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Salt concentration and salty taste perception in 'Chardonnay' and 'Shiraz' wines from own roots and different rootstocks under saline irrigation

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Summary

Salty taste can adversely affect the marketability of wine. To further examine salty taste, basic compositional and sensory assessment was conducted on 'Chardonnay' and 'Shiraz' wines produced from vines irrigated with salty water with a mean electrical conductivity of 1.5 dS m^{-1}. Vines of the cultivars on own roots and on up to five rootstocks that differed in capacity for chloride and sodium exclusion were used. The sensory attributes salty and viscosity were enhanced for the 'Chardonnay' wine from K51-40 rootstock with elevated chloride and sodium concentrations of 407.4 and 374.2 mg L^{-1}, respectively, and a potassium concentration of 470.1 mg L^{-1}, but not affected in 'Shiraz' wine from K51-40 with concentrations of 274.1, 130.5 and 1,110 mg L^{-1}, respectively. The salty and viscosity attributes in the 'Chardonnay' wine from K51-40 were closely associated and approximately equally correlated with the concentration of chloride and sodium, with the wine also having lower acidity and a higher overall fruit aroma. The chloride concentration in wine that aligns with perception of salty taste by a trained panel may be similar between a white and red wine. Wine chloride concentration above approximately 400 mg L^{-1} appears linked with, and a potential indicator of, salty taste, however the specific contribution of sodium and potassium requires further study.

Key words

Chloride, grapevine, potassium, salinity, sensory, sodium

Introduction

The concentration of sodium chloride (NaCl) and other salts required to give a perceptible taste to a beverage or solution has been examined extensively over many studies. Detection and recognition threshold studies using 2- or 3- alternative forced choice staircase approaches, or similar alternatives such as proportion correct methods (Wise and Breslin, 2013), report widely varying values depending on the specific methodology used (Van Gemert, 2011). The NaCl taste detection threshold in water has been reported to be 96 mg L^{-1}, with a recognition threshold of 818 mg L^{-1} (Wise and Breslin, 2013). For wine, studies involving sensory assessment of wines containing various concentrations of salts, achieved naturally by growing vines in a salt-affected region (Walker *et al.*, 2003, De Loryn *et al.*, 2014, Walker *et al.*, 2019), have provided an indication of the salt concentration required to give salty taste.

Wines produced from regions that have naturally salty soils or from regions that use irrigation water with high (0.8 to 2.3 dS m^{-1}) electrical conductivity (EC) (Hart, 1974) are more likely to have the salty taste attribute relative to wines produced from regions with non-saline soils and irrigated with water of low EC (0 to 0.3 dS m^{-1}) (Hart, 1974). For example, wines from Mexico have been reported to have a salty character (Cabello-Pasini *et al.*, 2013). The mean sodium (Na^+) concentration from a sample of 79 white and 421 red wines in that study was reported to be approximately 100 and 130 mg L^{-1}, respectively, with maximum values of 757 and 1152 mg L^{-1}, respectively, while wine chloride (Cl^-) concentration was not measured (Cabello-Pasini *et al.*, 2013). Wines of 'Marselan' and 'Ruby Cabernet' from the state of Rio Grande do Sul in Brazil have also been described as having weak salty characteristics, along with off-aroma, vegetal and off-flavour characteristics (Miele and Rizzon, 2011). Concentrations of ions in the wines from that study were, however, not provided.

In an extensive study of 1214 samples of grape juice taken from commercially processed grapes in the Australian states of South Australia and Victoria (Leske *et al.*, 1997), the mean concentration of Na^+ and Cl^- was 55 and 141 mg L^{-1}, respectively. In a further study of concentrations of Na^+ in Australian wines over 20 years (1984 to 2004) by Godden and Gishen (2005), data indicated a general trend towards lowering of the mean Na^+ concentration in white wine from 1995 onwards. A similar indication of a lowering in the concentration of Na^+ in red wines was evident over the same period, though with a less reliable trend due to a smaller sample size (Godden and Gishen, 2005). This apparent decrease in Na^+ concentration in Australian wines may have been due in part to greater awareness of best practice in both the winery and vineyard, the lat-

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ter to reduce the impact of salinity (Lanyon, 2011), together with increasing awareness of the amount of salt permissible in wines for domestic consumption and export (Stockley and Lloyd-Davies, 2001).

The study of De Loryn *et al.* (2014) evaluated sensory thresholds and perception of NaCl in grape juice and wine. The median NaCl taste detection threshold for a white ('Chardonnay') and red ('Shiraz') wine was found to be similar, mean of 0.305 g L^{-1} NaCl, while the median NaCl recognition thresholds were, as expected, higher, in the range 1.77 to 2.05 g L^{-1} NaCl. Wines made from fruit grown on salt-affected vineyards and wines spiked with NaCl were found to have less fruit expression and more salty taste and soapy mouthfeel (De Loryn *et al.*, 2014).

In the study of Scacco *et al.* (2010), 'Nero d´Avola' wines containing 0.5 to 1.0 g L^{-1} NaCl had lower fruit expression and were perceived as salty, drying and soapy. The soapy attribute has similarly been reported in other studies on wines made from fruit grown on salt-affected vineyards (Walker *et al.*, 2003, De Loryn *et al.*, 2014). Scacco *et al.* (2010) also found that an increase in soil salinity enhanced colour intensity, purple hues, salty, citrus, and fruit aroma attributes and furthermore, that wines from medium and high soil salinity were preferred in tastings over wines from negligible soil salinity. The study of Martinez-Moreno *et al.* (2022) also reported a preference, based on aroma and mouthfeel attributes, by a panel of consumers for wines made from grapes of cultivar 'Monastrell' on 1103 Paulsen rootstock irrigated with water high in Cl^- or in sulfate. In each case, the irrigation water had an EC of 5 dS m^{-1} relative to wines made from grapes of control vines (1.8 dS m^{-1}). The study, however, did not report ion concentrations in the wines.

This study used a range of root system genotypes (own roots and rootstocks) that differed in capacity for Cl^- and Na^+ exclusion (Walker *et al.*, 2010) to deliver 'Chardonnay' and 'Shiraz' wines containing a range of Cl^- and Na^+ concentrations. These wines were then used to investigate the occurrence of salty taste, basic wine composition, especially the concentration of Cl^-, Na^+ and K^+ ions, as well as wine aroma and flavour attributes that may be linked with salty taste.

Material and Methods

Vineyard set-up and trial design

'Chardonnay' and 'Shiraz' grapevines on own roots and on a range of rootstocks located in a commercial vineyard at Padthaway in South Australia (36º38'45"S, 140º31'0"E – 'Shiraz'; and 36º38'44"S, 140º30'42"E – 'Chardonnay') were used. The trials were planted in 1992 as complete randomised blocks with 1-year old vines.

Trellis type was vertical with foliage wires at 1.2 and 1.5 m, with 2.75 m between rows and 1.8 m between vines. All vines were mechanically pre-pruned with hand spur finish to maintain approximately 100 buds per vine.

