FROM PLANT WATER STATUS TO WINE FLAVONOID COMPOSITION: A PRECISION VITICULTURE APPROACH IN A SONOMA COUNTY VINEYARD

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Abstract:

Context and Purpose of the Study- Plant water status of grapevine plays a critical role in affecting berry and final wine chemical composition. The environmental variabilities existing in vineyard system have significant impacts on plant water status, but it is challenging to individualize environmental factors from the temporal and spatial variabilities in vineyard. Therefore, there is need to monitor the ecophysical variation through utilizing precision viticulture tools in order to minimize the separation in berry composition. This study aims at delineating vineyard into different management zones based on plant water status explained by soil texture, and utilize differential harvest to equilibrate the final berry and wine composition.

Material and Method - Ecophysical variation affecting wine flavonoid composition in a Cabernet Sauvignon/110R vineyard was modeled for 2016 and 2017. Soil properties of the vineyard were proximally sensed to acquire soil texture. An equi-distant 30 m × 30 m grid was overlaid to characterize grapevine primary and secondary metabolism. The mid-day stem water potential (□stem) integrals were calculated and delineated by k-means clustering into two water status zones in 2016: severely stressed (Zone 1) and moderately stressed (Zone 2). Primary metabolism, including total soluble solids, titratable acidity, pH, and berry weights; also, secondary metabolism, including anthocyanins and flavonols were measured throughout the whole season. The primary metabolism decoupled when Zone 2 reached 26 and 24 °Brix in 2016 and 2017, respectively with significantly higher °Brix values of 30 and 27 in Zone 1. Based on this decoupling in °Brix between two water stress zones, fruits were harvested differentially and vinified separately from two zones in both years.

Results - The research site received 39 mm of precipitation in 2016 and 162 mm in 2017. The surface soil texture could explain 84.20% of the variations in □stem while subsurface soil texture could explain 79.57%, depending on the loam to sandy loam contribution. In 2016, total anthocyanidins were higher in Zone 2. Di- and tri-hydroxylated anthocyanidins were more than 2× concentrated in Zone 2. Myricetin-, quercetin-, kaempferol-3-O-glucosides and total flavonols were higher in Zone 2. Proanthocyanidin subunits were also higher in Zone 2 in 2016. However, there was no difference in any flavonoid compound in 2017 except kaempferol-3-O-glucoside which was lower in Zone 2. The results indicated that in 2016, the water stress between the two zones was great enough to alter flavonoid concentration in base wine. However, in 2017, harvestcommenced earlier when two zones started separating in °Brix, and wine flavonoid concentration coalesced accordingly. This study provides fundamental knowledge to coalesce vineyard variability through linking soil texture to plant water status by using precision viticulture tools, further, their influences on flavonoid profiles in the final wine products.

Keywords: Grapevine, anthocyanins, flavonoids, water status, soil texture, spatial variability, viticulture.

1. Introduction.

From Plant Water Status to Wine Flavonoid Composition: A Precision Viticulture Approach in a Sonoma County Vineyard

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Abstract

Ecophysical variation affecting wine flavonoid composition in a Cabernet Sauvignon/110R vineyard was modeled for two growing seasons. The research site received 39 mm of precipitation in 2016 and 162 mm in 2017. Soil properties of the vineyard were proximally sensed to acquire soil texture. An equi-distant 30 m × 30 m grid was overlaid to characterize grapevine primary and secondary metabolism. The mid-day stem water potential (Ψ_{stem}) integrals were calculated and clustered by k-means into two water status zones: severely stressed (Zone 1) and moderately stressed (Zone 2) that explained 70% of water status variation. The surface soil texture explained 84% of the variation in Ψ_{stem} while subsurface soil texture explained 80%, depending on the loam to sandy loam contribution. The primary metabolism decoupled when Zone 2 reached 26 and 24 °Brix in 2016 and 2017, respectively with significantly higher °Brix values of 30 and 27 in Zone 1. Based on this decoupling in °Brix, fruit was harvested differentially in both years and vinified separately from two zones. In 2016, total anthocyanins were higher in Zone 2. Di- and tri-hydroxylated anthocyanins were more than 2× concentrated in Zone 2. Myricetin-, quercetin-, kaempferol-3-*O*-glucosides and total flavonols were higher in Zone 2. Proanthocyanidin subunits were also higher in Zone 2 in 2016. However, there was no difference in any flavonoid compound in 2017 except kaempferol-3-*O*-glucoside which was lower in Zone 2. The results indicated that in 2016, the water stress between the two zones was great enough to alter flavonoid concentration in base wine. However, in 2017, harvest commenced earlier when two zones started separating in Brix, and wine flavonoid concentration coalesced accordingly. This study provides fundamental knowledge to coalesce vineyard variability by linking soil texture to plant water status with precision viticulture tools, further, their influences on the final wine products' flavonoid profiles.

