STAYING HYDRATED – NOT EASY WHEN IT'S HOT!

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Abstract:
Context and purpose of the study – Heat and drought episodes during the growing season are becoming more frequent and more severe in many of the world's grape-growing regions. However, the responses of grapevines to a combination of these stress factors are incompletely understood, which hampers the implementation of deficit irrigation and heat mitigation strategies. Our team is investigating impacts of water deficit and temperature alone or in combination on physiology, growth, fruit production and composition of different grape cultivars. In addition, we are also testing different deficit irrigation strategies and novel approaches to canopy heat mitigation.

Material and methods – Experiments are conducted with both field- and pot-grown cultivars of own-rooted wine grapes in an arid climate. Drydown and rewatering cycles were applied to 18 cultivars in a vineyard, and changes in soil moisture, leaf water potential, and stomatal conductance were monitored during 4 growing seasons. In another experiment, pot-grown Cabernet Sauvignon and Riesling vines were exposed in environmentally controlled growth chambers to episodes of water stress, heat stress, and combined water and heat stress, followed by recovery periods. Changes in growth, leaf physiology, and fruit composition were compared with non-stressed control vines. Finally, a novel mist-type evaporative cooling system was installed in a Cabernet Sauvignon vineyard and is currently being tested for its ability to mitigate heat stress while maintaining fruit quality.

Results –All cultivars tested in the vineyard decreased their leaf water potential as the soil dried. Some cultivars behaved in classic anisohydric fashion, while others only decreased their leaf water status once soil moisture had declined below a threshold, and yet others showed highly variable responses. Irrespective of their hydraulic behavior, all cultivars also responded to soil drying by decreasing stomatal conductance. In the growth chambers, water stress dominated the responses of shoot growth and leaf physiology in both cultivars, but heat stress exacerbated the adverse impact of water stress. By contrast, heat stress dominated the responses of fruit composition, reducing titratable acidity and increasing the pH and total soluble solids. The evaporative cooling system effectively controlled canopy temperatures during heat waves with a minimum supply of water and without adverse effects on disease incidence, fruit yield, and composition.

Keywords: Heat stress, water stress, irrigation, anisohydric, isohydric, gas exchange.

1. Introduction

Climate change is impacting grape and wine production to varying degrees. Heat and drought episodes during the growing season are becoming more frequent and more severe in many of the world's grape-growing regions, but especially in warm and dry regions (White et al. 2006, Keller 2010). This presents a challenge for premium-quality grape production, because the use of regulated deficit irrigation (RDI) is typically associated with smaller and more open canopies with more sun-exposed fruit whose temperature can reach 15°C above ambient temperature (Keller et al. 2016). Moreover, the responses of grapevines to a combination of heat and water stress are incompletely understood, which hampers the implementation of deficit irrigation and heat mitigation strategies. For instance, grape cultivars are often classified as being either isohydric or anisohydric, depending on the degree to which they decrease their leaf water potential (Ψ_l) under water stress (Schultz 2003, Chaves et al., 2010, Lovisolo et al. 2010). Isohydric cultivars are thought to maintain their Ψ_l via sensitive stomata that close readily in response to water stress, whereas the comparatively insensitive stomata of anisohydric cultivars are thought to favor carbon acquisition at the risk of hydraulic failure. Yet only a few cultivars have been investigated to date, and results are often inconsistent, partly because hydraulic traits are determined by both genotype and environment (Hochberg et al. 2018). Moreover, heat stress may be problematic for grapevines because canopy temperatures are subject to higher diurnal variation than are air temperatures (Peña Quiñones et al. 2019). Our team is investigating impacts of water deficit and temperature alone or in combination on physiology, growth, fruit production and composition of different grape cultivars. In addition, we are also testing different deficit irrigation strategies and novel approaches to canopy heat mitigation. This presentation provides a brief overview of experiments conducted in the vineyard and in climate-controlled growth chambers over the last 5 years.

2. Material and methods

Plant material – Since 2015 experiments have been conducted in eastern Washington, USA, with both field- and pot-grown cultivars of own-rooted *Vitis vinifera* L. wine grapes. The climate in this region is arid (200 mm annual precipitation). The research vineyard was planted in 2010 and is drip-irrigated, and the soil is a uniform silt loam with a field capacity near 30% (v/v) and a permanent wilting point slightly below 8% (v/v). Pre- and postveraison drydown and rewatering cycles were applied in the vineyard to 12 to 18 cultivars (Table 1) growing side-by-side during 4 growing seasons. In another experiment, pot-grown Cabernet Sauvignon and Riesling vines were exposed at bloom, preveraison, or veraison in environmentally controlled growth chambers to 7-day episodes of water stress (15-20% soil moisture) heat stress (10°C above control), and combined water and heat stress, followed by 7-day recovery periods. Non-stressed control vines were maintained near 30% soil moisture in day/night temperature regimes similar to those typical of the region at each phenological stage. Finally, a novel mist-type evaporative cooling system was installed in a Cabernet Sauvignon vineyard irrigated using RDI and is currently being tested for its ability to mitigate heat stress while maintaining fruit quality.

