HEAT WAVES AND DROUGHT STRESS IMPACT GRAPEVINE GROWTH AND PHYSIOLOGY

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Abstract:
Context and purpose of the study – Recurring heat and drought episodes during the growing season can produce adverse impacts on grape production in many wine regions around the world. Although the effect of these factors on plant physiology and growth has been investigated separately, little is yet known about their interactions and the variability of these effects among genotypes and phenological stages. The main aim of this study was to evaluate the response of two grape varieties to heat and drought stress and subsequent recovery at different phenological stages.

Material and methods - Pot-grown Cabernet Sauvignon and Riesling plants were moved to environmentally-controlled growth chambers at bloom, pre-veraison and veraison in 2018. For each phenological stage, a different group of plants were used to avoid cumulative treatment effects. After 7 days of acclimation in the growth chambers, different treatments were imposed: control (no stress), water stress, heat stress (10°C above control), and combined water and heat stress. Growth, gas exchange, leaf water potential, photosystem electron transport and energy dissipation were measured in both young and mature leaves of 6 plants per treatment before the stress episode, during 7 days of stress, and through 7 days of recovery.

Results - At bloom, water stress decreased transpiration, stomatal conductance and photosynthesis in both varieties. Combined stress decreased gas exchange only in Riesling. During pre-veraison, heat stress reduced leaf water potential, gas exchange and chlorophyll fluorescence, both in young and mature leaves. Combined stress drastically decreased most of the parameters compared to control plants. This decline was higher in Riesling than in Cabernet Sauvignon. During veraison, drought was the dominant factor that affected most parameters. Additionally, heat stress exacerbated the drought stress effect on the physiological parameters. During the recovery periods, no significant differences were found among treatments in any parameter, indicating that both varieties were able to recover fully from the imposed stresses. Water stress and combined stress decreased shoot length, number of main leaves, lateral leaves and total leaf area in both varieties.

Keywords: high temperature, irrigation, leaf area, gas exchange, leaf age.

1. Introduction

Climate change is expected to bring significant changes in temperature and water availability in many wine regions around the world. For example, the frequency and magnitude of heat waves and drought events is predicted to increase over the coming decades, which could have serious impacts on the production of premium deficit-irrigated wine grapes (Diffenbaugh et al. 2006, White et al. 2011). Effects of soil water availability and heat stress on grapevine vegetative growth and plant physiology have been reported (Sepúlveda and Kliewer 1986, Chaves et al. 2007). Although the effect of these factors has been separately investigated in grapevines, the results found in the literature are sometimes contradictory (Kizildeniz et al. 2018), and little is yet known about their interactions and the variability of these effects among grape varieties and phenological stages. Edwards et al. (2011) reported a higher effect of water stress on leaf physiology and leaf area during high-temperature events. However, their study used fruitless cuttings. The reported decrease of carbon acquisition due to heat and drought stress during berry ripening can compromise the carbon demand of the berries (Greer and Weston

2010). For that reason, more studies using fruiting plants are necessary to quantify the consequences of climate change, and more specifically, the unpredictable extreme events. Recently, Kizildeniz et al. (2018)described the effects of a 4 °C increase on biomass accumulation and leaf physiology in Tempranillo cuttings. However, according to Lipiec et al. (2013) a 10-15°C rapid rise above typical, ambient temperature may be considered as heat stress or heat shock. Therefore, the present study aimed to quantify the response of grapevines to heat events combined with deficit irrigation and the subsequent recovery on Riesling and Cabernet Sauvignon grapevines at different phenological stages.

Material and methods

Plant material – Pot-grown Cabernet Sauvignon and Riesling plants (3-4 shoots per plant, 1 cluster per shoot) were moved to environmentally-controlled growth chambers at bloom, pre-veraison and veraison in 2018. After 7 days of acclimation in the growth chambers, different treatments were imposed: control (no stress), water stress, heat stress (10°C above control), and combined water and heat stress. The irrigation treatments were set at 15-20 % soil moisture for water-stressed plants and 30% for well-watered plants.

Plant measurements –Soil water content was measured using a HS2 Hydrosense probe (Campbell Scientific, UT, USA). Shoot growth, number and length of main leaves and lateral leaves were measured before and after 7 days of stress at each phenological stage, and plant leaf area was estimated. Before the veraison experiment was started, laterals were removed in all plants. Gas exchange (photosynthesis and stomatal conductance), photosystem electron transport and energy dissipation were measured in both young and mature leaves before the stress episode, during the stress, and through 7 days of recovery. Leaf gas exchange was measured using a portable ADC Lci gas exchange analyzer (ADC BioScientific, UK). Photosystem electron transport and energy dissipation was measured using a MultispeQ V2.0 device (PhotosynQ, MI, USA). Midday leaf water potential was measured using a Scholander pressure chamber.

Statistical analysis – Data were processed using ANOVA procedures, and means were separated by Tukey's test using JMP 14 (SAS Institute Inc., Cary, NC, USA).

Results and discussion

Plant growth

At bloom, shoot growth rates and leaf appearance was affected by variety, with higher values in Cabernet Sauvignon than in Riesling. However, leaf appearance rates were similar for both varieties after 7 days of stress. Only shoot growth rate was affected by temperature at this stage (Table 1). These results were in accordance with the study of Sepúlveda and Kliewer (1986), where Chardonnay vines were treated at 40 °C. However, Semillon grapevine growth was not affected by a 4-day exposure to 40 °C at any stage of development in another study (Greer and Weston 2010). Similarly, Kizildeniz et al. (2018) reported no effects of high temperature (4 °C above the control). At pre-veraison, none of the measured parameters were affected by irrigation or temperature treatments. This might have been due to the lower difference in soil water content between well-watered (30%) and water stressed (20%) plants at this stage. At veraison, shoot growth and leaf appearance rates were affected by water supply, but not by temperature or variety. Additionally, the increase in leaf area was affected by water supply and variety.

