Effect of elevated CO_2 and temperature on phenology, carbohydrates, yield and grape composition – preliminary results

By Rachel Kilmister[1], Dale Unwin[1], Michael Treeby[1], Everard Edwards[2] and Mark Krstic[3]
[1]Department of Economic Development, Jobs, Transport and Resources, PO Box 905, Mildura VIC 3502
[2]CSIRO Agriculture, Private Bag 2, Glen Osmond SA 5064
[3]Australian Wine Research Institute, PO Box 34, Mooroolbark VIC 3138

INTRODUCTION

Depending on the emissions scenarios used in climate modelling studies (Whetton 2013), current predictions have most Australian winegrape-producing regions tracking towards an increase in mean temperature of 0.1-0.7°C by 2020 and 1.1-6.4°C by 2100. Earlier harvest and the compression of vintage have both been already linked with global warming brought about by increasing levels of carbon dioxide (CO_2) in the atmosphere (IPCC 2013). This shift forward in grapevine phenology has been attributed, in part, to the shifts in temperature, but also to improvements in the way that vines are managed, such as irrigation, fertiliser supply and canopy management (Webb *et al.* 2012).

While there has been a great deal of interest in the effects of elevated temperature on vine phenology and a number of published scientific studies in this area (Webb *et al.* 2012, Petrie and Sadras 2009), there has been little study of the effect of elevated CO_2 on the vine. In general, plants respond to elevated CO_2 with increased photosynthesis, increased growth and reduced water use per unit area of canopy. However, studies have shown that the nitrogen concentration is often lower in plants exposed to elevated CO_2. For example, when wheat was grown under elevated CO_2 there was a decrease in grain protein content, a key quality attribute (Fernando *et al.* 2012). Unlike climate warming, there is no debate about whether atmospheric CO_2 concentrations are rising, therefore, there is a need to better understand the impacts of higher atmospheric CO_2 on winegrape production and potential wine quality.

When plants are grown in different environments they can adjust their growth, morphology and physiology to a degree, in order to optimise their success in each environment. This is known as 'acclimation' and can occur in response to changing levels of environmental CO_2. For example, leaves of plants grown under high CO_2 may have lower leaf nitrogen, protein content and photosynthetic capacity. Acclimation of this sort would be observable as a lower rate of photosynthesis in leaves from a plant grown under high CO_2 concentrations than that in leaves from plants grown under lower CO_2 concentrations, when measured in the same air (i.e., the same CO_2 concentration). However, acclimation is usually incomplete, that is leaves of plants grown under elevated CO_2 will still have higher assimilation rates under their growth conditions than leaves of plants grown under ambient CO_2 concentrations.

To provide the industry with knowledge about the effects of elevated CO_2 and temperatures on winegrapes, a collaborative study was initiated in 2013 between the Victorian Department of Economic Development, Jobs, Transport and Resources (DEDJTR) and CSIRO. The experiment was established in a Shiraz vineyard on the DEDJTR research station at Irymple, near Mildura, in the Murray Darling wine region. The Murray Darling, Riverland and Riverina wine regions are currently responsible for producing approximately 68% of Australia's grape crush (WFA 2015 Vintage Report).

Both elevated CO_2 and temperature treatments were applied, either alone or in combination, to determine the effect of each of these important environmental attributes and any interaction between them. The experimental set-up has been described previously (Sommer *et al.* 2013), but, briefly, it involved applying the elevated CO_2 and temperature treatments in 5.5m x 8m x 2.4m open top chambers (Figures 1 and 2) as described in Table 1.

This experiment has now been running for two growing seasons (2013-14 and 2014-15). This article describes observations over two seasons of the timing of key phenological events (budburst, flowering, veraison and harvest), changes in leaf carbohydrates, yield and grape composition. Because small but statistically significant differences were observed between the non-chambered control and the chambered control treatments for some data, all references to the control in this article refer to the chambered control to ensure that the 'chamber' effect is not overlooked or attributed wrongly to the treatments. In other words, because there was an effect on some aspects of the vines' behaviour simply from having them enclosed in an open-top chamber, it is from the starting point of the chambered control that the effects of elevated CO_2 and/or elevated temperature must be assessed.

