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REGULATED DEFICIT IRRIGATION AND CROP LOAD INTERACTION EFFECTS ON GRAPE HETEROGENEITY

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Abstract

Aim: To investigate the interaction effects between irrigation and crop load and the resulting impact on grape heterogeneity within a Geographical Indication in South Australia.

Methods and Results: Cabernet Sauvignon grapes were sampled at the time of harvest from the Coonawarra Geographical Indication where full and sustained deficit irrigation and crop load manipulations were implemented as a 2 × 2 factorial block design. Grape heterogeneity was quantified for each treatment at three levels (bunch, vine and block) using berry density categories that were related to grape maturity. Furthermore, each density category was characterised in terms of total soluble solids, berry fresh weight, tannin content and tartaric and malic acid concentrations. Irrigation and crop load interaction effects on grape heterogeneity were observed for intra- cluster, vine, and between blocks.

Conclusion: This research reveals the extent of heterogeneity existing in the vineyard at the time of harvest, and presents management techniques that may mitigate grape ripeness variation in the vineyard.

Significance and Impact of the Study: Grape heterogeneity is an important consideration for the production of high quality red wine, as high proportions of under ripe and/or overripe fruit present at the time of harvest have been shown to negatively impact colour, mouthfeel, and varietal aroma of the wine. Furthermore, the presence of overripe/shrivelled grapes with excessive sugar concentrations can lead to increased ethanol in the wine. Previous research has acknowledged the impact that the three focal aspects of terroir – climate, soil and cultivar – have on grape composition, with the overarching effects of climate being highlighted. Vine water status and vine balance can conceivably mediate some of the influences of climate on grape composition, but there has been limited literature delving into the effects on grape heterogeneity. By investigating vineyard management techniques with a view to minimising grape heterogeneity, this research gives insight into the optimisation of grape production, especially in hotter climates that are more susceptible to producing overripe fruit.

Keywords: Vineyard management techniques, vineyard variation, grape composition, Cabernet Sauvignon, red wine quality

Introduction

Grape heterogeneity describes the diverse physical and chemical qualities of berries within a vineyard. A population of berries from a bunch, vine, or block showing grape heterogeneity can differ in size, seed number, seed ripeness, and berry colour as well as being variable in the composition of chemical components, including sugars, organic acids and polyphenolic compounds (Bramley, 2005). The variability in grape chemical composition is spatial and temporal across a vineyard, partly due to climate differences and inconsistent biophysical features such as soil type and depth, elevation and water availability (Bramley, 2005). These are factors unique to a Geographical Indication (GI) and are incorporated in the term "terroir". Diverse vine responses to their distinct microenvironments are controlled by plant hormones (Davies and Böttcher, 2009) that can cause unsynchronised grape ripening (Vondras *et al.*, 2016) at block, vine and bunch levels (Pagay and Cheng, 2010). Although there is acknowledgement to the extent of grape heterogeneity present at the time of harvest (Bigard *et al.*, 2019) and the possible negative effects on wine style (Kontoudakis *et al.*, 2011), there is an insufficient amount of research regarding vineyard management strategies that may mitigate grape heterogeneity.

Deficit irrigation and adjusting vine crop load are considered two fundamentals of viticultural practices for the production of high quality red grapes (Keller *et al.*, 2008). The irrigation × crop load interaction effects have been investigated (Bowen *et al.*, 2011; Calderon-Orellana *et al.*, 2014; Keller *et al.*, 2008) over multiple vintages to conclude there were inconsistent and minor interaction effects. This suggests that crop load did not impact vine response to deficit irrigation and climate had an overarching effect on grape composition. Calderon-Orellana *et al.* (2014) made considerations for the effects on grape composition variability in California and concluded that post-veraison deficit irrigation led to greater heterogeneity of the grapes whereas lower cropping of vines had no major effects on fruit uniformity by the time of harvest. The present research aimed to implement full and deficit irrigation with high and low crop loads in a single GI of South Australia to gain further understanding of the impact these viticultural practices have on grape heterogeneity at harvest.

