2022). In the United States, however, water treatment of musts is an accepted practice that can be employed to facilitate fermentation, but the density of the juice cannot be reduced below 22 degrees Brix (United States Code of Federal Regulations 24.176, 2010).

In 2017, Australia implemented further regulatory changes where water addition into a pre-fermentative grape must is now permitted to 'facilitate fermentation' to 13.5 °Baumé (°Bé) (the measurement of grape sugar content) (FSANZ, 2017). The Australian approach was a response to the problems associated with high ethanol production arising during fermentation (Bindon *et al*., 2019) and as one answer to address the negative impacts on human health from the consumption of higher alcohol wines (Saliba *et al*., 2013). This study focuses on *Vitis vinifera* cv. Shiraz which is an important global grape cultivar and is the most planted red grape variety in Australia (Schelezki *et al*., 2020a); therefore, vinicultural approaches to maintain wine quality will have a high economic impact on both domestic consumers and the export market.

Recent studies have demonstrated that while water treatment of high sugar must facilitate the reduction of unfavourable ethanol yields during fermentation, it can also negatively impact the final wine flavour and colour (Harbertson *et al.,* 2009; Schelezki *et al*., 2020a; Schelezki et *al*., 2020b; Teng *et al*., 2020). While the outcomes of this study are relevant for Australian winemakers, should water treatment of pre-fermentative musts winemaking techniques become more generally recognised on a global scale, it is important that all winemakers are provided with additional mitigation strategies to address any consequential adverse impacts for final wine quality.

2. Accentuated Cut Edges (ACE) as an emerging wine-making approach

Accentuated Cut Edges (ACE) is one winemaking strategy that may address these impacts. ACE is a wine-making process in which the grape skins are mechanically cut into smaller fragments to assist in the extraction of phenolic components from the grape skin of the floating pomace cap in the early stages of fermentation (Sparrow *et al*., 2016a). During early fermentation, the extraction of phenolic compounds from the grape skins is greater due to more broken edges achieved through ACE. ACE has been shown to positively impact the phenolic composition of the final wine (Sparrow *et al.,* 2016a). In addition, it has been shown that ACE implemented by an industrial handheld mixer rather than by the implementation of an ACE machine-assisted approach can minimise seed damage, therefore limiting the extraction of associated bitter compounds (Sparrow *et al.,* 2016a).

Early studies for ACE processes focused on *Vitis vinfera* cv. Pinot noir, as this cultivar, can demonstrate poor colour development and low pigment stability, which can be negatively viewed by consumers who tend to prefer a more intense colour in red wines (Parpinello *et al*., 2009). ACE, when implemented to reduce grape skins to 6 % of their original size, was shown to produce Pinot noir wines with 50 % greater wine colour density and a 95 % higher stable pigment concentration when compared to the control no ACE wine (Sparrow *et al.,* 2016a). Tannin concentrations also increased for ACE-treated Pinot noir wines, together with higher intensities of fruity components, including banana, peach, blackcurrant and dark fruit, when compared to the control wine (Sparrow *et al*., 2016a; Sparrow *et al*., 2016b). An extended Pressed Early Accentuated Cut Edges (PEACE) vinification approach has also been shown to improve anthocyanidin and tannin levels for Pinot noir when compared to a no ACE control wine (Sparrow and Smart, 2017).

More recently, the ACE wine-making approach was applied to Shiraz, where Kang *et al*. (2020) found that for water-diluted treatments from 14.0 °Bé to 13.5 °Bé were also subjected to an ACE machine-assisted approach, the resultant accelerated release of wine components added to the flavour of earthy characters in the final wine. They also found that the impact on tannins and phenolic attributes of the final wine was not significantly affected when compared to a control wine; however, there were still significant negative dilution impacts on consumer-perceived wine aromas and flavours (Kang *et al*., 2020). When subject to an expert sensory panel, the water-diluted wines alone had a different astringency profile, but combining water dilution treatment with the ACE technique could address astringency, in particular the perception of adhesive and graininess aspects of the wine for the trained panel, but not the consumer panel (Kang *et al*., 2020). The later study by Wang *et al*. (2022) also investigated ACE impacts for water-treated must Shiraz wines. They observed that for volatiles, including acetates, higher alcohols, fatty acids, and isoprenoids, the results varied depending on the crushing methods employed as well as skin contact time. Apart from acetates, ACE short treatment (3 days racked off grape skins) demonstrated the highest potential for improvements to all groups of volatiles (Wang *et al*., 2022). Wang *et al*. (2022) also applied RATA (rate all that apply) sensory analysis (Danner *et al*., 2018) and found that it was only the 'red fruits', 'earthy/dusty', 'floral/ perfume/musk', 'herbaceous', and 'vanilla' attributes that were significantly different ($p < 0.1$) (Wang *et al*., 2022). Overall, Wang *et al*. (2022) found that ACE plus skin contact time had the potential to improve wine's volatile attributes as well as some sensory aspects of a final wine.

This study aims to expand on previous ACE studies to identify any changes in the chemical composition and sensory profiles of Shiraz wines that have also been subject to water dilution treatment of musts before fermentation, together with the ACE winemaking approach at three grape skin fragmentation levels. We test whether ACE implemented at varying levels can change the chemical composition of water-diluted wines when compared to wines that are not ACE-treated (non-diluted and diluted). We also test if ACE implemented at varying levels will influence consumer perceptions of different wine attributes between water-diluted wines when compared to the no ACE-treated wines (non-diluted and diluted) and if there is a difference in preference amongst consumers for each of the wine samples tested. Finally, we also test if different wine attributes impact consumer preferences more than others.

The outcomes of our study can be relevant for Shiraz wine producers in Australia and internationally as global warming continues to present winemakers with many challenges. This paper aims to provide advice to winemakers so that they can make supported and informed decisions when implementing a water dilution fermentation wine-making approach into high sugar musts to mitigate against the high production of ethanol during fermentation, together with alternative levels of ACE approaches implemented to further address desirable final phenolic and sensory wine quality parameters.

MATERIALS AND METHODS

1. Grape sample groups and fermentation

This Australian study relied on Shiraz grapes sourced from the Richard Tallis Winery (195 Major Plains Road, Dookie, North East Victoria, Victoria). Rows 85–91 were selected. These rows were all from the north-eastern block on Richard Tallis' property (36°21'08.2'S, 145°45'37.0'E). The block consisted of 18 rows of Shiraz grapes. These rows were selected for their relatively middle position within the block to reduce end-row influences. The rows selected consisted of 54 panels of 200 vines, with approximately 50 vines contributing to the grapes taken in each season. Row spacing was approximately 2.8 meters. Vines were planted approximately 1.2 meters apart. Only one late harvest at 15.5 °Bé was conducted for a total harvest of 900 kg of fruit. At harvest, fruit was selected randomly from panels along the length of each row, taking fruit from both sides of the vine. Each panel was assigned a number and, using a randomiser, selected at random for harvest. All fruit were hand-harvested.

There were 15 triplicate sample groups of 60 kg, each producing approximately 36 litres of wine; therefore, a total of 540 litres of wine (more due to dilution of ferments) was produced. All grape must treatment sample groups were subjected to crushing through rotary roller crushers set at 8 mm spacing before being separated into their own fermentation tanks/treatment groups (15 in total). Three triplicate sample groups were then subject to 3 levels of Accentuated Cut Extraction (ACE): low ACE, moderate (mod) ACE and high ACE treatments (as detailed below). All sample groups except for the triplicate 15.5 °Bé (non-diluted no ACE) sample group were then subject to diluted must treatment (+ 4.07 L water) to lower 15.5 °Bé to 13.5 °Bé (Figure 1). Deionised water was used for water treatments to minimise chlorine/chloramines that may impede fermentation and stain the flavour of the wine. The water addition to must winemaking approach is permitted under Australian regulations (FSANZ, 2017). The volume of water added was calculated using the Australian Wine Research Institute online water addition calculator (AWRI, 2023, available at : https://www.awri.com.au/industry_support/winemaking_resources/calculators/water-additions/). The two no ACE sample groups consisted of a 15.5 °Bé (non-diluted no ACE) treatment and a diluted to 13.5 °Bé (no ACE) treatment (Figure 1).

A standard 50 ppm SO_2 (*Sodium metabisulphite,* Australian Home Brewing, Victoria 2020) was added to all sample

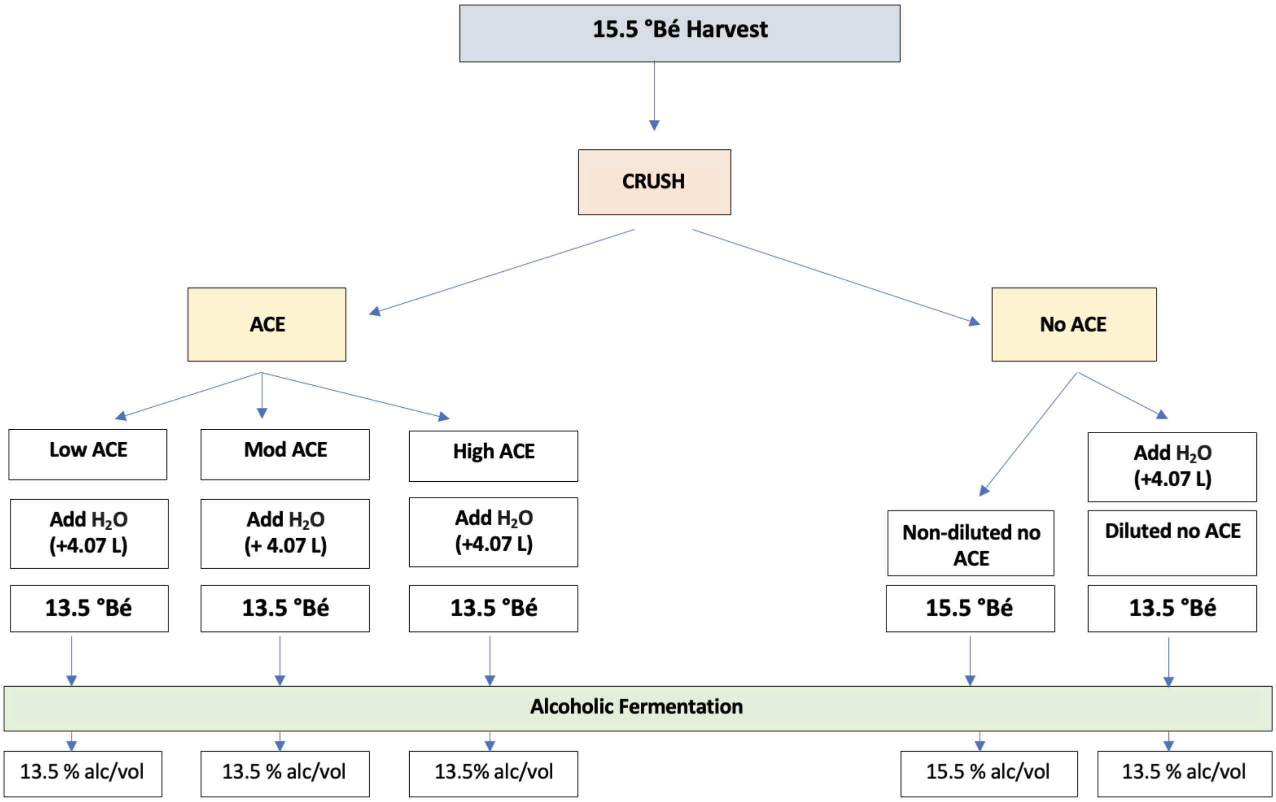

FIGURE 1. Pictorial representation of the ACE experimental design outline.

groups at crush, followed by inoculation with *Vitilevure Syrah* YSEO™ (*Saccharomyces cerevisiae var. cerevisiae*, Danstar, Rhone Valley, France 2020) commercial culture of yeast (at 30 g/hL). After 24 hours, all fermentations were then inoculated with *Martin Vialatte Reflexmalo 360™ (Oneoccocus oeni,* Martin Vialatte, Magenta, France, 2020) lactic acid bacteria (1 g/hL) to carry out malolactic fermentation. All fermentations were maintained on skins for 5 days using refrigeration to maintain temperatures between 20 °C and 30 °C before being pressed. A daily sampling of 100 mL from each treatment group was taken during fermentation, which tracked temperature and degrees Baumé (°Bé). Musts all finished alcoholic fermentation on day 5. Acid additions were made post-pressing on day 5 to target a titratable acidity (TA) of 6 g/L (2 g/L tartaric acid addition) (Australian Tartaric Products, Victoria, Australia, 2020). An additional 50 ppm SO_2 addition was added 21 days after fermentation prior to bottling wines in 750 mL glass wine bottles and matured at an average temperature of 18 °C for 12 months.