PHENOLOGICAL CHANGES

Budburst, flowering, veraison and harvest dates were earlier in both of the elevated temperature treatments (eTemp and eCO_2+eTemp). Elevated temperature had a stronger influence than elevated CO_2 alone on advancing phenology at all key stages of grapevine growth and development. However, there was evidence of an interaction between the elevated CO_2 and elevated temperature treatments, primarily on harvest date. In the first season, although elevated CO_2 did not alter harvest date when combined with warming, there was a small advancement (two days) when elevated CO_2 was supplied at ambient temperature (Figure 4, see page 42). In the second season, there was a larger effect of elevated CO_2 on harvest date at ambient temperature (advancing eight days), but elevated CO_2 also retarded harvest under the warming treatment by two days. While previous reports have demonstrated an advancement in phenology based on an increase in temperature (Petrie and Sadras 2009, Webb *et al.* 2012), early results in this study indicate that elevated CO_2 levels can also affect phenology, albeit to a lesser extent. However, potential effects of elevated CO_2 are probably indirect, via its influence on vine carbohydrate levels. This suggests that the effects of elevated CO_2 may increase year-on-year. The difference seen in effects of elevated CO_2 on harvest date between the first and second seasons of treatment is consistent with this scenario.

Table 1. The five treatments applied to drip-irrigated 17-year-old Shiraz grapevines, grafted to 1103 Paulsen and trained to a two-wire vertical trellis with a quadrilateral cordon with sprawling canopy. The vines received the equivalent of 6ML of irrigation water/ha/season.

Treatment	Technical details
Non-chambered control	Control vines not growing in an open-top chamber and exposed to ambient temperature and CO_2 (approximately 400ppm in 2015).
Chambered control	Control vines grown in open-top chambers, and exposed to ambient temperature and CO_2 (approximately 400ppm).
Elevated CO_2 (eCO_2)	Vines grown in open-top chambers and exposed to ambient temperature, but with CO_2 levels maintained at an average of 650ppm (the predicted atmospheric CO_2 concentration in 2060-2070) for the entire growing season (budburst through to leaf fall).
Elevated temperature (eTemp)	Vines grown in open-top chambers at ambient CO_2 levels, but with the air temperature inside the chamber maintained at an average of 2°C above ambient for the entire growing season, day and night, using in-field fan-assisted electrical heaters.
eCO_2+eTemp	Vines grown in open-top chambers with an average CO_2 concentration of 650ppm, and air temperature maintained at 2°C above ambient.

CHANGES IN CARBOHYDRATE LEVELS

The primary effect of elevated CO_2 on a plant is to increase the rate of leaf photosynthesis. This generally results in increased carbohydrate levels, which may be consumed in general metabolism, used for growth of plant organs such as shoots and fruit, or stored. The carbohydrate status of the canopies of the vines in this study was assessed and separated into water soluble (free sugars) and water insoluble (starch) fractions. The sum of these two fractions is referred to as total non-structural carbohydrates because it does not include carbohydrates such as cellulose, which are incorporated into vine structure and do not play a role in general metabolism. Leaves were collected at flowering (E-L stages 20-26), bunch closure (E-L Stage 32-34) and pre-harvest (E-L stage 37) during both experimental seasons. In addition, woody material and canes were sampled during dormancy, but these data are not currently available.

The data presented in Table 2 (see page 40) are averages of four sampling time points in 2013-14 and three in 2014-15. They clearly demonstrate that the elevated CO_2 treatments (eCO_2 and eCO_2+eTemp) enhance starch concentration and, hence, total non-structural carbohydrates in these tissues. This may be attributed to the higher rates of net photosynthesis observed in these two treatments (Unwin *et al.* 2015). No major differences were observed between any of the water soluble carbohydrate fraction averages. This suggests that levels of water soluble carbohydrates are tightly regulated in vines. It was also interesting to note that the elevated temperature (eTemp) treatment alone decreased the levels of starch in those grapevines by 12-15% compared with the control. The project team is planning to look more closely at vine physiology in the next couple of seasons, in particular examining night time respiration rates for each treatment because respiration is highly temperature responsive and may explain the lower starch concentrations in leaves from the elevated temperature treatments. ►

Figure 1. Open-top chambers in a 17-year-old Shiraz vineyard, used for applying the treatments described in Table 1. Chamber dimensions are 5.5m x 8m x 2.4m (LxWxH).