Main treatments were 'Chardonnay' and 'Shiraz' (*Vitis vinifera* L.) on their own roots or grafted to rootstocks Ruggeri 140 (*V. berlandieri* Boutin B *x V. rupestris* Du Lot), DAVIS K 51- 40 (*V. champinii* Planchon × *V. riparia* Michaux), Schwarzmann (*V.* riparia Michaux *x V. rupestris* Scheele), Couderc 1202 (*V. vinifera* Monastrell × *V. rupestris* Ganzin) and Kober 5 BB (*V. berlandieri* Rességuier #2 × *V. riparia* Gloire de Montpellier) (Maul *et al.*, 2021). Ruggeri 140, DAVIS K 51- 40, Couderc 1202 and Kober 5 BB are referred to in the text as 140 Ruggeri, K51-40, 1202C and Kober 5BB. 'Chardonnay' clone I10V1 was used, and for 'Shiraz', clone BGVSS Cl.30 was used. There were ten blocks, with single vine replicates of own roots and each rootstock in each block. Hence for each scion, own roots and each rootstock were replicated 10 times, with vines on own roots and each rootstock randomised within each block. The rootstocks were chosen based on the results from an earlier study (Walker *et al.*, 2010) which identified a range in the capacity of the rootstocks to exclude Cl^- from shoots and berries. No fruit thinning was applied.

Soil type, weather data, irrigation practices and water composition

Soil at Padthaway was uniform shallow brownish gravelly calcareous mottled clay (Alf Cass and Cliff Hignett, unpublished data, 1999). The physical and physicochemical properties of the soil at the 'Chardonnay' and 'Shiraz' sites are shown in Table S1.

Weather data were obtained from the Australian Bureau of Meteorology station at Padthaway South, which was approximately 5 km from the vineyard. Rainfall (July 2010 to June 2011) was 695 mm, well above the long-term average of 470 mm. Mean daily maximum temperatures for the months of October 2010 to March 2011 were respectively 20.7, 23.6, 25.1, 28.0, 26.9 and 23.0°C. All were lower than the long-term (22 year) monthly means for October to March of 20.8, 24.5, 26.9, 29.4, 28.5 and 26.0°C, respectively.

Irrigation was applied via drippers, with flow rate of 3.5 L h^{-1} and spacing between drippers of 60 and 90 cm for 'Chardonnay' and 'Shiraz', respectively. Soil water monitoring to assist irrigation scheduling for 'Chardonnay' and 'Shiraz' vines was carried out as described by Walker *et al.* (2010). Winter rainfall was relied on at Padthaway to provide adequate leaching of salts from the soil profile. The sites were irrigated with bore water, with total irrigation water applied at the 'Chardonnay' site being 1.70 ML ha^{-1}, and for the 'Shiraz' site it was 0.70 ML ha^{-1}.

The irrigation water had a mean EC of 1.5 dS m^{-1} and a sodium adsorption ratio (SAR) of 4.3. Irrigation water with EC in the range 0.8 to 2.3 dS m^{-1} is classified as high salinity water (Hart, 1974). Mean concentration of Cl^-, Na^+, potassium (K^+), magnesium (Mg^{2+}) and calcium (Ca^{2+}) in irrigation water used at the two sites was respectively 10.9, 9.2, 0.1, 1.4 and 3.2 mmol L^{-1}.

Harvest scheduling and yield measurement

Grapes were first sampled for compositional analyses then harvested for yield and yield component assessment and winemaking when juice total soluble solids (TSS) was as close

as possible to 22 and 24°Brix for 'Chardonnay' and 'Shiraz', respectively. Harvest dates were 7 March 2011 for 'Chardonnay' and 21-22 March 2011 for 'Shiraz'. Samples of 80 berries per vine were taken at each site on the day of harvest using the sampling procedure described by Walker *et al.* (2010), then taken to the laboratory and stored overnight at 4°C before processing next day. Fresh mass of each 80-berry sample was recorded, then each sample was gently crushed with mortar and pestle to extract juice. The juice samples were then centrifuged (Beckman J25i; Beckman Coulter Inc., Fullerton, CA, USA) for 15 min. at 4°C and 5930 g. The clear juice was decanted and used immediately for measurement of TSS, pH and titratable acidity. The samples were then frozen for later analysis of ions.

Fruit mass per vine for own roots and each rootstock was obtained by harvesting fruit from each replicate vine into one or more tared 10 L buckets then weighing. In some instances, for example, where there was a missing vine and where the grower permitted cordons from adjacent vines to grow into the vacant space, an adjusted yield for the adjacent vines was obtained. In such instances, the additional cordon length was measured, then yield per vine was adjusted to that for a standard cordon length.

Total soluble solids, pH and titratable acidity

Fresh grape juice samples were analysed for TSS (°Brix) with a digital refractometer (PR-1, Atago Co Ltd, Japan). Measurement of pH and titratable acidity (TA) in grape juice and wine was made using an autotitrator (Radiometer Analytical A/S, Copenhagen, Denmark).

Fermentation

Small-scale wines were made from 'Chardonnay' on own roots and on 140 Ruggeri, K51-40, Kober 5BB, Schwarzmann and 1202C rootstocks, and from 'Shiraz' on own roots and on 140 Ruggeri, K51-40, Kober 5BB and 1202C rootstocks. Once all vine replicates were harvested and fruit weighed, the fruit for winemaking was randomly sampled from the harvested fruit of each vine replicate and placed into plastic trays to create two winemaking replicates, each of approximately 10 kg of fruit.

Wines were made at the experimental winemaking facility at the former CSIRO Research Centre, Merbein, Victoria. The two winemaking replicates from own roots and each rootstock were delivered to the winery and cooled to 1°C overnight prior to crushing to minimize oxidation. Each replicate was fermented separately. A crusher/de-stemmer was used (Zambelli Enotech s.r.l., Italy) with adjustable rollers. Must pH was adjusted to 3.4-3.6 and potassium metabisulfite added to give 20-25 mg L^{-1} free SO_2. For 'Chardonnay', wines were immediately pressed-off skins using a small batch 50 kg Willmes press with a pneumatic center membrane, with pressure reaching 6 bar for one 'press without crumble' cycle. The must was then transferred to suitably sized glass fermenters in the case of 'Chardonnay' or plastic fermenters for 'Shiraz' and a pectinase addition from *Aspergillus aculeatus* supplied by Sigma made to assist juice settling. Inoculation was carried out with rehydrated yeast (Lalvin EC 1118, Lallemand Australia) at the rate of 0.25 g L^{-1} for 'Chardonnay' and 0.20 g L^{-1} for 'Shiraz', calculated at 600 mL kg^{-1} of fruit weight. Fermentation was initiated and temperature controlled at 18°C, with diammonium phosphate (DAP) added at the rate of 0.15 g L^{-1}. Fermentation lasted 14 days, with caps ('Shiraz') managed by plunging twice daily. Fermentation progress was checked daily using an Anton Parr Density Meter. For 'Shiraz' ferments, skins were pressed-off at approximately 2ºBaumé as described above.

Once sugars were less than 2 g L^{-1} (measured by an OenoFoss™ analyser), indicating very low or nil residual sugar, wine was racked off gross lees and free SO_2 adjusted to 30 mg L^{-1}. Copper sulfate (0.4% solution) was also added at a rate of 1 ml L^{-1} post first racking into full glass containers sealed with a bubble trap. After two weeks of settling at 18°C, a second racking was performed and SO_2 and pH checked and wines further adjusted as required. Wines were subsequently cold stabilized (1°C) for a minimum of three weeks prior to being racked and filtered through a Millipore filter housing (125 mm). The wines were filtered through a series of fine pads (3.1 µm, 2.5 µm, 1.1 µm and 0.7 µm, for 'Chardonnay' and 'Shiraz', plus 0.45 µm for 'Chardonnay' only) followed by bottling into 375 mL bottles, with screwcaps as bottle closures, and using N_2 in the ullaged headspace. CO_2 was used as a pre-fill gas at all times during processing, and all vessels and equipment were fully cleaned and sanitized. Copper sulfate additions were made at bottling as required based on copper fining sensory tests prior to bottling. Wines were stored at 15-16°C until required.