2. Accentuated Cut Edges (ACE) treatment approach

Accentuated Cut Edges (ACE) skin fragmentation approach using an industrial handheld mixer machine (Robot Coupe MP600 Ultra (B2B), with a 600 mm shaft) was implemented as this ACE approach has been shown to minimise seed damage (Sparrow *et al.*, 2016a); and to also further provide for different fragmentation levels. Three groups of must samples in triplicate were subject to skin fragmentation treatment, each at a different level of ACE. Low ACE involved holding the handheld mixer into fermenters for 10 seconds at low speed (set at speed level 1, where the highest speed was level 10). Moderate ACE was used for 20 seconds at low speed. High ACE is used for 40 seconds at low speed. These 3 sample groups were then all subject to water diluted must treatment (+ 4.07 L water) to lower 15.5 °Bé to 13.5 °Bé (Figure 1).

3. Chemical analysis approach

Samples of wines 12 months after bottling for this study were taken from each treatment group. Wine colour absorbances were measured using Agilent Cary 60 UV-Vis (Agilent Technologies Inc., Palo Alto, CA, USA) with a 1 mm path length quartz cuvette (Somers and Evans, 1974). Deionised water was set as the blank reference. Each analysis was performed in triplicate. Measures of wine pigmented tannin %, chemical age 1 and 2, colour density (a.u.), free anthocyanins (mg/L), hue, pigmented tannin (a.u.), total phenolics (a.u.), total pigment (a.u.) and total tannin (%) were undertaken for each of the must treatment sample groups. The Somers colour assay was modified to allow the standardisation of pH and ethanol concentrations of wine sample groups in a simple one-step dilution with a buffer solution, thus removing inconsistencies between wine matrices (Mercurio *et al.*, 2007). The main modification was to standardise wine pH to pH 3.4 and the alcohol concentration to 12 % v/v using a buffer solution before any analysis was undertaken. Sodium metabisulphite ($Na_2S_2O_5$) was incorporated into the buffer solution rather than being added directly to individual sample groups, thus minimising preparation time (Mercurio *et al*., 2007). Tannin measurements were derived from a calibration developed from the methylcellulose precipitable (MCP) tannin assay (Sarneckis *et al*., 2006).

4. Just-About Right (JAR) sensory analysis approach

Ethics approval was provided by the University of Melbourne's Human Research Ethics Committee (HREC) (No. 11684) for the Just-About-Right (JAR) naïve consumer sensory analysis surveys for the final wines utilising a Likert scale (Likert, 1932).

The naïve sensory analysis data was collected from sensory panels from wine students in February 2023. Testing was taken after students had some level of preliminary training in sensory analysis experiences through their concurrent studies. Visual, olfactory and mouthfeel sensory attributes were tested. Samples of wines 12 months after bottling were taken from each treatment group. Sample groups were evaluated by 79 naïve wine consumers to evaluate the properties of colour intensity, red fruit smell, dark fruit smell, ripe fruit smell, vegetal smell, odour complexity, our intensity, red fruit taste, dark fruit taste, ripe fruit taste, vegetal taste, astringency, hotness, body, viscosity and length. Data were collected on a non-structured linear scale, where the middle of the scale for each attribute corresponded to 'Just About Right' for the naïve sensory panellists (Likert, 1932). For each sensory attribute, panellists ranked the wine sample group on a five-level Likert scale ranging from too weak/pale, weak/pale, Just About Right, strong/a little dark, and too strong/too dark. Overall liking was scored on a 9-point line scale ranging from dislike extremely to neutral to like extremely. Likelihood to purchase was scored on a 5-point line scale ranging from extremely unlikely to neutral to extremely likely. In addition, the JAR was combined with overall liking scores to highlight those attributes of a wine that have the greatest impact on liking, where a Penalty Analysis was taken (Schraidt, 2009; Cadot *et al*., 2012). The aim of 'Penalty Analysis' generally is to assess the influence of a non-JAR category for a given attribute by assessing a 'penalty' to reflect the consumer's overall liking of a wine.

Panellists were provided with an introductory baseline session to inform them of the process and the requirements and risks associated with the JAR before commencing the survey. The panellists agreed upon reference standards to familiarise them with the colour and odour intensities and complexities, red, ripe and dark fruit attributes, as well as for vegetal, hotness, astringency, body, viscosity, length and balance. For colour intensity, panellists were provided with a chart of red colours, which displayed red from light to dark red. For odour complexity, intensity, length, balance, and panellists were engaged in repetitive training sessions. Other sensory attributes were measured against a reference sample standard of 30 mL of Shiraz wine. For red fruits 'aroma and taste', this consisted of mixing in 2 strawberries, 2 cherries and 4 raspberries. For dark fruit 'aroma and taste', this consisted of mixing in 4 blackberries and 4 blueberries. For ripe fruits 'aroma and taste', this consisted of mixing in 8 crushed raisins. For vegetal 'aroma and taste', this consisted of mixing in 1 teaspoon of grated capsicum. For hotness 'mouthfeel and texture', this consisted of mixing in food-grade ethanol to raise the alcohol level by 2 %. For astringency 'mouthfeel and texture', this consisted of adding 0.2 g powered white tannin. For body 'mouthfeel and texture', this consisted of adding 0.2 g of powdered tannin and food-grade ethanol to raise the alcohol level by 2 %. For viscosity 'mouthfeel and texture', this consisted of adding 0.02 g/L of food-grade soluble Xanthan gum (Table 1).

The 5 sample groups were then presented to panellists in 30 mL aliquots in coded ISO standard wine classes during daylight hours. Each panellist was provided with 5 sample groups, all presented at once in a randomised order. The 5 sample groups were evaluated in one sitting. Paper scoring sheets for each wine sample group were given to each panellist and collected by the researchers at the end of the sessions.

5. Statistical analysis approach - chemical compounds

Statistical analysis for chemical compounds (mean values and standard deviation (SD)) and sensory evaluation was undertaken by using independent sample group t-test, two-way analysis of variance (ANOVA) followed by Tukey's HSD multiple comparison test ($\alpha = 0.05$), and principal component analysis (PCA) were conducted with R Project for Statistical Computing. For individual phenolic components in each of the wine sample groups, data was analysed using repeated measures of variance (ANOVA) with treatment (process) approaches as fixed factors.

6. Statistical analysis approach - sensory parameters

A Linear Mixed Effects Model (LMM) approach was applied, where linear mixed-effects models were fitted to the ratings of each attribute (Zuur et al., 2009). A separate model was used for each attribute: for colour intensity, red fruit smell, dark fruit smell, ripe fruit smell, vegetal smell, odour complexity, odour intensity, red fruit taste, dark fruit taste, ripe fruit taste, vegetal taste, astringency, hotness, body, viscosity, length and overall liking and purchase likelihood. The linear mixed-effects model allowed for nested random effects for each attribute assessed. Wine treatment (process) was considered a fixed effect, while panellist was considered a random effect. Where the P-value was equal to or less than the significance level (≤ 0.05), then it could be assumed that the process (wine treatment) significantly affected the response received.

RESULTS

1. ACE treatments increase fragment size, particle number, total perimeter and surface area of grape berries

ACE was applied at three different levels, low, moderate, and high, to influence the fragment size, particle number, total perimeter (cm) and surface area (cm^2) in the grape berries.

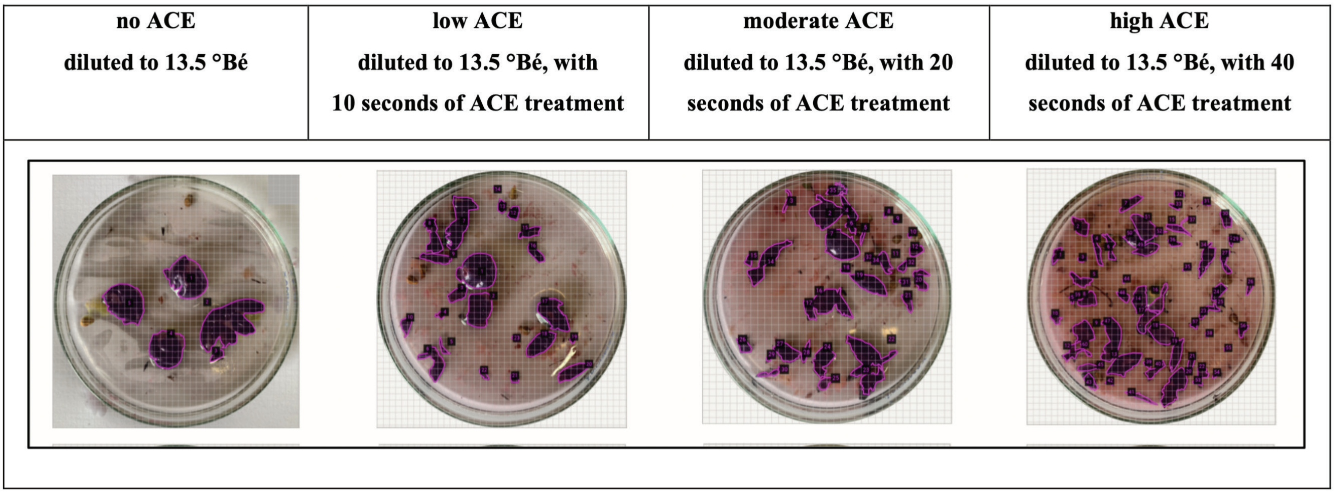

FIGURE 2A. Grape skin pulp and skin fragments based on the time of ACE treatment.

Representation of the skins after ACE treatment but before any water dilution or fermentation commences. A representative image of each triplicate group is shown.