Introduction

- Vineyards naturally have spatial variability in plant water status, which would usually result in keeping berry and further base wine flavonoid concentration from their optimal characteristics even within the same vineyard. These variabilities always appear to be the consequences of spatial variations in vine vigor, soil properties, and topography across the entire production blocks. To precisely and accurately monitor, manage, and eventually eliminate these variabilities, Global Positioning Systems (GPS), local and remote sensors, and Geographic Information Systems (GIS) along with their combination with on-site physiological measurements are utilized to evaluate the variabilities linked to specific locations [1].
- Our previous fundamental work presented that plant water status can be used as a proxy for delineating the vineyard into various management/harvest zones [2]. Selective harvest with separation inside the vineyard at different time points was suggested to be a solution in coalescing variations in flavonoid composition in grape berry.

Materials and Methods

- **Vineyard Site and Plant Materials:** This study was conducted in a commercial *Vitis vinifera* L. 'Cabernet Sauvignon' vineyard grafted onto 110R (*Vitis berlandieri* Planch × *Vitis rupestris* Scheele) rootstock located in Healdsburg, Sonoma County, CA, USA. Vines were planted at 1.83 m × 3.35 m (vine × row). The grapevines were spur pruned with 2 buds per spur, 7 spurs per meter of the row, and trained to two single high wires with two horizontal splits.
- **Soil Property and NDVI Assessment:** Soil texture measurements and maps were acquired by Soil Information System (SIS) of C3 consulting™ in the vineyard. Two depths of soil texture were assessed, including surface and deep. Soil electrical resistivity was acquired by EM38-MKII (Geonics Ltd., Mississauga, ON, Canada). NDVI was assessed by Crop Circle ACS-430 (Holland Scietific Inc., Lincoln, NE, USA)
- **Vine Measurements:** Plant water status was measured at solar noon as stem water potential (Ψ_{stem}). Temporal changes were summarized by calculating Ψ_{stem} over the season of 2016, two management zones were generated based on Ψ_{stem} integrals [2].
- **Berry and Wine Chemistry Analysis:** Berry and wine primary metabolites were quantified, including total soluble solids, total acidity, pH and berry weight. Skin and wine flavonoids, including anthocyanins and flavonols were analyzed by RP-HPLC [3]. Fruits were differentially harvested for further vinification on October 5, 2016, and September 20, 2017.

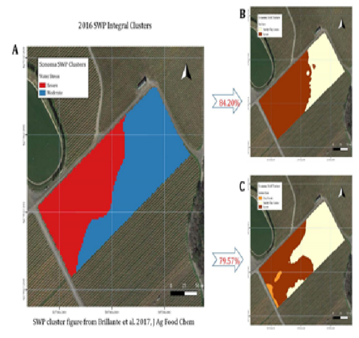

Figure 1. A) K-means clustering of vine stem water potential integral calculated from 2016 stem water potential (SWP) integrals [2]; **B)** Surface soil texture map of the experimental site; **C)** Deep soil texture map of the experimental site. Soil texture maps were obtained from Soil Information System (SIS) of C3 consulting™.