Ion concentrations in grape juice and wine

Chloride concentrations: Silver ion titration was conducted with a chloridometer (Model 442-5150, Digital Chloridometer, Lenexa, Kansas, USA). Juice and wine samples (1 mL) were added to 5 mL glass vials followed by addition of 3 mL of acid reagent (100 mL glacial acetic acid and 6.4 mL of 70% nitric acid made up to one L with MilliQ water) then allowed to extract for 30 min. Four drops of gelatin reagent (Labonco Corporation, Kansas City, MO, USA) were added just prior to analysis.

Cations, phosphorus and sulfur: Samples were examined for cation (K^+, Na^+, Ca^{2+} and Mg^{2+}), phosphorus (P) and sulfur (S) concentrations. The samples (2 mL) were dispensed into 25 mL pre-treated (Zarcinas *et al.*, 1987) glass test tubes and 2 mL of 15 mol L^{-1} nitric acid was added. After holding in a fume hood overnight at room temperature, a disposable polypropylene (SC417) watch glass was added to each tube. The tubes were placed on a 96 well HotBlock Pro Digestion System (SC 189-240) with a Pro Controller-Touch Screen (SC180-240) (Environmental Express, Mt Pleasant, SC, USA), then sequentially heated at 60, 70 and 115°C for 120, 60 and 240 min, respectively. The tubes were allowed to cool, then the samples were made-up to approximately 20 mL with Milli Q water and mixed thoroughly. The solutions were then filtered through No. 42 Whatman filter paper 125 mm. Aliquots of approximately 10 mL were transferred to polypropylene tubes for analysis. Concentrations were measured by induc-

tively coupled plasma-optical emission spectrometry (Spectro ARCOS, Spectro Analytical Instruments, Kleve, Germany, and Thermo Scientific iCAP 6000 Series, Thermo Electron, Cambridge, England) using appropriate standards for calibration and recalibration to correct for any drift that may occur during analytical runs.

Alcohol, volatile acidity, free and total SO_2 and red wine spectral characteristics

Alcohol and volatile acidity in wines were measured using a Foss WineScan FT 120 as outlined by the manufacturer (Foss, Hillerød, Denmark). Free and total SO_2 in wines were measured by the aspiration method as described by Rankine and Pocock (1970).

Spectral characteristics of the red wines were evaluated approximately five months after bottling in October 2011 according to the method of Somers and Evans (1977) using a GBC 918 UV/vis spectrophotometer (GBC Scientific Equipment Pty Ltd, Dandenong Australia). Wine colour density is the sum of absorbance (E) at wavelength 420 nm and at 520 nm, with E values determined from absorbance readings corrected to 10 mm pathlength; wine colour hue = E_{420}/E_{520}, and total phenolic compounds = $E_{280} - 4$ (Somers and Evans, 1977).

Descriptive sensory analysis

Preliminary assessment of the wines by experienced personnel from AWRI and CSIRO indicated that the wines were free of off-flavours and hence suitable for formal descriptive analysis, with the conclusion that all replicates from each treatment would be included in the study.

Descriptive sensory analysis of the wines using a generic approach (Heymann *et al.*, 2014) was undertaken by members of the AWRI descriptive sensory panel in March 2012, with twelve assessors, four male, eight female for 'Chardonnay' wines and five male, seven female for the 'Shiraz' wines. All assessors had extensive wine sensory descriptive analysis experience. For each study, assessors attended three training sessions to determine and define appropriate descriptors for formal assessment of the wines. During these sessions the assessors evaluated wines from the study which represented the full range of sensory properties. Wines were initially assessed by appearance, aroma and flavour/mouthfeel, however for the 'Chardonnay' study, the differences in appearance were minimal, and no appearance attribute was assessed formally. Following the first training session, standards for aroma attributes and basic tastes were presented. Aroma standards were also available for assessors during the formal assessment sessions.

Additional basic taste training was provided for assessors, which included ranking of salty, sweet, acid and bitter solutions, as well as tasting of wines with varying Cl^- concentrations, including some from the study. To avoid bias in their responses, assessors were not informed that salt was the focus of the study.

For each study, assessors attended a practice rating session where a subset of the wines were rated under the same conditions as those provided for formal sessions, except with constant presentation order across assessors, using the attribute list determined during training. Following this, attribute lists were refined as required to remove unused or highly correlated terms and to ensure that definitions were accurate. Details of the attributes, definitions and reference standards for formal rating sessions for each study (2011 'Chardonnay', 2011 'Shiraz') are given in Tables S2 and S3.

Samples were presented to assessors in 30 mL aliquots in 3-digit-coded, covered, ISO standard wine glasses at 22 – 24°C on trays in isolated booths under daylight lighting. Three wine samples were presented per tray and a maximum of five sets of three wines were presented per session. The presentation order of wine samples within each tray was randomized across judges. Assessors were forced to take a 60 sec break between wines on a tray. There was a forced 10 min break between trays, during which assessors left the booths. The two winemaking replicates made from each root system treatment (own roots and rootstocks) were assessed in a completely randomized design, with the same three samples presented to each assessor per tray. The wines were assessed in triplicate on separate days.

The intensity of each attribute was rated using an unstructured 15 cm line scale, from 0 to 10, with indented anchor points of 'low' and 'high' placed at 10% and 90%, respectively. Data were acquired using Fizz sensory software (Version 2.46, Biosystemes, Couternon, France).

Statistical methods

One way analysis of variance was applied to the grape juice and wine compositional data for each scion variety separately with root system genotype as the source of variation. The statistical tests aimed to determine differences between root system genotypes. Where significant ($P \leq 0.05$) effects were found, comparison between root system genotype means for that scion variety was made using the Fisher's protected least significant difference (LSD) test with 5% level of significance. Regression techniques were applied to examine specific relationships.

Analysis of variance (ANOVA) for descriptive sensory data and wine compositional data was carried out using JMP 7 (SAS Institute, Cary, NC). The effects of judge (J), root system genotype (R) and judge by root system genotype (JxR) interaction were assessed. For the wine compositional data, root system genotype effects were assessed. Following ANOVA, Fisher's least significant difference (LSD) value was calculated ($P = 0.05$). Panel performance for descriptive sensory analysis was assessed using Fizz, Senstools (OP&P, The Netherlands) and PanelCheck (Matforsk) software, and included analysis of variance for the effect of sample, judge and presentation replicate and their interactions, degree of agreement with the panel mean and degree of discrimination across samples.

Results

Yield, berry mass and juice composition

'Chardonnay'

Yield of 'Chardonnay' on 140 Ruggeri, Kober 5BB, Schwarzmann and 1202C was not significantly different from that on own roots, while yield of Kober 5BB was significantly lower than that for Schwarzmann (Table S4). Yield of K51-40, however, was just 2.8 kg per vine, or 3.9-fold lower than the mean yield of the other rootstocks and own roots (Table S4). Berry mass of 'Chardonnay' on 140 Ruggeri, K51-40 and Kober 5BB was significantly higher than that for own roots and 1202C but not significantly different from that for Schwarzmann (Table S4). There was no significant effect of root system genotype on grape juice TSS, pH or TA at harvest (Table S4). Juice Cl^- was highest for K51-40 > Kober 5BB > own roots = Schwarzmann = 140 Ruggeri, with 1202C not significantly different from Kober 5BB, own roots, Schwarzmann and 140 Ruggeri. Juice Na^+ was highest for K51-40 and Kober 5BB > Schwarzmann = 1202C = 140 Ruggeri = own roots (Table S4).

