Can plants save water and keep growing in the face of climate change?

Aude Coupel-Ledru, Alistair M. Hetherington

Can plants save water and keep growing in the face of climate change?

Aude Coupel-Ledru and Alistair M Hetherington
University of Bristol, United Kingdom

Adobe Stock © Andre Nery

Producing enough food for the increasing population of the world in the face of climate change is one of the greatest challenges currently facing society. Although timings and durations of climate events are unpredictable to some extent, we know with certainty that without united international political agreement and intervention, atmospheric CO_2 concentrations will increase—as will temperature. Consequently, there will be increased incidences of drought (IPCC, 2013). There is an urgent need to breed crops that will show resilience to climate change and exhibit improved yields.

While an important research effort has led to the understanding of plant responses to drought and elevated temperatures, less is understood about the impacts of elevated CO_2. This lack of understanding results in important uncertainties in global predictions of the impacts of climate change on agricultural production (IPCC, 2013).

CO_2 influences gas-exchange by controlling the aperture of the stomata, microscopic structures that function as valves, consisting of a pair of specialised cells (named 'guard cells') surrounding a central pore, found on aerial surfaces of most plants (Hetherington and Woodward, 2013). Their opening and closure controls CO_2 uptake for photosynthesis and water vapour loss by transpiration. Photosynthesis and transpiration co-vary with the aperture and density of stomatal pores, depending on plant species, varieties and environmental conditions. In addition, photosynthesis and transpiration rates are codetermined by the leaf area, which is involved in light capture and is subjected to evaporation. Thus, plant productivity is positively coupled with water losses through stomatal characteristics and shoot development. This coupling has prompted plant scientists to define water-use efficiency (WUE) as the amount of biomass produced per unit of water used through transpiration. At first sight, such a tight coupling makes it challenging to maximise WUE by limiting water loss while maintaining yield.

In this project, we aim at understanding how plants respond to CO_2 in order to decipher the processes that can uncouple carbon gain and water loss to improve WUE while maintaining yield.

Stomata display very variable responses to environmental cues. It is generally recognised that over a short time scale, plants dynamically respond to elevated CO_2 levels by reducing stomatal aperture (Franks *et al.*, 2013). Yet, compilation of independent studies covering a range of species actually shows extreme variability in stomatal response to changes in CO_2 concentration (Morison *et al.*, 2008). To better understand this variability, we first need to understand how the increase in the atmospheric concentration of CO_2 is sensed by the plant and translated into a physiological response. We first aim at better understanding the CO_2 response mechanisms that take place at the molecular level and its interplay with stress hormones that lead to stomatal closure when the CO_2 level increases. Variability of stomatal functioning may also lie in morphological variations. Stomata exhibit a range of shapes, sizes, and numbers across species (Bertolino, Caine, and Gray, 2019). Here, we also address the molecular mechanisms mediating the repression of stomatal development when plants are growing under elevated CO_2 concentrations.

Another crucial question is how plants respond to CO_2 when in combination with other environmental constraints. Soil water availability is considered the primary factor limiting growth and productivity. Thus, there is a clear and obvious need to study its interactive effects with elevated CO_2 on a range of plant water relations. Rising CO_2 is often predicted to stimulate the yield of crops, counteracting the negative impacts of drought on food production (Porter, 2014, pp.485–533). However, recent studies carried out on crops in field conditions have shown that intensifying drought can in fact eliminate the expected benefits of elevated carbon dioxide (Gray *et al.*, 2016). Because long-term responses to CO_2 usually result in greater leaf area, it can also lead to greater water use that might increase the risk of drought stress. The likelihood of positive or negative outcomes might depend not only on the intensity but also on the timing of drought stress relative to the development of the crop (Leaky *et al.*, 2019). This is true all the more because elevated CO_2 can alter plant