Figure 2. Inside an elevated CO_2 and temperature treatment (eCO_2+eTemp) open top chamber. CO_2 emitters and fan-assisted electrical heaters are located below the vines' canopies.

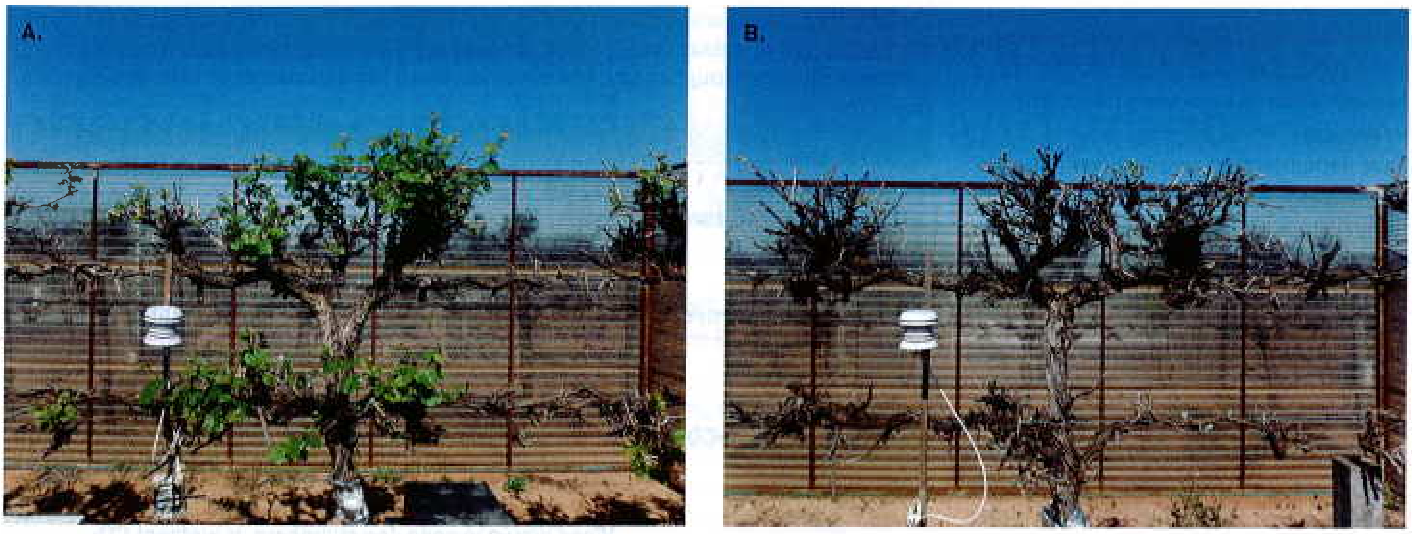

Figure 3. Images taken on 22 September 2014 showing the progress of budburst as a function of temperature. (B) Chambered control (treatment 2), and (A), eTemp (treatment 4). Note: the presence of the Stevenson screens hanging beneath the upper cordons in each image. A logger in each chamber continuously measures and records the air temperature.

INFLUENCE ON YIELD, YIELD COMPONENTS AND GRAPE COMPOSITION

The 2013-14 and 2014-15 growing seasons were quite different in the Murray Valley, with approximately 20 days >40°C in the 2013-2014 season (December to February), compared with 10 days >40°C in the 2014-15 season. These large seasonal differences make it challenging to determine whether differences in yield, yield components and grape composition between each of the treatments were consistent. Only the second season's observations are reported here because the grape production cycle is two years from the time of inflorescence initiation through to harvest. In other words, only the second season's potential crop size was determined under the influence of elevated CO_2 and/or elevated temperature.