Leaf gas exchange, leaf water potential and photosystem electron transport

At bloom, water stress decreased stomatal conductance, transpiration and photosynthesis rates in both varieties. Heat stress increased leaf gas exchange when the plants were well irrigated. Combined stress decreased gas exchange only in Riesling. At pre-veraison, heat stress reduced the physiological parameters in mature leaves, contrary to the results found by Edwards et al. (2011), where no significant high-temperature effect was found in well-watered plants. Combined stress drastically decreased gas exchange compared to control plants. According to Edwards et al. (2011) stomatal conductance of heated deficit-irrigated vines was significantly reduced by more than 40%. In our study, the reduction of stomatal conductance under heat stress conditions was more than 60% for mature leaves of well irrigated and water stressed plants after 7 days of stress. However, young leaves showed an increase in stomatal conductance and photosynthesis under heat stress. In the study of Kalituho et al. (2003) different sensitivity to heat stress in young and old tissues was reported. Moreover, after 7 days of stress, mature leaves showed an increase in the regulation of the excess of energy, and a reduction in the quantum yield of photosystem II, under heat stress. At this stage, plants that suffered a heat event maintained lower gas exchange than the control plants until the fifth day of the recovery period. However, at veraison, only the plants under combined stress showed lower stomatal conductance, transpiration, photosynthesis and quantum yield of photosystem II, compared to the control (Figure 1). At this stage, plants recovered within one day after the stress period ended.

Conclusions

Heat and drought effects varied among phenological stages of grapevines. Heat stress exacerbated the drought stress effect on the physiological parameters of mature leaves. Both Cabernet Sauvignon and Riesling recovered fully from the imposed stresses within 1-5 days, depending on the phenological stage. Water stress and combined stress decreased shoot length, number of main leaves, lateral leaves and total leaf area in both varieties.

Acknowledgments

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Table 1. Shoot growth, main leaf area increase, main leaf appearance rate and lateral leaf appearance rate in Cabernet Sauvignon and Riesling under control (CT) temperatures, high temperatures (HS, 10°C above control), well-watered (WW) and water stress (WS) conditions. Means followed by different letters indicate significantly different values.

Cultivar	Temperature	Irrigation	Shoot growth ($cm.day^{-1}$)	Total Main Leaf Area (m^2)	Main leaf appearance ($leaf\ number.day^{-1}$)	Lateral leaf appearance ($leaf\ number.day^{-1}$)
Cabernet sauvignon	CT	WW	0.7 ab	0.03 a	0.92 a	0.43 b
	CT	WS	0.36 b	0.02 a	0.73 a	1.05 a
	HS	WW	1.01 a	0.05 a	0.95 a	1.22 a
	HS	WS	0.73 ab	0.02 a	0.48 a	0.87 ab
Riesling	CT	WW	0.22 b	0.03 a	0.83 a	0.18 a
	CT	WS	0.1 b	0.01 b	0.35 a	0.3 a
	HS	WW	0.44 a	0.04 a	1.02 a	0.38 a
	HS	WS	0.17 b	0.03 ab	0.88 a	0.2 a
Variety			***	ns	ns	***
Temperature			**	ns	ns	ns
Irrigation			**	**	**	ns
Variety*Temperature			ns	ns	*	ns
Variety*Irrigation			ns	ns	ns	ns
Temperature*Irrigation			ns	ns	ns	**
Variety*Temperature*Irrigation			ns	ns	ns	ns

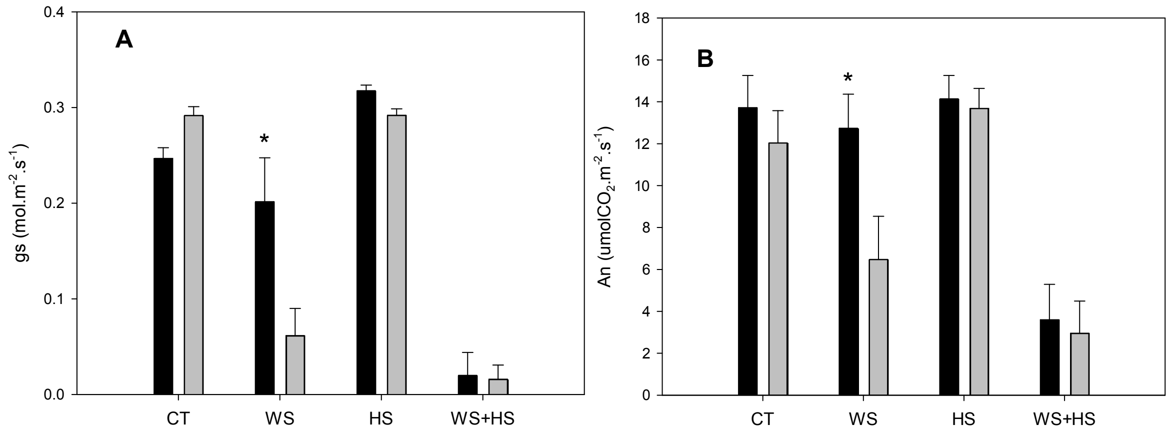

Figure 1. Stomatal conductance (A) and net leaf photosynthesis (B) at veraison stage after 7 days of stress for Cabernet Sauvignon (black) and Riesling (grey) under control (CT), water stress (WS), heat stress (HS) and combined heat and water stress (HS+WS). Asterisks denotes significant differences between varieties.