Materials and Methods

Cabernet Sauvignon grapes were sampled at the time of harvest (vintage 2020) from a commercial vineyard in the Coonawarra GI of South Australia. Vines were own-rooted and sustained deficit irrigation (DI) was implemented 12 weeks post flowering (wpf) at approx. 50 % of full-irrigation (FI). The low crop load (LC) treatments were initiated 8 wpf by cutting off every second bunch on each shoot to give lower bunches per vine compared to the high crop load (HC) treatments which were not manipulated. A 2 × 2 factorial randomised block design was triplicated with buffer rows between each block. For bunch level measures, forty bunches were randomly sampled per treatment, and 15 berries were sampled from each bunch, five from the top, middle and bottom. For vine measures, 12 vines were sampled per treatment, and 50 berries per vine were sampled at random. For block measures, four vines were analysed per treatment replicate, and 50 berries per vine randomly sampled. The total berry sample size per treatment for each level was approximately 600. Vine porosity was measured with the VitiCanopy app (De Bei *et al.*,2016) two weeks before harvest.

The average bunch, vine, and block berry fresh weights were measured and berries were sorted according to their maturity class using salt density baths (Bigard *et al.*, 2019). Individual maturity classes were homogenised and the average total soluble solids (°Brix) was taken. Grape tannin concentrations were determined by methyl cellulose precipitable tannin assay (Mercurio *et al.*, 2007). Grape organic acid content was calculated by summing malic and tartaric acid concentrations that were determined by enzymatic assays (Megazyme, Bray, Ireland).
The variability of berry compositions was represented by the coefficient of variance (CV%), calculated from the differences in the sorted grape maturity classes. The significant effects of irrigation × crop load on grape composition and CV% for the measured variables were determined by two-way ANOVA and pairwise comparisons were applied to significant values ($P \leq 0.05$) by Fisher's least significant difference (LSD) using XLSTAT (Version 2019.1.3, Addinsoft, Paris, France).

Results and Discussion

Heterogeneity in terms of grape chemical composition was analysed on three levels to understand the main effects of conventional vineyard management practices (irrigation and crop load treatment) on vineyard variability. Overall, it appears that intra-bunch grape compositional variability is lower than intra-vine and block variability (Table 1), which could be explained by less severe differences in the bunch microclimates compared to the differences in vine and block environments (Pereira *et al.*, 2006). This highlights the impact and importance of vineyard microclimates on grape heterogeneity.

Irrigation and crop load interactions had significant effects on mean berry sugar content at the different levels of potential heterogeneity. DI and LC treatments appeared to lower the mean berry sugar content significantly by the time of harvest (Table 1). Keller *et al.* (2008) and Bowen *et al.* (2011) also reported a lower sugar content from DI treatment, but significantly lower berry sugar content in the LC treatment of the current study contrasts with their findings. The LC treatment had 56.7 ± 4.4 bunches per vine which was significantly (P ≤ 0.01) less than the HC treatment with 89.7 ± 9.1 bunches per vine, therefore, the present findings might be attributable to mid-season water stress experienced by the LC treatment, which was significantly higher (P ≤ 0.05) than for HC (data not shown). The sugar content variability was not significantly different at the bunch and block level between treatments, but DI significantly increased vine sugar content variability, which had a dependency on crop load according to the significant interaction effects (Table 1). This may have been due to uneven water loss on a whole vine scale leading to slightly higher levels of sugar content variability, which has been previously observed (Calderon-Orellana *et al.*, 2014).

Table 1: The effects of irrigation × crop load on bunch, vine and block mean† and average variability‡ of Cabernet Sauvignon berry composition.§