'Shiraz'

There was no significant effect of root system genotype on yield, with 140 Ruggeri and 1202C at the higher end (mean of 4.7 kg per vine) and own roots, Kober 5BB and K51-40 at the lower end (mean of 3.6 kg per vine) (Table S5). The lower yield of 'Shiraz' relative to 'Chardonnay' for all rootstocks except K51-40 in this study was at least partly related to the lower irrigation per season for 'Shiraz' than for 'Chardonnay' (0.70 and 1.70 ML ha^{-1}, respectively). Berry mass was not affected by root system genotype (Table S5). Juice of 'Shiraz' on Kober 5BB had significantly lower TSS than that of own roots and all other rootstocks. There was a small (2%) difference between highest (140 Ruggeri) and lowest (own roots) juice pH and an approximate 12% difference between highest (1202C) and lowest (140 Ruggeri) juice TA. Juice Cl^- was highest for K51-40 >1202C > own roots = Kober 5BB = 140 Ruggeri. Juice Na^+ was highest for K51-40 (84.5 mg L^{-1}) and lowest for Kober 5BB (17.2 mg L^{-1}) (Table S5).

Wine basic composition and ion concentrations

'Chardonnay'

The only significant difference among root system genotypes in basic wine chemical composition (Table 1) was for alcohol, with K51-40 wines having a significantly lower concentration, by 2.3% relative to the mean for own roots and the other rootstocks. Wine from K51-40 also had the highest concentration of Na^+, Cl^- and Ca^{2+}, and along with 140 Ruggeri, the highest concentration of Mg^{2+}. The ranking for wine Cl^- concentration was K51-40 > 1202C = Kober 5BB > own roots = Schwarzmann = 140 Ruggeri. The ranking for wine Na^+ concentration was K51-40 > Kober 5BB > 1202C > 140 Ruggeri = own roots, with Schwarzmann not significantly different from Kober 5BB and 1202C. Wine from own roots had the highest concentration of K^+. No significant differences were observed among own roots and rootstocks for wine S or P concentration (Table 1).

'Shiraz'

The only significant differences among the root system genotypes in basic wine chemical composition (Table 2) were for alcohol, with 1202C = own roots = K51-40 > 140 Ruggeri > Kober 5BB, and volatile acidity (VA), with K51-40 and Kober 5BB > own roots and 140 Ruggeri and with 1202C intermediate. There was a 10% difference in alcohol concentration between the lowest (Kober 5BB) and highest (1202C) rootstock and a 14.3% difference in VA between the lowest (own roots and 140 Ruggeri) and highest (K51-40 and Kober 5BB) genotypes. The concentration of Cl^- and Na^+ in wine of 'Shiraz' on K51-40 was lower than that observed for 'Chardonnay' on K51-40. The ranking for wine Cl^- concentration was K51-40 > 1202C = own roots > 140 Ruggeri = Kober 5BB. The ranking for wine Na^+ concentration was K51-40 > own roots > Kober 5BB with 140 Ruggeri and 1202C not significantly different from Kober 5BB and own roots. Wine P concentration

Table 1: Wine pH, titratable acidity, alcohol, volatile acidity, free and total SO_2 concentration and concentrations of ions, phosphorus and sulfur for 'Chardonnay' on own roots and on five different rootstocks at Padthaway, South Australia in season 2011.

Rootstock	pH	TA ($g \cdot L^{-1}$)	Alc. (%v/v)	VA ($g \cdot L^{-1}$)	Free SO_2 ($mg \cdot L^{-1}$)	Total SO_2 ($mg \cdot L^{-1}$)	Cl^-	Ca^{2+}	K^+	Mg^{2+} ($mg \cdot L^{-1}$)	Na^+	P	S
Own Roots	3.27	8.15	12.87^a	0.40	31	114	72.8^c	51.8^c	584.3^a	78.2^{cd}	44.7^d	97.6	133.2
140 Ruggeri	3.25	7.81	12.85^a	0.39	32	125	41.8^c	58.7^{bc}	480.0^{bc}	82.6^{ab}	64.3^d	86.7	146.9
K51-40	3.26	7.92	12.58^b	0.37	31	118	407.4^a	73.9^a	470.1^{bc}	86.5^a	374.2^a	93.5	135.1
Kober 5BB	3.21	7.93	12.85^a	0.40	31	116	127.5^b	62.8^b	458.0^{bc}	75.0^d	116.9^b	90.2	138.1
Schwarzmann	3.26	8.16	12.97^a	0.37	33	116	66.5^c	61.3^{bc}	507.4^b	80.0^{bc}	96.4^{bc}	88.5	145.1
1202C	3.18	7.54	12.86^a	0.40	30	106	137.3^b	52.2^c	427.6^c	74.2^d	90.6^c	95.7	136.1
LSD_R			0.15				27.7	8.3	58.4	3.3	19.6		
Significance	n.s.	n.s.	*	n.s.	n.s.	n.s.	***	*	*	**	***	n.s.	n.s.

*$P \leq 0.05$; **$P \leq 0.01$; ***$P \leq 0.001$; different letters in the superscripts indicate significant differences between means; Alc. = alcohol; LSD = least significant difference ($P = 0.05$); n.s. = not significant; R = rootstock; TA = titratable acidity; VA = volatile acidity.

Table 2: Wine pH, titratable acidity, alcohol, volatile acidity, free and total SO_2 concentration and concentrations of ions, phosphorus and sulfur for 'Shiraz' on own roots and on four different rootstocks at Padthaway, South Australia in season 2011.

Rootstock	pH	TA ($g \cdot L^{-1}$)	Alc. (%v/v)	VA ($g \cdot L^{-1}$)	Free SO_2 ($mg \cdot L^{-1}$)	Total SO_2 ($mg \cdot L^{-1}$)	Cl^-	Ca^{2+}	K^+	Mg^{2+} ($mg \cdot L^{-1}$)	Na^+	P	S
Own Roots	3.40	8.75	12.86^{a}	0.18^{b}	46.0	96.0	154.4^{b}	88.9	1134	99.0	70.0^{b}	61.9^{b}	137.4
140 Ruggeri	3.49	8.17	12.14^{b}	0.18^{b}	32.0	73.0	53.7^{c}	81.3	1058	102.0	41.5^{bc}	60.1^{b}	112.3
K51-40	3.42	8.11	12.66^{a}	0.21^{a}	40.0	85.0	274.1^{a}	90.2	1110	113.6	130.5^{a}	44.6^{bc}	118.2
Kober 5BB	3.45	8.19	11.65^{c}	0.21^{a}	34.0	78.0	52.5^{c}	87.9	969	94.9	20.5^{c}	33.3^{c}	122.3
1202C	3.44	9.00	12.95^{a}	0.20^{ab}	40.5	82.5	177.2^{b}	79.9	1147	97.4	44.5^{bc}	100.9^{a}	114.0
LSD_R			0.38	0.012			27.5				26.2	13.9	
Significance	n.s.	n.s.	**	*	n.s.	n.s.	***	n.s.	n.s.	n.s.	***	**	n.s.

*$P \leq 0.05$; **$P \leq 0.01$; ***$P \leq 0.001$; different letters in the superscripts indicate significant differences between means; Alc. = alcohol; LSD = least significant difference ($P = 0.05$); n.s. = not significant; R = rootstock; TA = titratable acidity; VA = volatile acidity.

was highest for 'Shiraz' on 1202C and least on Kober 5BB, with own roots, 140 Ruggeri and K51-40 intermediate and not significantly different from each other. There were no significant differences among own roots and the rootstocks in the concentration of Ca^{2+}, K^+, Mg^{2+} and S (Table 2).