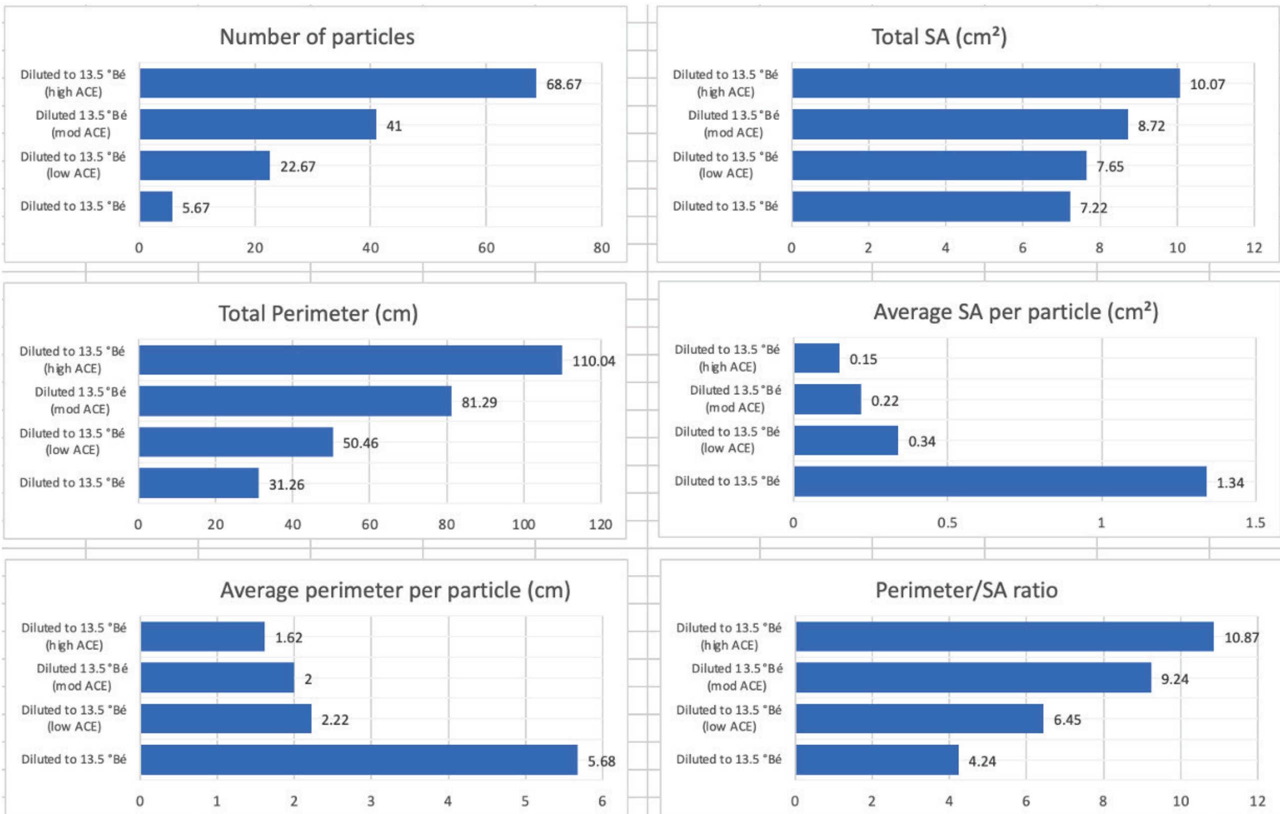

FIGURE 2B. Quantification of ACE skin fragmentation.

Mean results for triplicate samples are presented.

These 3 sample groups were repeated in triplicate, where the mean results are shown (Figures 2A, 2B).

Following ACE application, the 3 ACE treated sample groups were subject to diluted must treatment through the addition of deionised water (H_2O) (+ 4.07 L) to lower 15.5 °Bé to 13.5 °Bé. A further 2 sample groups consisted of 15.5 °Bé (non-diluted no ACE) (in triplicate) and diluted to 13.5 °Bé (no ACE) (in triplicate). Again, mean results are shown (Figures 2A, 2B).

A 5 g sample was taken from each fermentation and placed into 90 mm petri dishes. The fragments were floated in 15 mL water, pressed on a piece of graph (5 mm x 5 mm grid) paper and photographed. The number of fragments per berry from their surface area and perimeter was calculated using open-source image analysis software ImageJ 1.51a (Wayne Rasband, National Institutes of Health, USA, available at : https://imagej.net/ij/). (Figures 2A, 2B)

The number of particles (fragment size), as presented in the sample group Petri dishes, are at the highest levels with the implementation of a high ACE treatment (Figure 2A,B). When compared to the diluted to 13.5 °Bé (no ACE) sample group with 5.67 berry particles, the number of berry particles for the diluted to 13.5 °Bé high ACE sample group increased to 68.67. The total surface area (cm²) remained stable for all ACE treatments and increased only moderately from the diluted to 13.5 °Bé (no ACE) sample group with a surface area of 7.22 cm² up to 10.07 cm² for the diluted to 13.5 °Bé high-ACE sample group. The total perimeter (cm) increased progressively as the duration of ACE treatment undertaken increased, from low to moderate to high ACE implementation. For the diluted to 13.5 °Bé (no ACE) sample group, the total perimeter was 31.26 cm, which increased to 110.04 cm for the diluted to 13.5 °Bé high ACE sample group. The average surface area per particle (cm²) decreased as the duration of the ACE treatment undertaken increased. For the diluted to 13.5 °Bé high ACE sample group, the average surface area was 0.15 cm² when compared to 1.34 cm² for the diluted to 13.5 °Bé (no ACE) sample group. The average perimeter per particle (cm) also decreased as the duration of the ACE treatment undertaken increased. For the diluted to 13.5 °Bé high ACE sample group, the average perimeter per particle was 1.62 cm when compared to 5.68 cm for the diluted to 13.5 °Bé (no ACE) sample group. The Perimeter/Surface Area ratio increased as the duration of ACE treatment undertaken increased, where the Perimeter/Surface Area ratio for the diluted to 13.5 °Bé (no ACE) sample group was at a 4.24 ratio, increasing to a 6.45 ratio for the diluted to 13.5 °Bé low ACE sample group, up to a 9.24 ratio for the diluted to 13.5 °Bé moderate ACE sample group, increasing to a 10.87 ratio for the diluted to 13.5 °Bé high ACE sample group (also refer to Supplementary information Supplementary Table 1 for supporting data).

2. ACE treatment can have statistically different impacts on some but not all chemical compounds in wine

ACE applied at the three different levels, low, moderate, and high, can influence chemical parameters and outcomes for the treated wines at statistically different levels (Figure 3).

Figure 3 sets out ACE treatment effects on the chemical compounds of pigmented tannin %, chemical age 1 and 2, colour density (a.u.), free anthocyanins (mg/L), hue, pigmented tannin (a.u.), total phenolics (a.u.), total pigment (a.u.) and total tannin (%), as compared to the 15.5 °Bé (non-diluted No ACE) and diluted to 13.5 °Bé (no ACE) treatment groups (also refer to Supplementary materials Supplementary Table 2 for raw data that supports the representations in Figure 3).

Free anthocyanins are measured in the highest concentrations in the 15.5 °Bé (non-diluted no ACE) treatment group (538.00 mg/L), with all other treatments having statistically significant lower results for free anthocyanin concentration.

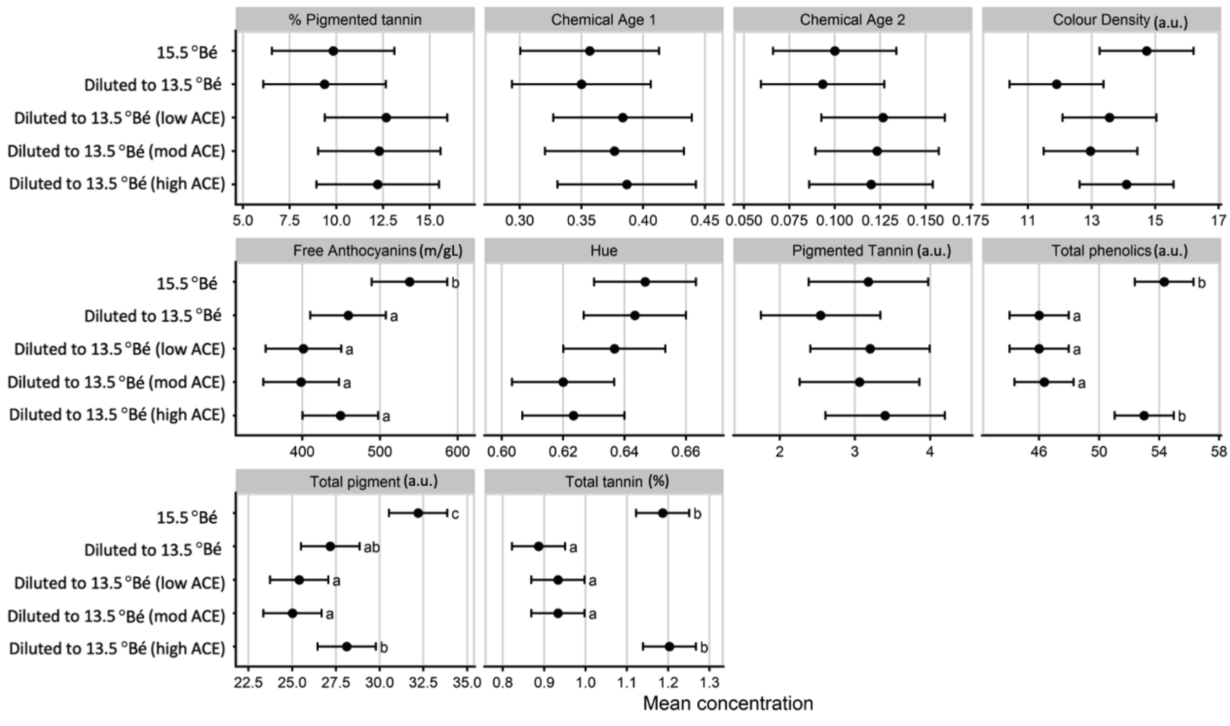

FIGURE 3. Chemical compound concentrations differ by ACE treatment and water dilution of must treatments.

Mean results for triplicate samples are presented. Error bars show 95 % confidence intervals for the mean. Groups not sharing a letter are statistically significantly different ($p < 0.05$).

The lowest observed free anthocyanin concentration is in the diluted to 13.5 °Bé low ACE and in the diluted to 13.5 °Bé mod ACE treatment groups (401.33 mg/L; 398.33 mg/L). The diluted to 13.5 °Bé high ACE treatment group shows higher free anthocyanin concentration (449.00 mg/L) than the diluted to 13.5 °Bé low ACE treatment group (410.33 mg/L) and in the diluted to 13.5 °Bé mod ACE treatment group (398.33 mg/L); however, this is not statistically significant. Total phenolic concentrations are highest in the 15.5 °Bé (non-diluted no ACE) treatment group (54.33 a.u.) and in the diluted to 13.5 °Bé high ACE treatment group (53.00 a.u.). All other treatments have statistically significantly lower results for total phenolics. The highest concentration of total pigment is shown in the 15.5 °Bé (non-diluted, no ACE) treatment group (32.20 a.u.). All other treatment groups have statistically significantly lower results for total pigment. Total tannin is shown to be highest in the 15.5 °Bé (non-diluted no ACE) treatment group (1.19 %) and in the diluted to 13.5 °Bé high ACE (1.20 %) treatment group. All other treatments have statistically significantly lower results for total tannin. For chemical ages 1 and 2, values are similar across all treatment groups, where none are statistically significantly different to each other (Figure 3, Supp. Table 2).

3. ACE treatment affects sensory attributes, including colour intensity, dark fruit taste, astringency, hotness and length

A Just About Right (JAR) approach was a direct approach to measure the deviation from ideal levels per sensory attribute for each wine sample (Rothman and Parker, 2009). The JAR measured the perceived attribute intensities but did not directly quantify them (Cadot *et al*., 2010). The sensory attributes of each wine sample were scored by the consumer naïve panellists according to the sensory standards developed (Table 1).

The JAR sensory outcomes show that the diluted to 13.5 °Bé high ACE treatment group has the highest colour intensity; however, this is observed as being ‘too high’. All treatments without ACE show the lowest preference relating to vegetal smell. The 15.5 °Bé (non-diluted no ACE) treatment group also shows high odour intensity; however, this is rated as ‘too high’. All ACE treatment groups show the highest overall preference for dark fruit taste, with the diluted to 13.5 °Bé mod ACE being the highest preference treatment. The diluted to 13.5 °Bé (no ACE) treatment group shows the lowest observed dark fruit taste. All ACE treatment groups show increased astringency; however, this is not demonstrated to

TABLE 1. Sensory standards given to panellists for wine attributes for type, definitions, and reference standards.