	Mean sugar content (g/g berry)			Mean organic acid content (mg/g berry)			Mean tannin content (mg/g berry)		
Treatment	Bunch	Vine	Block	Bunch	Vine	Block	Bunch	Vine	Block
Irrigation	ns	*	*	ns	***	*	ns	ns	ns
Full	0.27 ± 0.00	0.25 ± 0.00	0.25 ± 0.01	4.34 ± 0.03	4.06 ± 0.14	4.08 ± 0.14	3.28 ± 0.09	2.87 ± 0.24	2.89 ± 0.34
Deficit	0.26 ± 0.00	0.24 ± 0.01	0.24 ± 0.01	4.20 ± 0.04	3.78 ± 0.14	3.78 ± 0.14	3.21 ± 0.05	2.93 ± 0.15	2.94 ± 0.23
Crop load	***	***	***	ns	ns	ns	***	*	**
High	0.28 ± 0.00	0.26 ± 0.01	0.26 ± 0.01	4.31 ± 0.03	3.94 ± 0.15	3.96± 0.15	3.47 ± 0.06	3.05 ± 0.19	3.08 ± 0.27
Low	0.25 ± 0.00	0.24 ± 0.00	0.24 ± 0.01	4.22 ± 0.04	3.90 ± 0.13	3.90 ± 0.13	3.02± 0.08	2.75 ± 0.20	2.75 ± 0.30
Interactions	*	**	*	ns	ns	ns	***	ns	ns
	Sugar content variability %			**Organic acid content variability %**			**Tannin content variability %**		
Treatment	Bunch	Vine	Block	Bunch	Vine	Block	Bunch	Vine	Block
Irrigation	ns	*	ns	ns	ns	ns	***	***	**
Full	3.5	6.5	6.9	4.5	11.8	12.1	17.3	29.2	29.0
Deficit	3.2	8.2	8.3	5.9	12.9	13.2	9.6	18.6	19.2
Crop load	ns	ns	ns	**	ns	ns	***	ns	ns
High	3.3	7.5	7.7	3.9	13.0	13.5	10.6	22.0	21.5
Low	3.4	7.3	7.5	6.4	11.7	11.9	16.3	25.8	26.7
Interactions	ns	**	ns	*	ns	ns	***	*	ns

†Mean values (bunch n = 40; vine n = 12; block vines n = 4) ± standard error. ‡Variability values shown as CV%. §Two way ANOVA followed by Fisher's LSD comparisons with significance level indicated: *, **, ***, representing P ≤ 0.05, P ≤ 0.01 and P ≤ 0.001, respectively. Interaction effects analysed within a column.

The main effect for lowering mean organic acid content seemed to be DI, which was significant at the vine and block level (Table 1). This may be due to lower transpiration levels creating warmer microclimates that promote acid degradation, as previously described by Bowen *et al.* (2011). On the other hand, there appeared to be no treatment effects on organic acid variability on the vine and block level, although bunches from the HC treatment had significantly lower acid content variability that also depended on the irrigation treatment according to the significant interaction effects (Table 1). This implies that the HC environment was more homogenous on the bunch level than the LC treatment in terms of organic acid catabolism, especially when full irrigation was applied. With regard to mean tannin content, LC had a significant effect on the bunch, vine and block level (Table 1). Mean tannin content on the bunch level was also dependent on the applied irrigation treatment regarding the significant interaction effect (Table 1). A significantly higher (P = 0.05) vine canopy porosity of the LC treatment (data not shown) might have increased the solar radiation and temperature at the bunch-zone. This has been suggested to downregulate tannin (flavan-3-ol) biosynthesis in favour of anthocyanins (Boss and Davies, 2009), which could explain the lower tannin content of the LC treatment. Interestingly, irrigation treatment had a significant effect on tannin content variability at all three levels and crop load appeared to have a significant interaction effect on the bunch and vine level (Table 1). It has been shown that exposed bunches are more variable in terms of berry anthocyanin and flavonol content (Pereira *et al.*, 2006) and DI led to higher intra-vine anthocyanin variability Calderon-Orellana *et al.* (2014), but neither authors reported on the tannin content variability. From the current results, it could be suggested that the HC and DI treatments led to more uniform biosynthesis and/or degradation of grape tannins.

Conclusions

The presented research shows the extent of grape heterogeneity still present at the time of harvest in terms of sugar, organic acid, and tannin content under different vineyard management practices. Statistically significant lower mean sugar contents at the vine and block level for DI and at all three levels for LC treatments were observed, with significant interaction effects. However, DI significantly decreased the mean organic acid content on the vine and block level. While lower sugar content is desired by winemakers to manage wine alcohol content, acidity is necessary for taste, wine colour and antimicrobial activity. The main effect for mean tannin content was crop load; HC treatment on all three levels had significantly higher tannin content, but this may have been a result of vine canopy differences, such as porosity, between crop load treatments instead of source/sink relations. DI significantly lowered grape tannin variability, whereas treatment effects on grape sugar and organic acid content variability were slight. Grape chemical composition can vary in additional quality parameters; therefore, greater work is required to appreciate the potential of irrigation and crop load interactions to mitigate grape heterogeneity by the time of harvest.

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