Wine from Kober 5BB had the lowest colour density, lowest concentration of total and ionized anthocyanin and total phenolics but the highest colour hue (Table 3). Apart from Kober 5BB, there were no significant differences between wine from own roots and the other rootstocks for ionized anthocyanin concentration, total phenolics and colour hue. Wine from 140 Ruggeri had the highest colour density, but not significantly different from that of own roots and K51-40. Wine from own roots had the highest total anthocyanin concentration, significantly higher than that for 140 Ruggeri and K51-40, but not significantly different to that from 1202C (Table 3).

Wine descriptive sensory analysis

'Chardonnay'

There were significant differences among root system genotypes for the aroma attributes honey ($P \leq 0.001$), overall fruit aroma ($P \leq 0.01$) and for citrus, yeasty and musty/mouldy ($P \leq 0.05$) (Table 4), while for the palate attributes, there were significant differences for salty, viscosity and acidity ($P \leq 0.001$), overall fruit flavour ($P \leq 0.01$) and honey ($P \leq 0.05$) (Table 4). Significant differences were observed between judges ($P \leq 0.001$) for all aroma and palate attributes assessed. There were also significant interactions between root system genotype and judge ($P \leq 0.05$) for overall fruit aroma, musty/mouldy and salty (Table 4). Variation between wine replicates was observed for the aroma attributes citrus and honey, for the palate attribute honey and for the salty taste attribute (Fig. S1).

Figure 1 shows the mean data for the attributes. It highlights the significantly higher scores for the attributes salty and viscosity and significantly lower score for acidity for K51-40 compared with the other root system genotypes. The salty and viscosity attributes were correlated (r = 0.94, $P = 0.006$, n = 6). There were smaller differences among root system genotypes in several attributes, especially honey aroma, where Kober 5BB was rated highest, K51-40, 140 Ruggeri and 1202C intermediate, and own roots and Schwarzmann lowest. Schwarzmann was rated highest for citrus, and own roots was rated highest for musty/mouldy, with most aroma attributes of relatively low intensity.

Table 3: Wine colour density, colour hue, concentration of total and ionized anthocyanins and total phenolics for 'Shiraz' on own roots and on four different rootstocks at Padthaway, South Australia in season 2011.

Rootstock	Colour density (au)	Colour hue (E_{420}/E_{520})	Total Antho ($mg \cdot L^{-1}$)	Ionised Antho ($mg \cdot L^{-1}$)	Total Phenolics (au)
Own roots	8.37^{bc}	0.52^{a}	512.2^{c}	73.2^{b}	40.9^{b}
140 Ruggeri	8.77^{c}	0.55^{a}	417.6^{b}	68.4^{b}	39.6^{b}
K51-40	7.85^{bc}	0.53^{a}	418.2^{b}	66.7^{b}	37.3^{b}
Kober 5BB	5.77^{a}	0.63^{b}	261.3^{a}	42.6^{a}	28.4^{a}
1202C	7.42^{b}	0.54^{a}	457.6^{bc}	61.9^{b}	38.5^{b}
LSD_R	1.23	0.03	59.0	13.9	5.2
Significance	***	***	***	**	***

**$P \leq 0.01$; ***$P \leq 0.001$; different letters in the superscripts indicate significant differences between means; Antho = anthocyanins; au = absorbance units; E = absorbance (10 mm); LSD = least significant difference ($P = 0.05$); R = rootstock.

Table 4: Summary of ANOVA results showing F-values, levels of significance and mean square error for sensory attributes of 'Chardonnay' wines from vines on own roots and on five different rootstocks at Padthaway, South Australia in season 2011.

Attribute	F ratio†			Error
	Rootstock	Judge	Rootstock*Judge	(Mean Square)
Aroma				
Overall Fruit aroma	3.23**	26.86***	1.50*	0.95
Citrus	2.51*	27.93***	0.83	1.51
Stonefruit	1.39	49.07***	1.56	1.33
Honey	5.99***	17.05***	1.02	1.93
Yeasty	2.94*	19.34***	1.37	1.69
Musty/Mouldy	2.50*	10.24***	1.54*	2.22
Palate				
Overall Fruit flavour	3.85**	29.44***	1.24	0.75
Salty	13.79***	28.71***	1.39*	1.34
Honey	2.50*	18.20***	0.86	1.33
Sweet	1.45	16.54***	0.72	1.15
Viscosity	7.90***	159.8***	0.83	0.41
Acidity	5.24***	29.33***	1.04	0.89
Hotness	0.95	100.4***	1.01	0.97
Bitter	1.93	28.78***	1.23	1.64
Burning AT	0.93	40.79***	0.95	1.61

†Significance: *$P \leq 0.05$; **$P \leq 0.01$; ***$P \leq 0.001$; AT = after taste; the heading 'Rootstock' includes own roots.

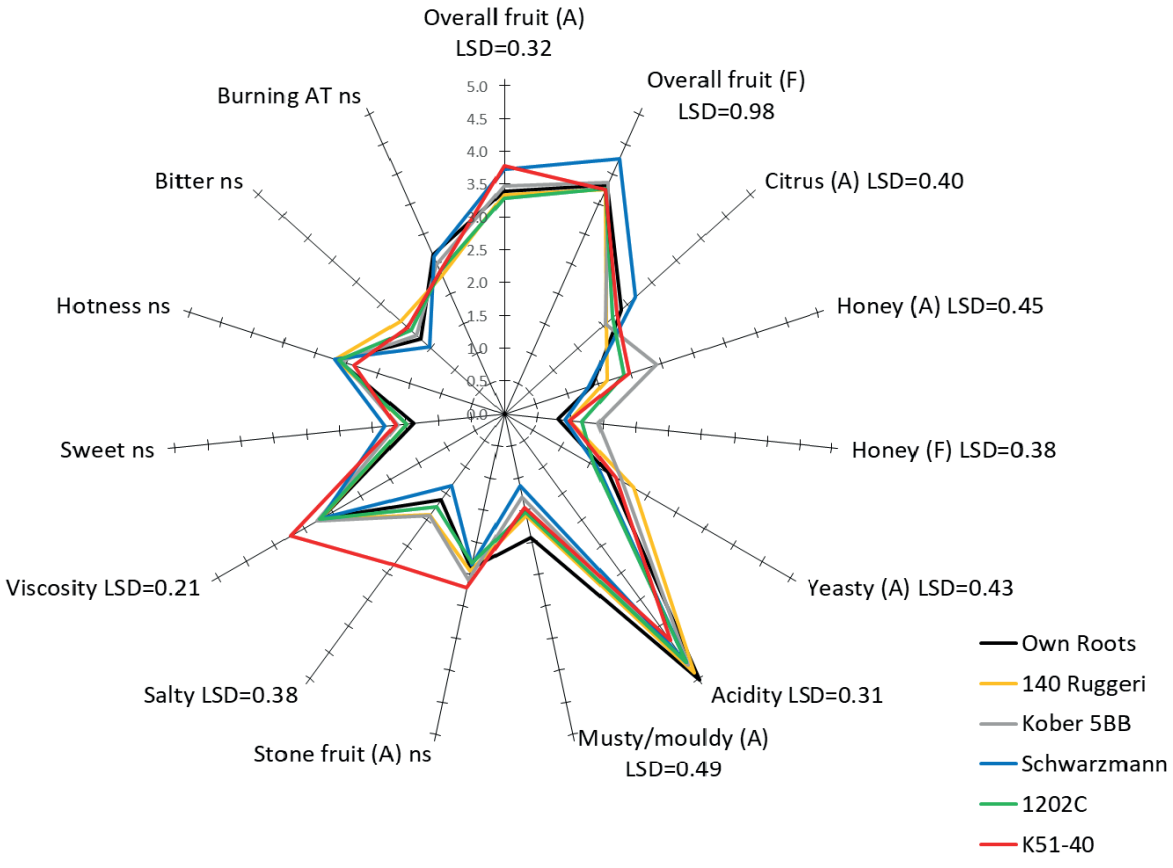

Fig. 1: Mean sensory attribute intensity ratings (A: aroma, F: flavour) of 'Chardonnay' wine made from vines on own roots and on five different rootstocks at Padthaway, South Australia in season 2011. LSD = least significant difference ($P = 0.05$). All axes in the Figure have the same gradations and numbering as shown on the vertical axis. Where significant differences between root system genotypes occur, the LSD is provided to show the differences.