Wine Attributes	Type	Definitions	Reference Standard mixed with 30 mL of Shiraz wine
Colour intensity	Visual	Intensity of colour	Provided a chart of red colours displayed from light to dark red.
Odour complexity	Olfactive (aroma)	Overall smell, complexity, richness	Repetitive training sessions
Odour intensity	Olfactive (aroma)	Intensity of odours overall	Repetitive training sessions
Red fruits	Olfactive (aroma and taste)	Wine aromas that suggest strawberry, raspberry, cherry smells and taste	2 strawberries, 2 cherries and 4 raspberries
Dark fruits	Olfactive (aroma and taste)	Wine aromas that suggest black currants and taste	4 blackberries and 4 blueberries
Ripe fruits	Olfactive (aroma and taste)	Wine aromas and tastes that suggest ripe fruits, candied fruits	8 raisins crushed
Vegetal	Olfactive (aroma and taste)	Vegetal, Herbaceous, sweet pepper smell and taste	1 teaspoon of grated green capsicum
Hotness	Mouthfeel/texture	Warmth perception of overly pronounced or high levels of alcohol	Add food-grade ethanol to raise alcohol level by 2%
Astringency	Mouthfeel/ Texture	Tannins with smooth and fine textured astringency	Add 0.2 g of powered white tannin
Body	Mouthfeel/Texture	Wine marked by richness, fullness; full-bodied	Add 0.2 g powered white tannin and food-grade ethanol to raise the alcohol level by 2%
Viscosity	Mouthfeel/Texture	The viscosity as an indicator of a full-bodied style	Add 0.02 g/L food-grade soluble Xanthan gum
Length	Mouthfeel/Texture	The time that aftertaste persists in the mouth	Repetitive training sessions
Balance	Mouthfeel/Texture	Balance between aromas, flavour, structure and mouthfeel	Repetitive training sessions

be a positive preference by panellists. The 15.5 °Bé (non-diluted, no ACE) and diluted to 13.5 °Bé high ACE treatment groups both show greatest overall preference for hotness. The diluted to 13.5 °Bé high ACE treatment group also shows the greatest overall observed length; however, this is demonstrated to be 'too high' with the lowest preference of all other treatment groups, including diluted to 13.5 °Bé (no ACE) and 15.5 °Bé (non-diluted no ACE) treatment groups (Figure 4, Figure 7A,B) (Refer to Supplementary materials Supplementary Table 3 for supporting data).

4. Assessment and purchase likelihood are increased in ACE-treated wines

The diluted to 13.5 °Bé high ACE and the diluted 13.5 °Bé mod ACE treatment groups are the highest rated in overall assessment when compared to all other treatment groups; however, there is no statistically significant difference shown between treatment groups and consumer overall liking of the wines. (Figure 5) Purchase likelihood shows a statistically significant preference for the diluted to 13.5 °Bé mod ACE treatment group when compared to the diluted to 13.5 °Bé (no ACE), 15.5 °Bé (non-diluted no ACE) and the diluted to 13.5 °Bé low ACE treatment groups. These results are not statistically different from the diluted to 13.5 °Bé high ACE treatment group; however, both the diluted to 13.5 °Bé mod ACE and diluted to 13.5 °Bé high ACE treatment groups show a statistically significant increased preference for purchase likelihood when compared to diluted to 13.5 °Bé (no ACE) and 15.5 °Bé (non-diluted no ACE) treatment groups (Figure 5).

Penalty analysis results demonstrate that 'too little' body and 'too little' red fruit taste are the only two attributes in the critical corner. 'Too little' of these two attributes are observed to have the most negative impact on overall liking when observed in the JAR scale. The diluted to 13.5 °Bé low ACE treatment group has the lowest in the observed body. The diluted to 13.5 °Bé (no ACE) treatment group has the lowest observed red fruit taste. Consumer perception is that these two treatment groups have the lowest observed concentration of the attributes; however, this is not statistically significantly different from any other treatment group in each attribute category (Figure 6).

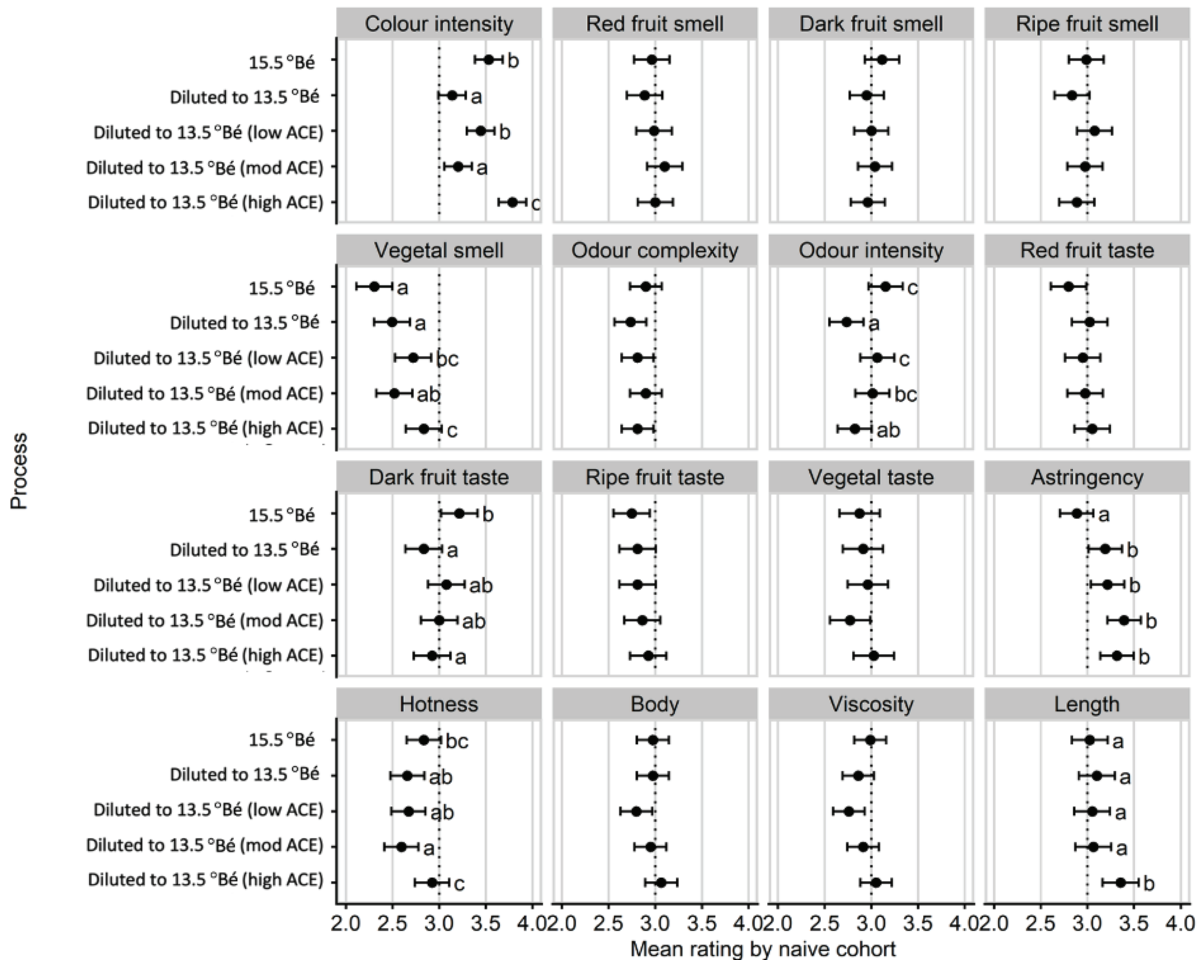

FIGURE 4. ACE impact on sensory parameters of a final wine.

Mean results for triplicate samples are presented. Error bars show 95 % confidence intervals for the mean. Groups not sharing a letter are statistically different ($p < 0.05$).

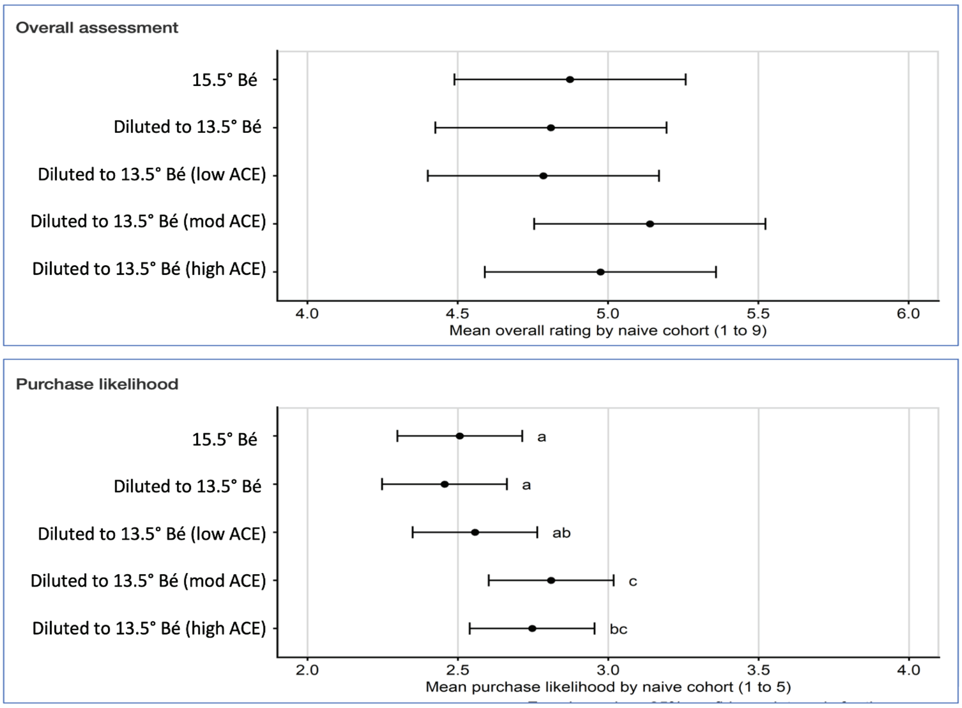

FIGURE 5. Sensory assessment of overall assessment and purchase likelihood for the naïve panellists.

Mean results for triplicate samples are presented. Error bars show 95 % confidence intervals for the mean. Groups not sharing a letter are statistically different ($p < 0.05$).