Preliminary results indicate that Shiraz yield in the 2014-15 season was increased in both the elevated CO_2 treatments by more than 25% (Table 3). This was consistent with the carbohydrate data, which demonstrated that the elevated CO_2 levels improved carbohydrate status of vines (Table 2). The cause of this increase in yield appears to be explained by bigger berries and more berries per bunch (data not shown). The latter observation suggests that elevated CO_2 levels may also influence the percentage of flowers that set and become berries. This is something that needs to be examined more closely in future seasons.

In terms of grape composition, some interesting differences were observed in relation to juice pH and titratable acidity (TA) levels. The surprising result was that both elevated CO_2 and elevated temperature, alone and in combination, appeared to increase the level of acidity in grapes (Table 3). This appears counterintuitive for the elevated temperature treatment, and something that requires further investigation. The differences observed in both anthocyanins and tannins appear minor in relation to the differences observed in carbohydrate levels, and suggest that there may be contrasting mechanisms for enhancing anthocyanin levels when elevated CO_2 or elevated temperature are applied alone,

Table 2. Effect of elevated CO_2 and/or elevated temperature on leaf carbohydrate fractions, expressed as a percentage relative to the control. Positive numbers indicate higher concentrations than the control, and negative numbers indicate lower concentrations than the control. Note – WSC = water soluble carbohydrates; Insol = water insoluble carbohydrates (starch); and TNC = total non-structural carbohydrates.

	2013-14 Season			2014-15 Season		
Treatment	WSC	Insol	TNC	WSC	Insol	TNC
		% diff			% diff	
eCO_2	3	47	22	6	19	15
eTemp	-2	-12	-6	9	-15	-7
eCO_2+eTemp	-1	29	12	6	30	22

Table 3. Control vines' average yield, yield components and grape composition for the 2014-15 growing season, and the effects of elevated CO_2 and/or elevated temperature, expressed as a percentage relative to the control vines.

	Treatment			
Parameter	Control	eCO_2	eTemp	eCO_2+eTemp
		%diff		
kg grapes/vine	18	27	-9	27
bunches/vine	233	17	7	0
g/berry	1.0	19	15	14
pH	4.1	-5	-4	-6
g TA/L	4	9	24	34
mg anthocyanins/g skin	6	12	20	-3
mg tannin/g skin	11	1	-4	-10

but when applied together they appear to negate each other. This demonstrates that more years of observations are required to better understand the likely changes in key grape compositional and quality components, particularly given that these compounds are known to be present in lower amounts in grapes produced in warmer climates compared with grapes produced in cooler climates.

SUMMARY AND CONCLUSIONS

This article summarises findings from the second year of a project investigating the influence of the projected future atmospheric CO_2 levels and temperature on grapevine growth and development. Results demonstrate that while increases in temperature have the effect of advancing phenology and harvest date, the interaction with elevated CO_2 is more complex and will likely change over the length of time a vine grows under elevated CO_2 conditions.

It appears that, as with other crop plants, elevated CO_2 levels play an important role in modifying the carbohydrate status of grapevines. This, in turn, has secondary influences on growth, yield and fruit composition. It is clear that a number of years of data will be required to fully understand the long-term complexities of elevated temperature and CO_2 levels on grapevine physiology, productivity and wine quality potential. Wine Australia has recently committed to a further two seasons of funding, providing at least four years of continuous elevated CO_2 and warming treatments to examine these important impacts.

Climate change and climate variability present a major challenge to grapegrowing and winemaking worldwide. Understanding how vines will function and behave in a different environment is critical to enabling the Australian wine industry to better plan for its future.