Plant measurements – Volumetric soil moisture (θ_v) in the vineyard was monitored with neutron probes (ICT International), predawn and midday Ψ_l of bagged leaves was measured with pressure chambers (PMS Instrument Company), and midday stomatal conductance (g_s) was measured with an infrared gas analyzer (ADC BioScientific). Leaf water potential and gas exchange were also measured, in addition to shoot growth, in the pot experiment during and after each stress episode. The vineyard evaporative cooling system comprises misting, sensing, and controlling units to cool the canopy depending on canopy temperature and leaf wetness. An infrared thermometer (Apogee Instruments) monitors the canopy temperature to activate misting at temperatures above 35°C and deactivate it at temperatures below 32°C. Leaf wetness sensors monitor surface water to stop misting as the leaves become wet. Water use, canopy temperature, and humidity are being measured, and disease development is being monitored. Berries were collected in the pot experiment and the canopy cooling trial and analyzed for total soluble solids (TSS) by refractometry, titratable acidity (TA) by titration, and pH with a pH meter (all Mettler-Toledo).

Statistical analysis – Data were analyzed by ANOVA and correlation procedures as appropriate for each experiment.

3. Results and discussion

None of the cultivars investigated in the field behaved in true isohydric fashion. All cultivars decreased predawn and midday Ψ_l and g_s as the soil dried, but they did so to varying degrees (Table 1), consistent with the idea of a continuum of responses (Hochberg et al. 2018). In some cultivars (e.g. Cabernet Sauvignon, Sémillon) Ψ_l decreased linearly with declining θ_v; these cultivars might thus be classified as anisohydric. In other cultivars (e.g. Merlot, Grenache) Ψ_l did not begin to decrease until θ_v declined below a threshold of about 14% (v/v) in this silt loam soil. In yet other cultivars (e.g. Riesling, Muscat blanc) the response to θ_v was often masked by other factors, such as atmospheric vapor pressure deficit (VPD), making this last group appear relatively insensitive to changes in θ_v. Contrary to what is commonly assumed in the literature, the anisohydric cultivars did not have less sensitive stomata than the other cultivars (Table 1). Moreover, g_s was highly variable at high Ψ_l but was invariably low at low Ψ_l. This indicates that the stomatal response was dominated by VPD, and hence temperature, when θ_v was not limiting but became dominated by root water uptake as θ_v decreased. Water loss from the vines continued even when the stomata were fully closed due to the high evaporative demand during the summer months.

In the growth chambers, water stress dominated the responses of shoot growth and leaf physiology in both Cabernet Sauvignon and Riesling. However, while the influence of heat stress alone was small and inconsistent, it exacerbated the adverse impact of water stress on Ψ_l, g_s, and photosynthesis (A_n). This latter response was similar to earlier research with fruitless cuttings (Edwards et al. 2011). Water stress may aggravate heat stress because closure of stomata to prevent excessive water loss during water stress decreases heat removal from the leaves. Both g_s and A_n recovered within days under subsequent non-stress conditions. In contrast to leaf physiology, heat stress dominated the responses of fruit composition, while the effect of water stress was not significant. Heat stress reduced TA and increased the pH before and after veraison and also increased TSS during ripening. We had shown previously that high temperature (high VPD) stimulates berry transpiration and that rapid transpiration accelerates sugar accumulation by enhancing phloem import (Zhang and Keller 2015, 2017).

Installation of a novel evaporative cooling system in a Cabernet Sauvignon vineyard showed that the system's feedback controls may be able to effectively control canopy temperatures with a minimum supply of water. The instant flow rate was about 14% of that of small overhead sprinklers. Canopy temperature in the treated sections was maintained between 32°C and 35°C during the repeated heat waves of the 2018 summer. Unlike hydrocooling using overhead sprinklers (Gilbert et al. 1971), our evaporative cooling system did not alter disease incidence, fruit yield, TSS, TA, and pH. However, it is possible that this is partly due to the small scale of this preliminary trial. Lager blocks may be required to eliminate any possible interference between control and cooling treatments.

4. Conclusions

Our results show that the appealing isohydric/anisohydric categorization of grape cultivars is an oversimplification of reality. Tailoring RDI or other irrigation strategies to individual cultivars requires a careful assessment of each cultivar. The present results also demonstrate that heat stress exacerbates the impact of water stress. However, the effects of water stress and heat stress on grapevines vary depending on the plant organ or process investigated. While effects on shoot growth and leaf physiology are dominated by water stress, effects on fruit composition are instead dominated by heat stress. Evaporative cooling using feedback controls may effectively control canopy temperatures during heat waves with a minimum supply of water.

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Table 1. Correlation coefficients (r) for the relationship between soil moisture (θ_v) and midday leaf water potential (Ψ_l) or stomatal conductance (g_s) of 18 grape cultivars grown in a vineyard in eastern Washington, USA. Data for the 2015 to 2018 growing seasons were pooled (n.d. = not determined); θ_v ranged approximately from 25% to 8%.

Cultivar	r (Ψ_l vs. θ_v)	r (g_s vs. θ_v)
Albariño	0.73	0.63
Auxerrois	0.75	n.d.
Cabernet franc	0.67	0.81
Cabernet Sauvignon	0.66	0.81
Chardonnay	0.69	0.54
Gewürztraminer	0.59	0.85
Grenache	0.51	0.62
Lemberger	0.57	0.62
Malbec	0.60	0.79
Merlot	0.53	0.61
Muscat blanc	0.57	0.81
Nebbiolo	0.60	n.d.
Petit Verdot	0.60	n.d.
Pinot gris	0.62	n.d.
Pinot noir	0.67	n.d.
Riesling	0.44	0.73
Sauvignon blanc	0.58	n.d.
Sémillon	0.85	0.92