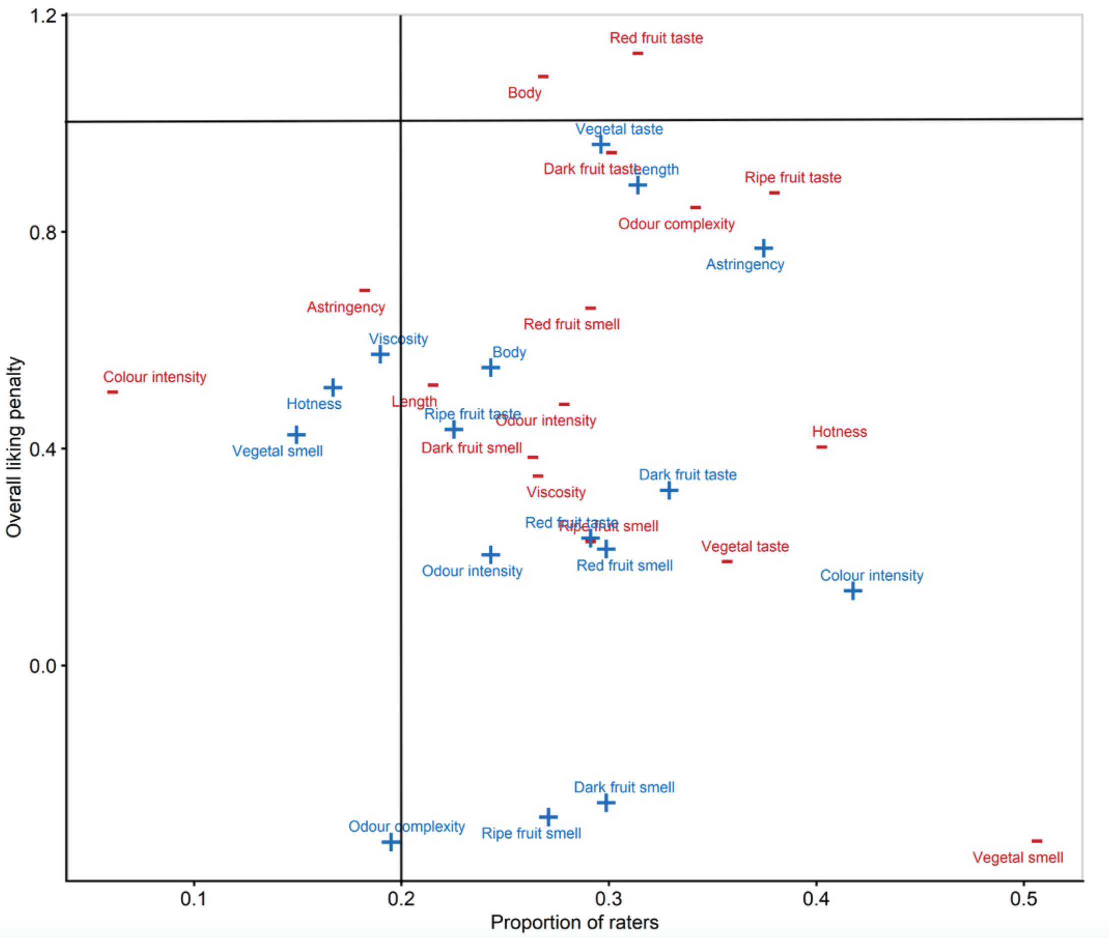

FIGURE 6. Overall Liking Penalty and Proportion of raters for sensory attributes.

'+' denotes too much of an attribute, and '-' denotes too little of an attribute.

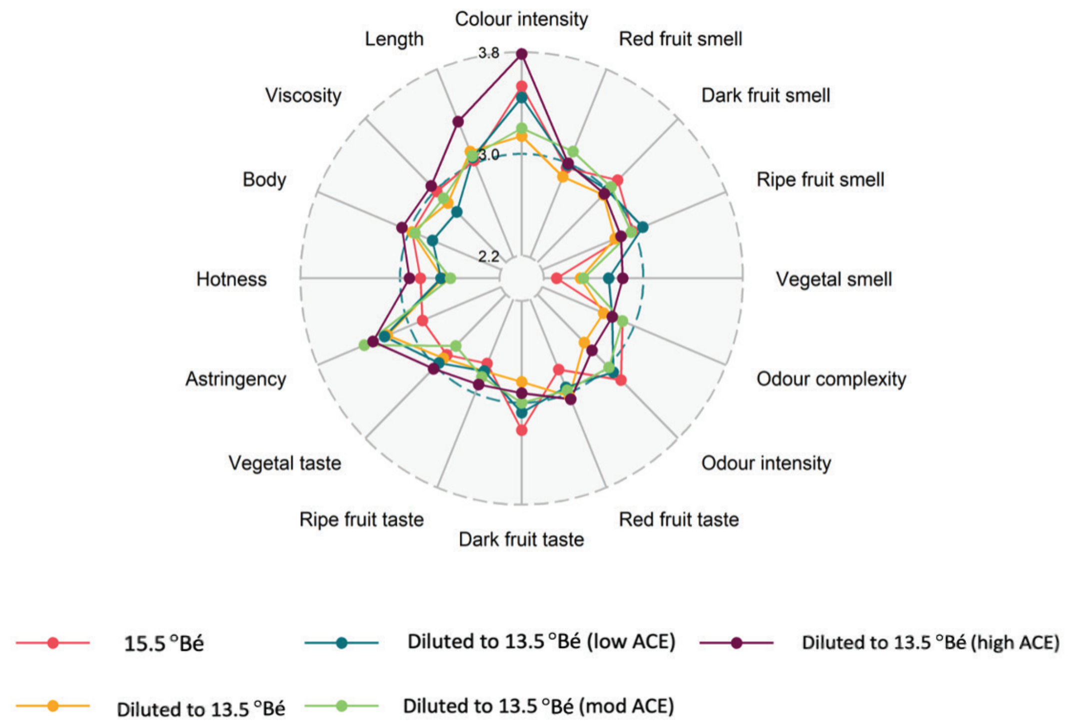

FIGURE 7A. Descriptive sensory analysis of the wines made with ACE-treated must.

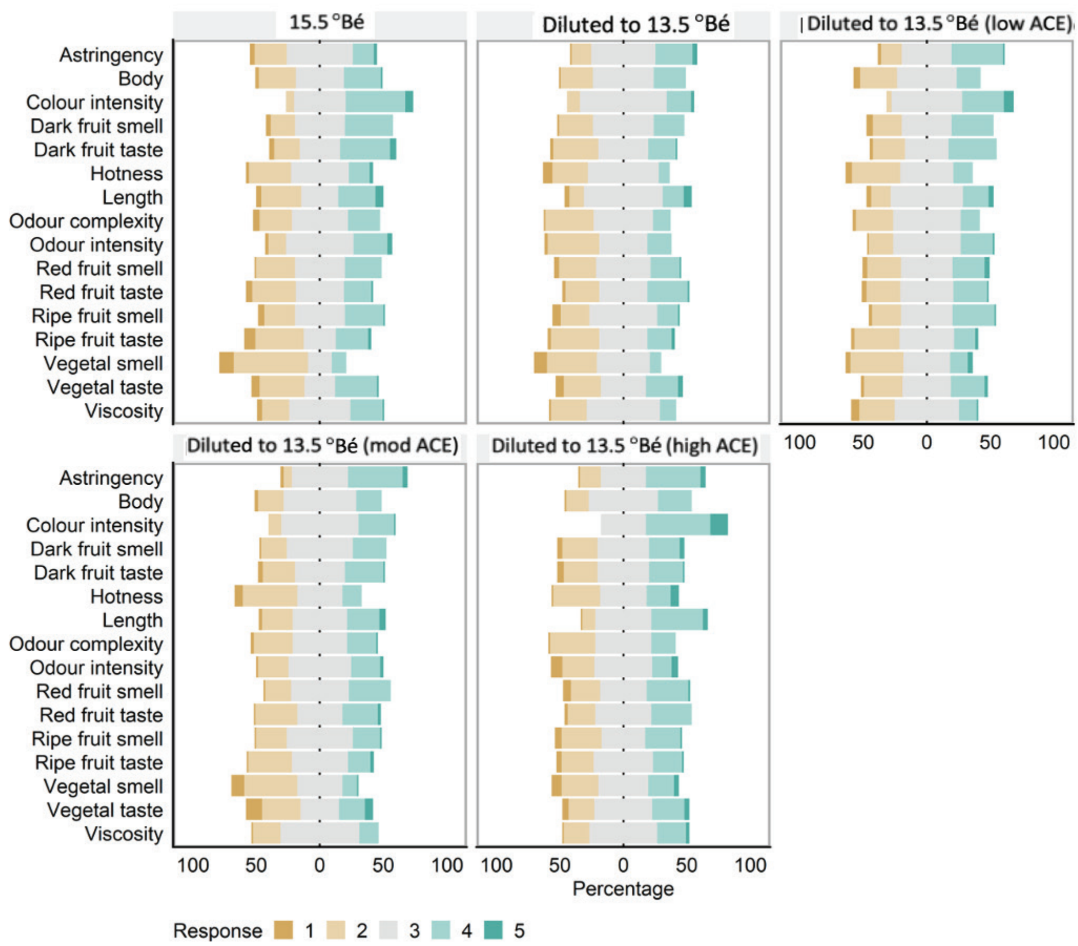

FIGURE 7B. Likert Plot - Visual representation of the sensory Just-About-Right (JAR) naïve sensory panellist JAR datasets where the larger the grey mid-section, the higher preference a particular attribute is.

DISCUSSION

Concerns regarding wine quality (Jackson, 2008) and consumer aversion to the production of high-alcohol wines (Saliba *et al*., 2013; Gawel *et al*., 2013; Burro *et al*., 2023) have led to a number of fermentation strategies being adopted in both the laboratory and commercially to address the reduction of ethanol yields during fermentation of musts, while also considering the impact on other wine organoleptic qualities. One approach is water addition or water substitution into pre-fermentation high sugar musts (FSANZ, 2017; Bindon *et al*., 2019; Teng *et al*., 2020; Schelezki *et al*., 2020a). However, recent studies show that this winemaking approach can lead to a significant decrease in phenolic concentrations and can also negatively impact sensory parameters when compared to a late-harvest non-treated wine (Teng *et al*., 2020; Schelezki *et al*., 2020a). Previous studies have also indicated that because ethanol will contribute to the final wine aroma, tannins and flavour (Carpena *et al*., 2020), there is also a need to balance the desired reduction in ethanol production with other desirable wine flavonoids (Remize *et al.,* 1999). These concerns are addressed by this study, where the implementation of the Accentuated Cut Edge (ACE) wine-making technique to maintain final wine quality is examined.

1. Diluted 13.5 °Bé ACE treatment can restore total phenolics (a.u.), but none of the ACE treatments can restore free anthocyanins (mg/L) levels for a water-treated must, young Shiraz wine

The extraction of phenolic compounds is important in determining final wine quality attributes (Rousserie *et al*., 2019; Kassara and Kennedy, 2011). Total phenolics in wines which have been subjected to water treatment of their musts pre-fermentation have been shown to be negatively impacted (Schelezki *et al*., 2020a; Schelezki *et al*., 2020b; Teng *et al*., 2020). We find that the diluted to 13.5 °Bé high ACE treatment can restore total phenolics (53.00 a.u.) to similar levels to that of 15.5 °Bé (non-diluted no ACE) (54.33 a.u.) treatment, where all other treatments are observed to have statistically significantly lower results for total phenolics. These outcomes agree with other previous work implementing ACE wine-making approaches (Sparrow *et al*., 2016a; Kang *et al*., 2020; Wang *et al*., 2022; Cheng *et al*., 2022).

Anthocyanins are water-soluble flavonoid pigments that, depending on pH and, in some cases, complexing agents, can contribute diverse colours in red wine, from slight red to dark purple (Gil-Muñoz *et al*., 2021). Water dilution treatment of high sugar musts has decreased wine anthocyanins or colour density (Teng *et al*., 2020). Our findings also find that water addition to the 15.5 °Bé must results in a statistically significant decrease in free anthocyanins in the diluted 13.5 °Bé (no ACE) treatment (538.00 mg/L; 459.00 mg/L). We show that applying ACE at all levels into water diluted musts does not significantly address this impact. These findings can be related to all ACE treatment wine samples being tested early after only one-year post-bottling. In young wines, wine anthocyanins have not yet had time to react with other acids and compounds in the wine, such as tannins, pyruvic acid and acetaldehyde, which will change the colour of the wine, causing it to develop more ‘brick red’ hues (Teng *et al*., 2020). Our outcomes indicate that for this wine quality parameter, ACE implemented at all levels in a water-treated must young Shiraz wine will have minimal influence.