Correlations of the ion concentrations of the wines (all wines, from vines on own roots and the five rootstocks) with the salty and viscosity attribute ratings were explored. Salty taste was positively associated with Na^+ and Cl^- concentration (r = 0.90 and 0.91 respectively, P = 0.01, n = 6) but not with K^+ concentration. There were weaker correlations of salty taste with Ca^{2+} and Mg^{2+}. Viscosity was also strongly correlated with Na^+ and Cl^- concentration. The correlations were strongly influenced by the K51-40 wine, but excluding this wine there remained a trend for a positive association (for example P = 0.16 for the correlation of Na^+ concentration and viscosity).

'Shiraz'

There were significant differences among root system genotypes for the appearance attribute opacity (colour intensity, $P \leq 0.001$), the aroma attributes dark fruits and cooked vegetable ($P \leq 0.01$) and for the palate attributes viscosity and hotness ($P \leq 0.05$) (Table 5). Salty taste did not differ significantly among the root system genotypes. Significant differences were observed between judges ($P \leq 0.001$) for all aroma and palate attributes assessed. There were also significant interactions between root system genotype and judge ($P \leq 0.05$) for the palate attributes viscosity and hotness (Table 5). Variation between wine replicates was observed for the aroma attributes dark fruits and cooked vegetable, and for the appearance attribute opacity (Figure S2).

Figure 2 shows the mean data for all attributes. It highlights the higher opacity (colour intensity) and dark fruits aroma of wine from 140 Ruggeri relative to that from the other root system genotypes. Wine from own roots and Kober 5BB was rated significantly higher in the 'cooked vegetable' attribute than that for 140 Ruggeri and K51-40 with 1202C intermediate. The Kober 5BB and 140 Ruggeri wines had low scores for hotness, reflecting the significantly lower alcohol concentration for Kober 5BB though not significantly lower for 140 Ruggeri (Table 2). The wines from Kober 5BB and own roots had lower viscosity, with K51-40 rated highest for this attribute, which was weakly associated with the non-significant attribute salty taste (r = 0.71, P = 0.18, n = 6) (Figure 2).

Correlations between compositional measures for 'Shiraz'

Strong positive ($P \leq 0.001$) correlations were obtained between 'Shiraz' wine P concentration and grape juice TSS at harvest, between wine K^+ concentration and both total anthocyanin concentration and total phenolics, between wine Cl^- and Na^+ concentrations, between wine total phenolics and each of wine total and ionized anthocyanin concentration and between wine colour density and each of wine ionized anthocyanin and total phenolics (Table S6).

Table 5: Summary of ANOVA results showing F-values, levels of significance and mean square error for sensory attributes of 'Shiraz' wines from vines on own roots and on four different rootstocks at Padthaway, South Australia in season 2011.

Attribute	F ratio†			Error
	Rootstock	Judge	Rootstock*Judge	(Mean Square)
Appearance				
Opacity	42.85***	95.26***	1.54	0.62
Aroma				
Overall Fruit aroma	1.03	15.56***	0.73	1.22
Red fruits	1.69	11.85***	1.13	1.78
Dark fruits	4.40**	28.41***	1.36	1.67
Pepper	0.39	29.63***	0.87	1.04
Vanilla	1.23	33.40***	0.86	1.60
Cooked Vegetable	4.33**	8.78***	0.85	3.59
Stalky	0.56	17.46***	0.87	1.25
Palate				
Overall Fruit flavour	1.00	18.87***	0.94	0.84
Red fruits	1.43	14.96***	0.76	1.69
Dark fruits	1.72	14.67***	1.06	1.92
Stalky	0.69	58.51***	1.47*	1.19
Sweet	0.71	26.44***	1.02	0.62
Salty	0.84	29.01***	1.36	1.17
Acidity	0.52	27.61***	0.91	0.68
Viscosity	2.28*	155.9***	1.43*	0.34
Hotness	3.33*	81.10***	1.71**	0.77
Astringency	1.48	67.28***	0.94	0.91
Bitter	1.36	21.22***	0.73	1.59

†Significance: *$P \leq 0.05$; **$P \leq 0.01$; ***$P \leq 0.001$; the heading 'Rootstock' includes own roots.

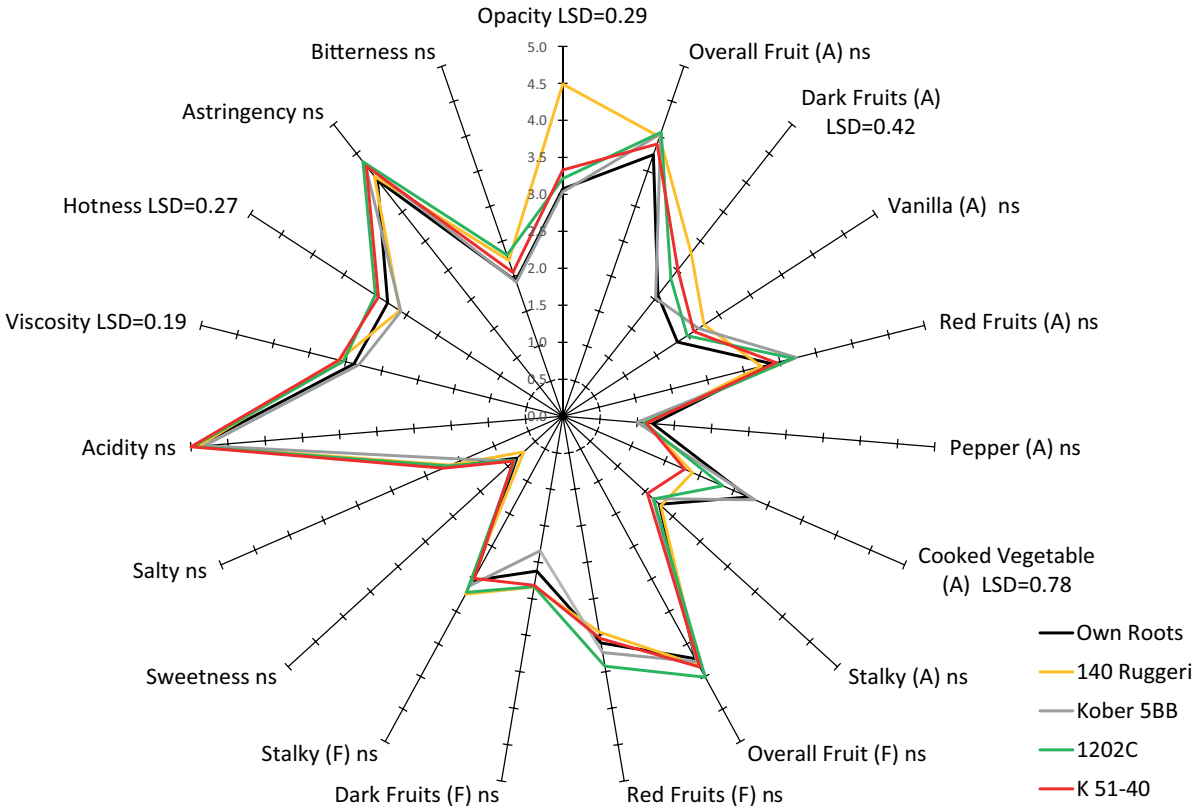

Fig. 2: Mean sensory attribute intensity ratings (A: aroma, F: flavour) of 'Shiraz' wine made from vines on own roots and on four different rootstocks at Padthaway, South Australia in season 2011. LSD = least significant difference ($P = 0.05$). ns = not significant. All axes in the Figure have the same gradations and numbering as shown on the vertical axis. Where significant differences between root system genotypes occur, the LSD is provided to show the differences.