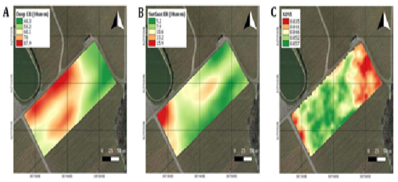

Figure 2. A) Deep soil electrical resistivity interpolation map of the experimental site; **B)** Surface soil electrical resistivity interpolation map of the experimental site; **C)** Ground NDVI interpolation map of the experimental site.

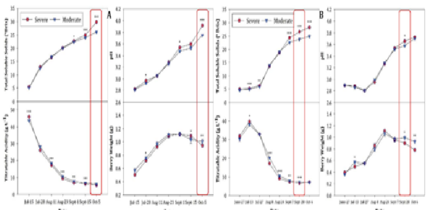

Figure 3. Wine Physical Characteristics of Cabernet Sauvignon as separated by water status zoning in Sonoma County, CA in **A)** 2016 and **B)** 2017. Harvest dates in both years are highlighted.

Conclusion

- Assessing soil texture with assistance of precision viticulture technologies can be a prompt way to estimate plant water status without redundant and time-sensitive on-site water status measurements.
- The spatial variabilities in soil texture had a significant impact on plant water status, and the difference in water status between the two zones was reflected in the base wine flavonoid concentration.
- Water stress exacerbated the anthocyanin degradation when harvesting relatively later in 2016.
- An earlier harvest time in this study showed that without hanging the fruits for an unnecessary long time could coalesce the variability of the two zones in flavonoid concentration.

Table 1. Wine physical characteristics of Cabernet Sauvignon as separated by water status zoning in Sonoma County, CA in 2016 and 2017 [a]

	2016			2017		
	Severe Water Stress ± SE	Moderate Water Stress ± SE	*p* value	Severe Water Stress ± SE	Moderate Water Stress ± SE	*p* value
Alcohol Content (% v/v)	16.63 ± 0.07 a	15.50 ± 0.27 b	0.015	15.05 ± 0.05 a	13.64 ± 0.29 b	0.009
pH	3.64 ± 0.00	3.68 ± 0.01	0.055	3.68 ± 0.05	3.74 ± 0.01	0.258
Titratable Acidity (g/L)	6.28 ± 0.15	6.06 ± 0.27	0.517	6.93 ± 0.10	6.96 ± 0.07	0.809
Residual Sugar (g/L)	0.74 ± 0.06	0.61 ± 0.01	0.081	0.80 ± 0.08 a	0.60 ± 0.04 b	0.012
Acetic Acid (g/L)	0.34 ± 0.01 a	0.27 ± 0.01 b	0.020	0.22 ± 0.01	0.18 ± 0.01	0.070

[a] ANOVA to compare data (*p* value indicated); Letters within columns indicate significant mean separation according to Tukey's HSD test.

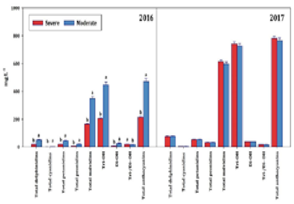

Figure 4. Base wine anthocyanin concentration of Cabernet Sauvignon as separated by water status zoning in Sonoma County, CA in 2016 and 2017. **Abbreviation:** -OH, hydroxylation.

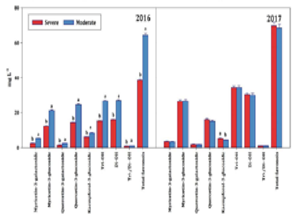

Figure 5. Base wine flavonol concentration of Cabernet Sauvignon as separated by water status zoning in Sonoma County, CA in 2016 and 2017. **Abbreviation:** -OH, hydroxylation.

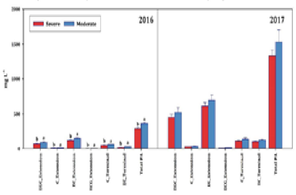

Figure 6. Base wine proanthocyanidin subunit concentration of Cabernet Sauvignon as separated by water status zoning in Sonoma County, CA in 2016 and 2017. **Abbreviation:** C, (+)-catechin; EC, (-)-epicatechin; ECG, (-)-epicatechin-3-O-gallate; EGC, (-)-epigallocatechin, PA, proanthocyanidin.

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