2. Diluted to 13.5 °Bé high ACE treatment can increase total tannin (%) but has no effect on Chemical Age 1 or 2 for water treated must, young Shiraz wine

Tannins are important flavonoids in wine production. Tannins will come from the grape skins, pips (seeds) and stems, and the wood barrels used during ageing. Tannins provide texture and mouthfeel to wine as well as a sense of weight, structure and ageing potential (Schelezki *et al*., 2020b). The extraction and retention of tannins from the skins and seeds of red grapes in must are significantly influenced by the conditions throughout the wine fermentation process, including temperature, ethanol concentration, and pH levels (Beaver *et al*., 2019; Watrelot and Norton, 2020). Grape skin tannins are readily extractable in the must due to grape skin breakage and the presence of ethanol, which serves as a solvent during fermentation and maceration, allowing for the early release of tannins and anthocyanins into the wine (Kennedy, 2008). Extraction of tannins from grape seeds takes longer and depends on ethanol produced by yeasts during alcoholic fermentation of grape sugars present in the must (González-Manzano *et al*., 2004).

In our study, temperatures of all ferments were maintained to address any possible associated impacts on chemical compounds. However, we find that water dilution treatments affect chemical compound concentrations to varying degrees. Previous research has shown that adding water to the fermentation process inevitably dilutes the must, affecting the overall sugar concentration, impacting the fermentation process’s ability to produce ethanol. In turn, changes in ethanol content caused by adding water to a must have a significant adverse impact on the tannin extraction kinetics since ethanol plays a major role in the extraction of tannins (Schelezki *et al*., 2020b; Teng *et al*., 2020; Harbertson *et al*., 2009). Our results are in line with these findings, where we show that the diluted to 13.5 °Bé (no ACE) treatment wine (with a corresponding decrease in final alcohol levels (13.5 % alc/vol)), has a statistically significant decrease in total tannin (0.89 %) when compared to the 15.5 °Bé (non-diluted no ACE) treatment (1.19 %). By implementing ACE treatment, we show that total tannin (%) in the diluted high ACE treatment group (1.20 %) is restored to a similar level as the 15.5 °Bé (non-diluted no ACE) treatment group (1.19 %) (Figure 3, Supp. Table 2). Our results are consistent with those of Kang *et al*. (2020), who also show that ACE can increase the concentration of tannin and total phenolics in wine, which has had its must subject to pre-fermentation water treatment (Kang *et al*., 2020). It could be that the high ACE treatment in our study can enhance tannin extraction where the usual binding of tannin molecules by polysaccharide structures of cell wall fibres reached saturation point before the seed tannins are fully extracted (Bindon *et al*., 2010), which allows for a significant proportion of extracted tannins to remain in the wine matrix rather than being discarded with the grape marc at pressing. In early maceration and fermentation, anthocyanins can bind with proteins in the grapes and drop out as sediment. Keeping tannins in the must allows some tannins to bind with the proteins instead. Tannins will also bind with anthocyanins, which can stabilise dissolved pigments, which will also assist in preserving colour (Li *et al*., 2020). The restoration of tannins by high ACE treatment in water-treated musts is thus an important positive outcome that winemakers can consider.

Notably, while the chemical age 1 level is highest for the diluted to 13.5 °Bé high ACE treatment group, and the chemical age 2 level is highest for the diluted to 13.5 °Bé low ACE treatment group, these levels are not statistically significantly different from any other treatment groups. Chemical age 1 and chemical age 2 have been defined by the extent to which monomeric anthocyanins are displaced by polymeric pigment forms and can indicate wine ageing potential (Somers and Evans, 1977). Previous findings have found that chemical age 1 and 2 indices significantly correlate with maturation time regardless of other influences (Basalekou *et al.,* 2017). Our results agree with this, where they may be attributed to the Shiraz treatment wines in this study all being young (1 year after bottling), where no statistically significant changes will occur for these chemical attributes regardless of treatments implemented.

3. ACE treatments can restore some sensory parameters in water treated must, young Shiraz wine

3.1. Diluted to 13.5 °Bé high ACE treatment can restore colour intensity

In this study, all wine samples were first tested visually. This is because colour and appearance generally provide a first impression and can be associated with wine quality. If the colour is not what is expected for the wine in question, this may impact all other sensory parameters being tested (Ailer *et al*., 2020). Water-diluted must-treated wines have negatively impacted wine colour intensity (Teng *et al*., 2020). By combining ACE with water treatment of musts, we show that for colour intensity, diluted to 13.5 °Bé high ACE treatment wine has the greatest overall colour intensity score, which agrees with Sparrow *et al*. (2016b), who observed that ACE-treated Pinot noir wine had the highest proportion of red colour, when compared to non-ACE treated wine samples (Sparrow *et al*., 2016b). However, in our study, sensory panellists find it 'too high' with the lowest preference of all treatment groups. Interestingly, 15.5 °Bé (non-diluted, no ACE) treatment wine and diluted to 13.5 °Bé mod ACE treatment wine show greatest preference for colour intensity. For this sensory parameter alone, it can be deduced that while ACE can restore colour intensity in Shiraz wines with pre-fermentation musts subject to water treatment, untreated wines can still be preferred.

3.2. Diluted to 13.5 °Bé high ACE treatment can restore mouthfeel and texture

The mouthfeel and texture properties of wine are a complex mixture of taste and mouthfeel sensations, mostly astringency and flavour (Canon *et al*., 2022). These non-taste sensations are a consequence of oral-tactile stimulations and are considered just as important as wine appearance, aroma and taste sensory parameters of a wine (Canon *et al*., 2022). Studies have shown that water addition treatments of musts implemented to reduce final alcohol levels in final wines can negatively impact mouthfeel and texture sensory parameters (Teng *et al*., 2020). Petrie *et al*. (2019) showed that late harvest 15.5 °Bé non-treated wines displayed higher hotness, viscosity, astringency and opacity than wines produced from water-treated musts (Petrie *et al*., 2019). In this study, we assess the mouthfeel and texture sensory parameters of astringency, hotness, body, viscosity and length for all diluted ACE treatment wines to determine if ACE can address the impacts on these sensory parameters from water treatment of musts.

Addressing the sensory parameter of hotness, in particular, can be important, especially for water-diluted treated wines where ethanol levels are decreased. This is because the sensation of hotness is associated with ethanol, which can increase the complexity perceived in a wine (Meillon *et al*., 2009). In this study, our naïve sensory study panellists score the diluted to 13.5 °Bé high ACE treatment wine with the greatest overall preference for hotness along with the 15.5 °Bé (non-diluted no ACE) treatment wine, where all other treatment wines are observed as having hotness as 'too low'. This indicates that the diluted to 13.5 °Bé high ACE treatment can replicate or offset the loss in hotness when compared to other treatments with dilution and match that of the 15.5 °Bé (non-diluted no ACE) treatment wine effectively. This could result from an increase in other structural chemical compounds in the wine, such as total phenolics and total tannin, as noted above (Li *et al*., 2020). A high ACE wine-making implementation in a diluted must may, therefore, address the negative impact of the loss of ethanol on sensory parameters in a water-treated wine alone. Related to this is the sensory parameter of wine astringency (Vidal *et al*., 2015; Piombino *et al*., 2020). Total tannins and total phenolic chemical measures will also contribute to the perception of astringency. As noted above, the diluted to 13.5 °Bé high ACE diluted treatment will positively impact these chemical parameters. We also find that all ACE treatments will modify the astringency reduction caused by water dilution alone (diluted to 13.5 °Bé (no ACE)). This may be associated with an increased perception of graininess intensities (Bajec and Pickering, 2008). This result is consistent with previous studies undertaken for the Pinot noir variety (Sparrow *et al*., 2016b). In our study, however, sensory panellists found that astringency levels were 'too high' for all ACE treatment Shiraz wines, with no preference for any of the treatments indicated by panellists.

The sensory parameter of length is also important for a wine, as it can also indicate its quality. The longer the taste of the wine lingers, the higher the quality it is perceived to have

(Canon *et al*., 2022). This study's sensory outcomes show that the diluted to 13.5 °Bé high ACE treatment wine has the greatest overall observed length. However, it is observed as 'too high' and has the lowest preference of all treatment wines. No difference in length is observed between other treatments. It may be deduced that the diluted to 13.5 °Bé high ACE treatment increases length too much. However, in lower implementation, diluted to 13.5 °Bé low ACE and diluted to 13.5 °Bé mod ACE treatments can maintain a preference for length comparable to that of other treatments without ACE (15.5 °Bé (non-diluted no ACE), diluted to 13.5 °Bé (no ACE)).

3.3. Diluted to 13.5 °Bé high ACE treatment can produce preferred vegetal smell, and diluted to 13.5 °Bé mod ACE treatment can produce preferred odour intensity

Wine aromas will also play an important role in the acceptability of wine and will influence consumer preferences (Sáenz-Navajas *et al*., 2016; André *et al*., 2023). For this study, treatment wines without ACE (15.5 °Bé (non-diluted no ACE) and diluted to 13.5 °Bé (no ACE)) have the lowest preference relating to vegetal smell. We find that ACE can increase the preference for vegetal smell, where sensory panellists indicate the highest preference for the diluted to 13.5 °Bé high ACE treatment wine. For odour intensity, 15.5 °Bé (non-diluted no ACE) treatment wine exhibits the highest score; however, this is rated as 'too high' by the sensory panellists and has the lowest preference of all treatment wines. This may be attributed to corresponding high ethanol levels of 15.5 % alc/vol compared to other diluted treatments at 13.5 % alc/vol. The lowest odour intensity is shown in the diluted to 13.5 °Bé (no ACE) treatment wine, where all ACE treatment groups effectively increase odour intensity. This is in line with previous studies that found that ACE can positively address decreases in odour intensity for wines that have been subject to water treatment of must pre-fermentation (Kang *et al*., 2020). Interestingly, our study finds that the diluted to 13.5 °Bé mod ACE treatment wine has the highest preference for odour intensity, indicating that ACE at this level is an effective strategy to increase odour intensity concentrations and preference in water diluted wines, whereas it does not become 'too high'.

3.4. All ACE treatments can restore dark fruit taste sensory parameter with diluted to 13.5 °Bé mod ACE treatment most preferred

Taste is also an essential element that will indicate wine quality and can demonstrate varying levels of consumer liking (Canon *et al*., 2022). Taste covers four main receptor-mediated, gustatory sensations: sweet, bitter, sour and salty. The flavour is the combination of the taste buds and the olfactory receptors. Non-volatile compounds contribute to taste, and volatile compounds contribute to aroma (Canon *et al*., 2022). Previous studies have found that for wines which have had their musts subject to water treatment pre-fermentation, negative impacts on wine sensory parameters of taste and flavour will result (Petrie *et al*., 2019; Piccardo *et al*., 2019; Schelezki *et al*., 2018a; Schelezki *et al*., 2018b). This can include 'cooked vegetable', drain, savoury, and acidic characteristics (Petrie *et al*., 2019; Piccardo *et al*., 2019). By adding ACE to water-treated must, ACE can restore some of the favourable taste/ flavour sensory parameters in a final wine. 15.5 °Bé (non-diluted, no ACE) treatment wine has the highest observed dark fruit taste; however, this is noted as 'too high' and has the lowest preference of all treatments. Diluted to 13.5 °Bé (no ACE) treatment wine shows the lowest observed dark fruit taste. The diluted to 13.5 °Bé mod ACE treatment wine has the highest preference, indicating that ACE treatment can effectively offset the dilution of dark flavours. However, there is no statistical difference between diluted to 13.5 °Bé (no ACE) treatment and all other ACE treatments despite their increased preference. We also show that with respect to red fruit taste and flavour, ripe fruit taste and flavour, and vegetal taste and flavour, no statistical differences were observed between any of the treatments. These results may be related to Shiraz wines, which are generally associated with attributes of dark fruits (Pearson *et al*., 2018), where ACE may have less impact for this variety on these sensory parameters.