Strong negative ($P \leq 0.001$) correlations were obtained between grape juice TA at harvest and wine ionized anthocyanin concentration and colour density, and between wine colour hue and each of wine K^+ concentration, ionized and total anthocyanin concentrations, total phenolics and colour density (Table S6).

Discussion

The site used for this study (2011) was previously assessed in seasons 1996 and 1997. Comparison of grape juice Cl^- concentration in 2011 with means from seasons 1996 and 1997 (Walker *et al.*, 2010) revealed no increase in concentration over time for 'Chardonnay' on own roots, 140 Ruggeri and 1202C rootstocks, but with increases of 2.8- and 1.4-fold for 'Chardonnay' on K51-40 and Schwarzmann rootstocks, respectively. For 'Shiraz', there was a trend to lower concentrations in 2011 when compared with means from 1996 and 1997, including that for K51-40. A reduction in electrical conductivity of the irrigation water from 2.5 dS m^{-1} in 1996 and 1997 (Walker *et al.*, 2010) to 1.5 dS m^{-1} in 2011 may have contributed.

Cl^- and Na^+ concentrations in 'Chardonnay' wine were highest from the rootstock K51-40 (containing 407.4 mg L^{-1} Cl^- and 374.2 mg L^{-1} Na^+) which resulted in significant elevation ($P \leq 0.05$) of salty taste by the panel, whereas it was not evident for 'Chardonnay' wine from own roots or the other rootstocks (all < 127.5 mg L^{-1} Cl^- and < 116.9 mg L^{-1} Na^+). The low salty taste ratings for own roots and the other rootstocks, from 1.4 to 1.9 on the 0-10 scale, are negligible and comparable to that commonly found in sensory studies for other attributes such as taints in samples where the taint compound is not present (e.g., in smoke taint studies such as Parker *et al.*, 2012). Likewise, salty taste was not noted in 'Shiraz' wines from own roots or any of the rootstocks in this study (all < 274.1 mg L^{-1} Cl^- and 130.5 mg L^{-1} Na^+, salty taste intensity of 1.5-1.75) nor at 384.7 mg L^{-1} Cl^- and 30.4 mg L^{-1} Na^+ in a previous study (Walker *et al.*, 2019). The mean concentration of Cl^- at which salty taste was detected in 'Shiraz' wine in the Walker *et al.* (2019) study (482.4 mg L^{-1}) was just 18% higher than that for 'Chardonnay' wine in this study (407.4 mg L^{-1}), which suggests that with respect to Cl^-, the concentration that is linked to a perceptible salty taste by a trained panel may be similar between a red and white wine.

Salty taste is generally considered to be primarily caused by sodium ions, with potassium salts also found to have a salty taste (Schiffman, 2000). A strong positive correlation between salty taste and both wine Cl^- and Na^+ concentration in this study concurs with the previously reported strong correlation between salty taste and wine Cl^-, Na^+ and K^+ concentration (Walker *et al.*, 2003). Further, unlike 'Shiraz' in this study where there was no relationship between the concentration of Cl^-, Na^+ or K^+ and viscosity score for wine, the salty taste attribute for 'Chardonnay' wine was linked with the viscous attribute and both were approximately equally correlated with wine Cl^- and Na^+ concentrations. The high-

er rating for salty and the viscous attribute in 'Chardonnay' wines from K51-40 rootstock is consistent with earlier data in which the salty taste attribute has been linked with a viscous (Walker *et al.*, 2003) and soapy (Walker *et al.*, 2003; Scacco *et al.*, 2010; De Loryn *et al.*, 2014) mouthfeel attribute. Both salty and soapy attributes were similarly found to be correlated and associated with higher wine Na^+ and Cl^- concentrations by De Loryn *et al.* (2014). Apart from the salty taste and viscosity attributes for 'Chardonnay' wine and their links to specific mineral elements as discussed above, we found no correlation between mineral composition (Cl^-, Na^+, K^+, Ca^{2+}, Mg^{2+}, P or S) and other key sensory attributes for 'Shiraz' and 'Chardonnay' wines. The low perceived acidity of 'Chardonnay' wine from K51-40 rootstock in this study, despite no differences among own roots and rootstocks in both grape juice and wine TA, may relate to the salty taste attribute having a masking effect on acidity.

The 14-fold difference in mean Na^+ concentration between the 'Chardonnay' wine in this study (374.2 mg L^{-1}) and the 'Shiraz' wine in the Walker *et al.* (2019) study (26.4 mg L^{-1}) most likely reflects the different rootstocks involved, specifically K51-40 for 'Chardonnay' and Merbein 6262 for the 'Shiraz' study. Since salty taste was detected in both the 'Chardonnay' (this study) and 'Shiraz' (Walker *et al.*, 2019) wines, with an 18% difference in Cl^- concentration and a 14-fold difference in Na^+ concentration, the salty taste is potentially linked more with Cl^- than Na^+. Moreover, in two studies in which the Na^+ concentration in the wines were similar (26-30 mg L^{-1}), specifically, 'Shiraz' on K51-40 in this study (274 mg L^{-1} Cl^- and 30 mg L^{-1} Na^+) and 'Shiraz' on K51-40 in the Walker *et al.* (2019) study (482 mg L^{-1} Cl^- and 26 mg L^{-1} Na^+), salty taste was perceptible in the latter wine but not in the former, again implicating Cl^- as an indicator of salty taste.

Wine K^+ concentration is unlikely to have been a primary driver of salty taste in 'Chardonnay' wine, as no correlation between salty taste and wine K^+ concentration was found. The K^+ concentration in 'Chardonnay' wine from K51-40 rootstock (470.1 mg L^{-1}), where salty taste was detected (407.4 mg L^{-1} Cl^-), was within the range of K^+ concentrations in wine from own roots and the other 4 rootstocks (427.6 to 584.3 mg L^{-1}) for which salty taste was not detected (wine Cl^- concentrations were all below 137.3 m mg L^{-1}). Also, when comparing wine of 'Shiraz' on K51-40 rootstock with that of 'Chardonnay' on K51-40, a 2.4-fold higher K^+ concentration (1,110 mg L^{-1} for 'Shiraz' compared with 470 mg L^{-1} for 'Chardonnay') together with Cl^- and Na^+ concentrations for 'Shiraz' wine of 274.1 and 130.5 mg L^{-1}, respectively, did not result in a salty taste. Further, apart from weak correlations of salty taste with Ca^{2+} and Mg^{2+} concentration, the study revealed no correlation between salty taste and wine P or S concentration. While the available evidence links Cl^- with salty taste, a contribution from Na^+ and K^+ to the salty taste of the 'Chardonnay' wine cannot be ruled-out without further study.