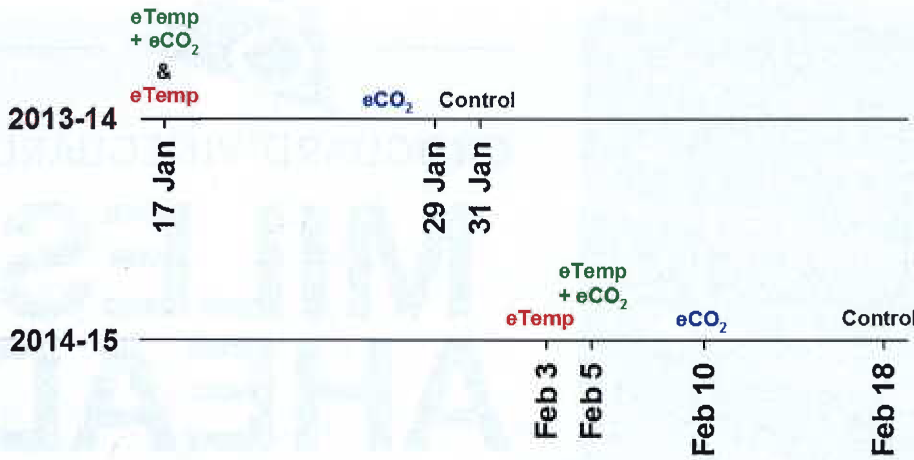

Figure 4. Timelines for times to reach target maturity of 13.3Baume (24° Brix) for the 2013-14 and 2014-15 seasons as affected by elevated CO_2 and/or elevated temperature.

ACKNOWLEDGEMENTS

This project (DPI 1202 'The impact of elevated CO_2 and its interaction with elevated temperature on production and physiology of Shiraz') is supported by Australian winegrape producers and winemakers through their investment body Wine Australia, with matching funds from the Australian Government, and with co-investment from DEDJTR and CSIRO. Annette Boettcher and Alex Lawlor (CSIRO) assisted with the carbohydrate sampling and analysis. Mark Krstic was engaged by DEDJTR to assist in the production of this article and was not involved in any of the research conducted in this project.

REFERENCES

Fernando, N.; Panozzo, J.; Tausz, M.; Norton, R.; Fitzgerald, G. and Seneweera, S. (2012) Rising atmospheric CO_2 concentration affects mineral nutrient and protein concentration of the wheat grain. J. Food Chem. 133:1307-1311.

IPCC 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Stocker, T.F.; Qin, D.; Plattner, G.-K.; Tignor, M.; Allen, S.K.; Boschung, J.; Nauels, A.; Xia, Y.; Bex, V. and Midgley, P.M. (eds.)). Cambridge University Press: Cambridge UK and New York, NY, USA, 1535pp.

Mollah, M.R.; Norton, R.M. and Huzzey, J. (2009) Australian grains free air carbon dioxide enrichment (AGFACE) facility: design and performance. Crop and Pasture Sci. 60:697-707.

Petrie, P.R. and Sadras, V.O. (2009) Advancement of grapevine maturity in Australia between 1993 and 2006: putative causes, magnitude of trends and viticultural consequences. Aust. J. Grape Wine Res. 14:33-45.

Sommer, K.; Unwin, D.; Kilmister, R.; Edwards, E.; Mollah, M.; Fitzgerald, G. and Downey, M. (2013) Tank installation aids grape research at Mildura. Aust. N.Z. Grapegrower and Winemaker 598:28-29.

Unwin, D.; Sommer, K.; Kilmister, R.; Mollah, M. and Edwards, E. (2015) Shiraz in a future climate. Aust. N.Z. Grapegrower and Winemaker 613:30-31.

Webb, L.B.; Whetton, P.H.; Bhend, J.; Darbyshire, R.; Briggs, P.R. and Barlow, E.W.R. (2012) Earlier winegrape ripening driven by climate warming an drying and management practices. Nature Clim. Change 2:259-264.

WFA 2015 Vintage Report - http://www.wfa.org.au/assets/vintage-reports/WFA-Vintage-Report-2015.pdf. Accessed on 1/12/2015.

Whetton, P. (2013) Climate predictions for key wine growing regions in 2030 and beyond - http://www.awri.com.au/wp-content/uploads/2013/06/Penny_Vintage_CSIRO.pdf. Presentation given at 'Vintage 2030 and beyond - producing quality wines in warmer times' symposium on 19 June 2013 at the University of Melbourne, Parkville, Melbourne, VIC. Accessed on 1/12/2015.

WVJ