4. Consumer preference for ACE and water-treated must, young Shiraz wines

By adding ACE to water-treated musts, we find that diluted to 13.5 °Bé high ACE and diluted to 13.5 °Bé mod ACE treatment wines are highest rated overall compared to other treatment wines. However, no statistically significant difference was observed in consumers' overall liking of the wines between treatments. Regarding purchase likelihood, the diluted to 13.5 °Bé mod ACE treatment wine shows a statistically significant preference compared to the 15.5 °Bé (non-diluted no ACE), diluted to 13.5 °Bé low ACE, and diluted to 13.5 °Bé (no ACE) treatment wines, but these are not statistically significantly different from the diluted to 13.5 °Bé high ACE treatment wine. Both the diluted to 13.5 °Bé high ACE and diluted to 13.5 °Bé mod ACE treatment wines demonstrate a statistically significant increase in purchase likelihood when compared to 15.5 °Bé (non-diluted no ACE) and diluted to 13.5 °Bé (no ACE) treatment wines. The overall increase in purchase likelihood is consistent with statistically significant differences observed in individual attribute preferences. Overall, liking analysis is undertaken using a penalty analysis approach. This penalty analysis demonstrates that the 'too little' body and 'too little' red fruit taste are the only two attributes in the critical corner. 'Too little' of these two attributes is shown to have the most negative impact on overall liking when observed in the JAR scale. Diluted to 13.5 °Bé low ACE treatment wine is shown as having the lowest score for body. Diluted to 13.5 °Bé (no ACE) treatment wine shows the lowest score for red fruit taste. It could be noted that although consumer perception is that these two treatments have the lowest observed concentration of these attributes, this is not statistically significantly different from any other treatment in each attribute category, so definite conclusions cannot be adequately drawn from these results.

CONCLUSION

In this study, the must extraction wine-making technique Accentuated Cut Edges (ACE) was applied at three different levels (low ACE, mod ACE and high ACE), where the ACE-treated musts were then subjected to water dilution treatment pre-fermentation. The diluted to 13.5 °Bé high ACE treatment was effectively able to offset the outcome of reduced total tannin (%) and total phenolics (a.u.) due to water dilution alone, but not for free anthocyanins (mg/L). Sensory results demonstrated that the diluted to 13.5 °Bé mod ACE treatment wine had the greatest preference for colour intensity, odour intensity and dark fruit taste for the Shiraz cultivar. In addition, the diluted to 13.5 °Bé high ACE treatment wine showed the greatest preference for hotness and vegetal smell and an increase in preference for dark fruit taste. Wine producers can implement ACE must extraction techniques when they are required to address final wine alcohol levels while still addressing impacts on flavour and taste associated with pre-fermentative water treatments. While water treatments of pre-fermentation musts are not yet approved winemaking approaches in many countries, we suggest that as global warming and its impacts on grape growing and wine production continue to be of increasing concern, international winemakers can be kept abreast of developments in Australia. This study demonstrates ACE as a valid wine-making process for Shiraz, which has the potential to positively address any resultant negative impacts on final wine phenolic and sensory aspects related to water dilution fermentation approaches.

ACKNOWLEDGEMENTS

This work, predominately conducted at the University of Melbourne's Dookie Campus, was funded by Australia's grape growers and winemakers through their investment body, Wine Australia, and Australian Research Training Program funding from the Australian government. We thank Richard Smart for his encouragement relating to the trials undertaken in this study. We are very appreciative to Richard Tallis for supplying the Shiraz grapes from his vineyard in Dookie, Victoria, which were used in this study. We would also like to thank those students who put time aside to undertake the wine tastings. Lastly, we would also like to thank Cameron Patrick, who was instrumental in collating the chemical and sensory data presented in the figures and tables.

REFERENCES

Ailer, S., Magdalena, V., Jaroslav, J., Jakub, M., & Mojmír, B. (2020). Influence of Sugar and Ethanol Content and Color of Wines On the Sensory Evaluation: from Wine Competition 'Nemčiňany Wine Days' in Slovak Republic (2013-2016). *Erwerbs-Obstbau. 62*(24**).** https://doi.org/10.1007/s10341-020-00486-x

André, F. C., Riquier, L., de Revel, G., & Tempere, S. (2023) Sensory dominances depend on the wine quality dimension. *Food Quality and Preference*, *112*. https://doi.org/10.1016/j.foodqual.2023.104998

Bajec, M. R., & Pickering, G. J. (2008). Astringency: Mechanisms and perception. *Crit. Rev. Food Sci. Nutr*., *48*, 858–875. https://doi.org/10.1080/10408390701724223

Basalekou, M., Pappas, C., Kotseridis, Y., Tarantilis, P.A., Kontaxakis, E., & B Kallithraka, S. (2017) Red Wine Age Estimation by the Alteration of Its Color Parameters: Fourier Transform Infrared Spectroscopy as a Tool to Monitor Wine Maturation Time. *J Anal Methods Chem*., 5767613. https://doi.org/10.1155/2017/5767613

Beaver, J. W., Miller, K. V., Medina-Plaza, C., Dokoozlian, N., Ponangi, R., Blair, T., Block, D., & Oberholster, A. (2019) Heat-Dependent Desorption of Proanthocyanidins from Grape-Derived Cell Wall Material under Variable Ethanol Concentrations in Model Wine Systems. *Molecules, 24*, 3561. https://doi.org/10.3390/molecules24193561

Bindon, K. A., Smith, P. A., Holt, H., & Kennedy, J. A. (2010). Interaction between grape derived proanthocyanidins and cell wall material. 2. Implications for vinification. *J Agric. Food Chem*., *58*, 10736-10746. https://doi.org/10.1021/jf1022274

Bindon, K. A., Teng, B., Smith, P. A., Nandorfy, D. E., Solomon, M., & Petrie, P. R. (2019). Winemaking with high Baume juice: optimising fermentation and extraction. Paper presented in cooperation with the Seventeenth Australian Wine Industry Technical Conference 21–24 July 2019. Edited by Kate Beames, Ella Robinson, Peter Dry and Dan Johnson. 131-133. Conference Proceedings. https://awitc.com.au/proceedings/17AWITC.pdf

Burro, R., Branchini, E., Capitani, E., Barnaba, V., Fermani, A., Paradis, C., & Bianchi, I. (2023). Is there an association between consumers' personality traits and the sensory characteristics they look for in wine? *Food Quality and Preference*, *105*, 104767. https://doi.org/10.1016/j.foodqual.2022.104767

Cadot, Y., Caillé, S., Samson, A., Barbeau, G., & Cheynier, V. (2010). Sensory dimension of wine typicality related to a terroir by Quantitative Descriptive Analysis, Just About Right analysis and typicality assessment. *Analytica Chimica Acta, 660*(1-2**),** 53-62. https://doi.org/10.1016/j.aca.2009.10.006

Cadot, Y., Caillé, S., Thiollet-Scholtus, M., Samson, A., Barbeau, G., & Cheynier, V. (2012). Characterisation of typicality for wines related to terroir by conceptual and by perceptual representations. An application to red wines from the Loire Valley. *Food Quality and Preference*, *24***,** 48-58. https://doi.org/10.1016/j.foodqual.2011.08.012

Canon, F., Caillé, S., Sarni-Manchado, P., & Cheynier, V. (2022). 2 - Wine taste and mouthfeel, Editor: Andrew G. Reynolds, In Woodhead Publishing Series in Food Science, Technology and Nutrition, Managing Wine Quality (Second Edition), Woodhead Publishing, 41-95. https://doi.org/10.1016/B978-0-08-102067-8.00009-9

Carpena, M., Fraga-Corral, M., Otero, P., Nogueira, R. A., Garcia-Oliveira, P., Prieto, M. A., & Simal-Gandara, J. (2020). Secondary Aroma: Influence of Wine Microorganisms in Their Aroma Profile. *Foods, 10*(1), 51. https://doi.org/10.3390/foods10010051

Cataldo, E., Eichmeier, A., & Mattii, G. B. (2023). Effects of Global Warming on Grapevine Berries Phenolic Compounds—A Review. *Agronomy*, *13*(9), 2192. https://doi.org/10.3390/agronomy13092192

Cheng, Y., Savits, J. R., & Watrelot, A. A. (2022). Effect of the Application Time of Accentuated Cut Edges (ACE) on Marquette Wine Phenolic Compounds. *Molecules, 27*, 542-557. https://doi.org/10.3390/molecules27020542

Christmann , M. (2022). International Organisation of Vine and Wine (OIV), Information Report On Water In Oenology. Available at https://www.oiv.int/public/medias/8821/oiv-information-report-on-water-in-enology.pdf

Danner, L., Crump, A. M., Croker, A., Gambetta, J.M., Johnson, T.E., & Bastian, S. E. P. (2018). Comparison of rate-all-that-apply and descriptive analysis for the sensory profiling of wine. *American Journal of Enology and Viticulture, **69**(1),* 12-21. https://doi.org/10.5344/ajev.2017.17052

European Commission Regulation (2018). (EU) No 1308/2013 of the European Parliament and of the Council of 17 December 2013 establishing a common organisation of the markets in agricultural products and repealing Council Regulations (EEC) No 922/72, (EEC) No 234/79, (EC) No 1037/2001 and (EC) No 1234/2007. *Official Journal of the European Union*, *347*, 671-854. http://data.europa.eu/eli/reg/2013/1308/oj

FSANZ (2017). Food Standards Australia New Zealand -FSANZ-Standard 4.5.1: Wine Production Requirements. https://doi.org/10.4135/9781412972093.n134

Gawel, R., Van Sluyter, S. C., Smith, P. A., & Waters, E. J. (2013). Effect of pH and Alcohol on Perception of Phenolic Character in White Wine. *American Journal of Enology and Viticulture*, *64*(4), 425. https://doi.org/10.5344/ajev.2013.13016

Gil-Muñoz, R., Moreno-Olivares, J. D., Paladines-Quezada, D. F., Bleda-Sánchez, J. A., Cebrían-Pérez, A., Giménez-Bañón, M. J., & Fernández-Fernández J. I. (2021). Characterization of Anthocyanins From Intraspecific Crosses of Monastrell With Other Premium Varieties. *Frontiers in Nutrition, 8*. https://doi.org/10.3389/fnut.2021.664515

González-Manzano, S., Rivas-Gonzalo, J. C., & Santos-Buelga, C. (2004) *Extraction* of flavan-3-ols from grape seed and skin into wine using simulated maceration. *Anal. Chim. Acta., 513*, 283-289. http://doi: 10.1016/j.aca.2003.10.019

Harbertson, J. F., Mireles, M. S., Harwood, E. D., Weller, K. M., & Ross, C. F. (2009). Chemical and sensory effects of saignée, water addition, and extended maceration on high brix must. *American Journal of Enology and Viticulture, 60*, 450-460. https://doi.org/10.5344/ajev.2009.60.4.450

Jackson, R. S. (2008). Wine Science: Principles and Applications, 3rd ed.; Academic Press: San Diego, CA, USA, 270–331.