Sensory perception of NaCl in grape juice and wine was also examined by De Loryn *et al.* (2014) using two parameters (1) the NaCl taste detection threshold and (2) the NaCl taste recognition threshold. NaCl taste detection threshold was defined in that study as the lowest concentration at which the taster could perceive a taste sensation, and the NaCl taste recognition threshold as the lowest concentration at which the taster could correctly identify the taste quality as salty (De Loryn *et al.*, 2014). Of the two parameters used by De Loryn *et al.* (2014), the one comparable with the approach used in our study is the NaCl taste recognition threshold. Using that as a basis for comparison, the median NaCl recognition threshold was marginally (14%) higher for the white than for the red wine, with a white wine mean of 2,050 mg L^{-1} as NaCl (1,244 mg L^{-1} Cl^- and 806 mg L^{-1} Na^+) and a red wine mean of 1,770 mg L^{-1} as NaCl (1,074 mg L^{-1} Cl^- and 696 mg L^{-1} Na^+) (De Loryn *et al.*, 2014). The measured concentrations that gave a salty taste perception for 'Chardonnay' in our study, 407.4 mg L^{-1} Cl^- and 374.2 mg L^{-1} Na^+ (equivalent to a NaCl concentration in the range 671-952 mg L^{-1}) and for 'Shiraz' in a previous study, 482 mg L^{-1} Cl^- and 26 mg L^{-1} Na^+ (Walker *et al.*, 2019), were lower than the NaCl taste recognition threshold values reported by De Loryn *et al.* (2014). The De Loryn *et al.* (2014) values are relatively high, which may have been related to the methodology used, with a potential response bias possibly due to not including an alternative forced choice test or reversals with repeated testing. In addition, it has been suggested that threshold testing may not be accurate as a result of NaCl remaining in the mouth after tasting a solution (Morino and Langford, 1978), and that studies assessing intensity ratings in foods or beverages may be more reliable (Pangborn and Pecore, 1982).

Sensory descriptive analysis was not reported for Mexican white and red wines containing up to 757 and 1152 mg L^{-1} Na^+, respectively (Cabello-Pasini *et al.*, 2013). Wines of the red variety, 'Nero d'Avola', grown in Sicily and made from grapes harvested from vineyard zones with soils classified as median salinity (ECe of 1.2 dS m^{-1} for 0-55 cm depth and 2.1 dS m^{-1} for 56-105 cm depth) and high salinity (ECe of 1.0 dS m^{-1} for 0-55 cm depth and 7.6 dS m^{-1} for 56-105 cm depth) were reported to be preferred by a panel of 10 assessors, while those from negligible salinity (ECe of 0.7 dS m^{-1} for 0-105 cm depth) were judged flat and dull (Scacco *et al.*, 2010). The wines from the medium and high salinity zones in that study had higher concentrations of tartaric acid, total polyphenols, anthocyanins and flavonoids, a higher colour intensity but lower colour hue, with sensory analysis reporting enhanced colour intensity, purple hues, citrus, fruit in the spirit aroma and salty taste (Scacco *et al.*, 2010). Wine ion concentrations were not presented from that study. In our study, irrigation water was applied uniformly across the 'Shiraz' site, with only minor variation in EC of 1:5 soil:water extracts (mean of 0.43 ± 0.04 dS m^{-1}) prepared from the top 30 cm of four soil cores taken post-harvest in the previous season (R.R. Walker, D. H. Blackmore and P.R. Clingeleffer, unpublished data). While this suggests that spatial effects were unlikely, there were differences between the rootstocks in both composition and sensory attributes of wines, with 140 Ruggeri among the rootstocks with least Cl^- and Na^+ accumulation in wine but having significantly higher opacity than wine from K51-40 rootstock, where Cl^- and Na^+ accumulation was highest.

Salty taste was the primary sensory attribute studied. Root system genotype appears to have a bigger influence than season on the amount of salt accumulated in wine. For example, the range in Cl^- concentration due to root system genotype in

this study was 9.8-fold for 'Chardonnay' (41.8 to 407.4 mg L^{-1}) and 5.2-fold for 'Shiraz' (52.5 to 274.1 mg L^{-1}). Seasonal variation in wine Cl^- concentration in a separate study involving 8 different rootstocks ranged from 1.2-fold to 2.2-fold for the 8 rootstocks used (Walker *et al.*, 2019). Given the number of judges (12) and 22 wines assessed (6 for 'Chardonnay' and 5 for 'Shiraz', each replicated) it was clear that across all wines examined a statistically significant detection of salty taste occurred only when wine Cl^- concentration reached 407 mg L^{-1}, marginally below the concentration (482 mg L^{-1}) found for the detection of salty taste in 'Shiraz' wine from a previous study (Walker *et al.*, 2019). Hence, while there can be seasonal effects on wine Cl^- concentration, the root system genotypes used provided a sufficient range in wine Cl^- concentration to potentially expect a panel of judges of similar size and training to arrive at a similar result for salty taste detection in a different season once wine Cl^- concentration was in the range 400 to 500 mg L^{-1}.

Based on means across all root system genotypes, Cl^- and Na^+ concentrations respectively increased between juice samples of 'Shiraz' taken from berries at harvest and finished wine by 2.4-fold and 1.3-fold, respectively. These increases were comparable with the 2.2-fold and 1.1-fold increases for Cl^- and Na^+, respectively, found previously (Walker *et al.*, 2019). However, for 'Chardonnay', Cl^- and Na^+ concentrations respectively increased between grape juice and wine by 1.5-fold and 1.6-fold, which was higher than the approximate 1:1 relationship between grape juice and wine observed by Walker *et al.* (2010). The winemaking procedures were similar between the studies. Season 2011 was, however, wetter than average, with rainfall in January (74.9 mm) and February (57.4 mm) 3.3 and 3.1-fold higher, respectively, than the long term means for each month, which may have affected Chardonnay berry development and potentially skin integrity with implications for release of ions from skins (Gong *et al.*, 2010) during crushing/destemming.

Strong positive correlations between colour density of the 'Shiraz' wines and the concentration of phenolic substances, ionized anthocyanins (both $P \leq 0.001$) and total anthocyanins ($P \leq 0.01$) were also reported by Walker *et al.* (2019). The strong positive correlation between 'Shiraz' wine Cl^- and Na^+ concentrations ($P \leq 0.001$) is potentially driven largely by K51-40 rootstock, which in this study, led to highest concentrations of both ions in wines. However, in other studies involving 'Shiraz' on different rootstocks, for example Merbein 6262, high wine Cl^- concentration was not accompanied by high wine Na^+ concentration since in that study Merbein 6262 was an effective excluder of Na^+ (Walker *et al.*, 2019).

The concentration of Cl^- in 'Chardonnay' wine that corresponded with perception of salty taste was within 18% of that at which a salty taste was perceived for a red wine ('Shiraz') in a previous study, suggesting that the link between salty taste and Cl^- concentration for red and white wines by a trained panel may not be dissimilar. The salty and viscosity attributes in the 'Chardonnay' wines were closely associated and were approximately equally correlated with the wine Cl^- and Na^+ concentration. Salty taste appeared to be more strongly linked with Cl^- than with Na^+ and K^+, however the specific contribution of Na^+ and K^+ to the salty taste of 'Chardonnay' wine requires further study.

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Conflicts of interest statement

The authors declare that they do not have any conflicts of interest.

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