Kang, W., Bindon, K. A., Wang, X., Muhlack, R. A., Smith, P. A., Niimi, J., & Bastian, S. E. P. (2020). Chemical and Sensory Impacts of Accentuated Cut Edges (ACE) Must Polyphenol Extraction Technique on Shiraz Wines. *Foods, 9*(8), 1027-1055. https://doi.org/10.3390/foods9081027

Kassara, S., & Kennedy, J. A. (2011). Relationship between red wine grade and phenolics. 2. Tannin composition and size. *Journal of Agricultural and Food Chemistry*, *59,* 8409-8412. https://doi.org/10.1021/jf201054p

Kennedy, J. A. (2008). Grape and wine phenolics: Observations and recent findings. *Cienc. Investig. Agrar., 35*, 107–120. https://doi: 10.4067/S0718-16202008000200001

Li, L., Li, Z., Wei, Z., Yud, W., & Cui, Y. (2020). Effect of tannin addition on chromatic characteristics, sensory qualities and antioxidant activities of red wines. *RSC Advances, 10,* 7108-7117. https://doi.org/10.1039/c9ra09846a

Likert, R. (1932). A Technique for the Measurement of Attitudes. *Archives of Psychology, 140*, 1-55. https://idoc.pub/documents/1932likerta-technique-for-the-measurement-of-attitudespdf-vlr0oozp3xlz

Meillon, S., Urbano, C., & Schlich, P. (2009). Contribution of the Temporal Dominance of Sensations (TDS) method to the sensory description of subtle differences in partially dealcoholized red wines. *Food Quality and Preference, 20*(7), 490-499. https://doi.org/10.1016/j.foodqual.2009.04.006

Mercurio, M. D., Dambergs, R. G., Herderich, M. J., & Smith, P. A. (2007). High Throughput Analysis of Red Wine and Grape Phenolics - Adaptation and Validation of Methyl Cellulose Precipitable Tannin Assay and Modified Somers Color Assay to a Rapid 96 Well Plate Format. *Journal of Agricultural and Food Chemistry*, *55* (12), 4651-4657. https://doi.org/10.1021/jf063674n

Parpinello, G. P., Versari, A., Chinnici, F., & Galassi, S. (2009). Relationship among sensory descriptors, consumer preference and color parameters of Italian Novello red wines. *Food Res. Int., 42,* 1389-1395. https://doi.org/10.1016/j.foodres.2009.07.005

Pearson, W., Schmidtke, L., Franci, L., & Blackman, J. (2018). Sensory analysis: Provenance, preference and pivot: Exploring premium Shiraz with international sommeliers and Australian winemakers using a new rapid sensory method. *Wine Vitic. Journal, 33***,** 35-38. Retrieved from https://winetitles.com.au/wvj/articles/wine-viticulture-journal-volume-33-no-4-2018/provenance-preference-and-pivot-exploring-premium-shiraz-with-international-sommeliers-and-australian-winemakers-using-a-new-rapid-sensory-method/

Petrie, P. R. & Sadras, V. O. (2017). Practical options to manage vintage compression. Beames, K.S. Robinson, E.M.C. Dry, P.R. & Johnson, D. (Eds.). *Proceedings of the 16th Australian Wine Industry Technical Conference, Adelaide, SA, 24-28 July 2016. Adelaide, SA: Australian Wine Industry Technical Conference Inc*, 63–67. Retrieved from https://awitc.com.au/proceedings/16AWITC.pdf

Petrie, P. R., Teng, B., Smith, P. A., & Bindon, K. A. (2019). Sugar reduction: Managing high Baume juice using dilution. *Wine & Viticulture Journal*, *34*(1), 36-37.

Piombino, P., Pittari, E., Gambuti, A., Curioni, A., Giacosa, S., Mattivi, F., Parpinello, G. P., Rolle, L., Ugliano, M. & Moio, L. (2020). Preliminary sensory characterisation of the diverse astringency of single cultivar Italian red wines and correlation of sub-qualities with chemical composition. *Australian Journal of Grape and Wine Research*, *26*, 233-246. https://doi.org/10.1111/ajgw.12431

Piccardo, D., Gombau, J., Pascual, O., Vignault, A., & Pons, P., *et al*. (2019). Influence of two prefermentative treatments to reduce the ethanol content and pH of red wines obtained from overripe grapes. *Vitis, 58(*5), 59-67. https://hal.inrae.fr/hal-02619863

Remize, F., Roustan, J. L., Sablayrolles, J. M., Barre, P., & Dequin, S. (1999). Glycerol Overproduction by EngineeredSaccharomyces cerevisiaeWine Yeast Strains Leads to Substantial Changes in By-Product Formation and to a Stimulation of Fermentation Rate in Stationary Phase. *Applied And Environmental Microbiology*, 65(1), 143-149. https://doi.org/10.1128/aem.65.1.143-149.1999

Rothman, L., & Parker, M. J. (2009). Structure and Use of Just-About-Right Scales. In Rothman, L., & Parker M. J. (Eds.), *ASTM MNL63, Just-About-Right (JAR) Scales: Design, Usage, Benefits, and Risks*, 1–13. https://doi.org/10.1520/mnl11481m

Rousserie, P., Rabot, A., & Geny-Denis, L. (2019). From Flavanols Biosynthesis to Wine Tannins: What Place for Grape Seeds? *Journal of Agricultural and Food Chemistry, 67,* 1325-1343. https://doi.org/10.1021/acs.jafc.8b05768

Sáenz-Navajas, M-P., Avizcuri, J. M., Echávarri, J. F., Ferreira, V., Fernández-Zurbano, P., & Valentin, D. (2016). Understanding quality judgements of red wines by experts: Effect of evaluation condition. *Food Quality and Preference, 48*, 216-227. https://doi.org/10.1016/j.foodqual.2015.10.001

Saliba, A., Ovington, L., & Moran, C. (2013). Consumer demand for low-alcohol wine in an Australian sample group. *International Journal of Wine Research, 5*, 1-8. https://doi.org/10.2147/ijwr.s41448

Sarneckis, C. J., Dambergs, R. G., Jones, P., Mercurio, M., Herderich, M.J., & Smith, P. A. (2006). Quantification of condensed tannins by precipitation with methyl cellulose: development and validation of an optimised tool for grape and wine analysis. *Aust. J. Grape Wine Res*., *12*(1**)**, 39-49. https://doi.org/10.1111/j.1755-0238.2006.tb00042.x

Schraidt, M. (2009). Appendix L: Penalty Analysis or Mean Drop Analysis. In L Rothman, L., & Parker, M. J. (Eds.), *ASTM MNL63, Just-About-Right (JAR) Scales: Design, Usage, Benefits, and Risks,* 50-53. https://doi.org/10.1520/mnl11493m

Somers, T. C., & Evans, M. E. (1974). Wine quality: Correlations with colour density and anthocyanin equilibria in a group of young red wines. J. *Sci. Food Agric*., *25,* 1369-1379. https://doi.org/10.1002/jsfa.2740251105

Somers, T. C., & Evans, M. E. (1977). Spectral evaluation of young red wines : Anthocyanin equilibria, total phenolics, free and molecular SO2, “chemical age”. Journal Of The Science Of Food And Agriculture/Journal Of The Science Of Food And Agriculture, 28(3), 279-287. https://doi.org/10.1002/jsfa.2740280311

Sparrow, A. M., Smart, R. E., Dambergs, R. G., & Close, D. C. (2016a). Skin particle size affects the phenolic attributes of Pinot noir wine: Proof of concept. *Am. J. Enol. Vitic*., *67,* 29-37. https://doi.org/10.5344/ajev.2015.15055

Sparrow, A. M., Holt, H. E., Pearson, W., Dambergs, R. G., & Close, D. C. (2016b). Accentuated cut edges (ace): Effects of skin fragmentation on the composition and sensory attributes of Pinot Noir wines. *Am. J. Enol. Vitic., 67*, 169-178. https://doi.org/10.5344/ajev.2015.15094

Sparrow, A. M., & Smart, R. E. (2017). Pinot noir wine processing and quality improved by skin fragmentation. *Catal. Discov. Pract*., *1,* 88-98. https://doi.org/10.5344/catalyst.2017.17004

Schelezki, O. J., Šuklje, K., Boss, P. K., & Jeffery, D. W. (2018a). Comparison of consecutive harvests versus blending treatments to produce lower alcohol wines from Cabernet Sauvignon grapes: Impact on wine volatile composition and sensory properties. *Food Chemistry, 259,* 196-206. https://doi.org/10.1016/j.foodchem.2018.03.118

Schelezki, O. J., Smith, P. A., Hranilovic, A., Bindon, K. A., & Jeffery, D. W. (2018b). Comparison of consecutive harvests versus blending treatments to produce lower alcohol wines from Cabernet Sauvignon grapes: impact on polysaccharide and tannin content and composition. *Food Chemistry, 244***,** 50-59. https://doi.org/10.1016/j.foodchem.2017.10.024

Schelezki, O. J., Deloire, A., & Jeffrey, D. W. (2020a). Substitution or Dilution? Assessing Pre-Fermentative Water Implementation to Produce Lower Alcohol Shiraz Wines. *Molecules, 25,* 2245. https://doi.org/10.3390/molecules25092245

Schelezki, O. J., Antalick, G., Šuklje, K., & Jeffery, D. W. (2020b). Pre-fermentation approaches to producing lower alcohol wines from Cabernet Sauvignon and Shiraz: Implications for wine quality based on chemical and sensory analysis. *Food Chemistry, 309,* 125698 (2020b). https://doi.org/10.1016/j.foodchem.2019.125698

Schultz, H. R. (2010). Climate change and viticulture: research needs for facing the future. *Journal of Wine Research, 21*(2/3), 113-116. https://doi.org/10.1080/09571264.2010.530093

Teng, B., Petrie, P. R., Smith, P. A., & Bindon, K. A. (2020). Comparison of water addition and early-harvest strategies to decrease alcohol concentration in *Vitis vinifera* cv. Shiraz wine: impact on wine phenolics, tannin composition and colour properties. *Australian Journal of Grape and Wine Research, 26,* 158-171. https://doi.org/10.1111/ajgw.12430

Terral, J-F., Tabard, E., Bouby, L., Ivorra, S., Pastor, T., Figueiral, I., Picq, S., Chevance, J-B., Jung, C., Fabre, L., Tardy, C., Compan, M., Bacilieri, R., Lacombe, T., & This, P. (2010). Evolution and history of grapevine (*Vitis vinifera*) under domestication: new morphometric perspectives to understand seed domestication syndrome and reveal origins of ancient European cultivars. *Annals of Botany, 105*(3), 443-455. https://doi.org/10.1093/aob/mcp298

United States Code of Federal Regulations 24.176 (2010). Crushing and fermentation (United States Government: Washington, DC, USA). Retrieved from https://www.ecfr.gov/current/title-27/chapter-I/subchapter-A/part-24/subpart-F/section-24.176

Vidal, L., Giménez, A., Medina, K., Boido, E., & Ares, G. (2015). How do consumers describe wine astringency? *Food Res. Int*., *78,* 321-326. https://doi.org/10.1016/j.foodres.2015.09.025

Wang, X., Capone, D. L., Kang, W., Roland, A., & Jeffery, D. W. (2022). Impact of accentuated cut edges (ACE) technique on volatile and sensory profiles of Shiraz wines. *Food Chemistry, 372,* 131222. https://doi.org/10.1016/j.foodchem.2021.131222

Watrelot, A. A., & Norton, E. L. Chemistry and Reactivity of Tannins in Vitis spp.: A Review. (2020) *Molecules*, *25*(9), 2110. htpps://doi:10.3390/molecules25092110

Webb, L., Tozer, C., Bettio, L., Darbyshire, R., Robinson, B., Fleming, A., Tijs, S., Bodman, R., & Prakash, M. (2023). Climate Services for Agriculture: Tools for Informing Decisions Relating to Climate Change and Climate Variability in the Wine Industry. *Australian Journal of Grape and Wine Research*. https://doi.org/10.1155/2023/5025359

Zuur, A. F., Ieno, E. N., Walker, N. J., Saveliev, A. A., & Smith, G. M. (2009). Mixed Effects Models and Extensions in Ecology with *R*. New York, Springer. https://doi.org/10.1007/978-0-387-87458-6.