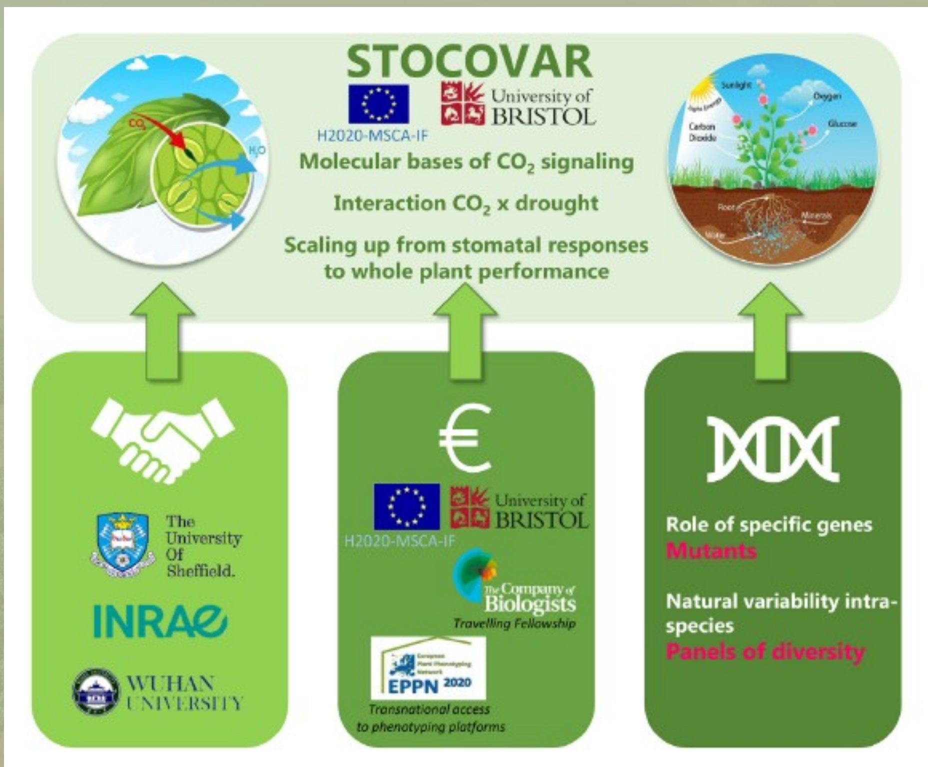

Figure 1: Overview of the project.

phenology (Engineer *et al.*, 2016) (i.e. the timing of seasonal events such as budburst and flowering) and because the severity of drought depends on its occurrence during the plant cycle. We thus aim at revealing whether and how the drought- and CO_2-signalling cascades overlap and interact depending on the timing of drought to ultimately alter the trade-offs between carbon gain and water loss by leaves.

To address these questions, we use genetic diversity in different forms. We use Arabidopsis thaliana, a popular model species in plant biology and genetics. Because it has a relatively small genome—the first to be sequenced—it is a very useful tool for understanding the molecular details underlying many plant traits. We first employ mutants, in which particular genes are disrupted, to investigate their stomatal behaviour and thus understand the role played by these specific genes in the traits of interest (reverse genetics). On the other hand, we use natural genetic variability by screening large populations for stomatal responses to CO_2 and linking their variability to allelic variations (forward genetics). We further extend this study to perennial crops, to which these questions are of particular relevance because their genetic turnover is much slower than annual species, and for which environmental constraints often have cumulative effects over years. Through a collaboration with the French INRAe (Travelling Fellowship from The Company of Biologists), we are screening the European genetic diversity of grapevine for their stomatal responses to elevated CO_2.

At the University of Bristol, we deploy state-of-the-art cellular physiology and molecular genetics resources in order to study fine-scale stomatal behaviours while tightly controlling the amount of CO_2 the leaves are exposed to. To scale up to the whole plant water use strategy, we use high-throughput phenotyping facilities at partner institutes (EPPN2020 transnational access), where we deploy innovative tools to precisely monitor plant transpiration and growth while controlling the atmospheric CO_2 and level of drought in the soil.

Overall the aim of our work is to seek to better understand the effect of increased atmospheric concentrations of CO_2 on plants in order to have a better understanding of the effects of global environmental change on crop production.

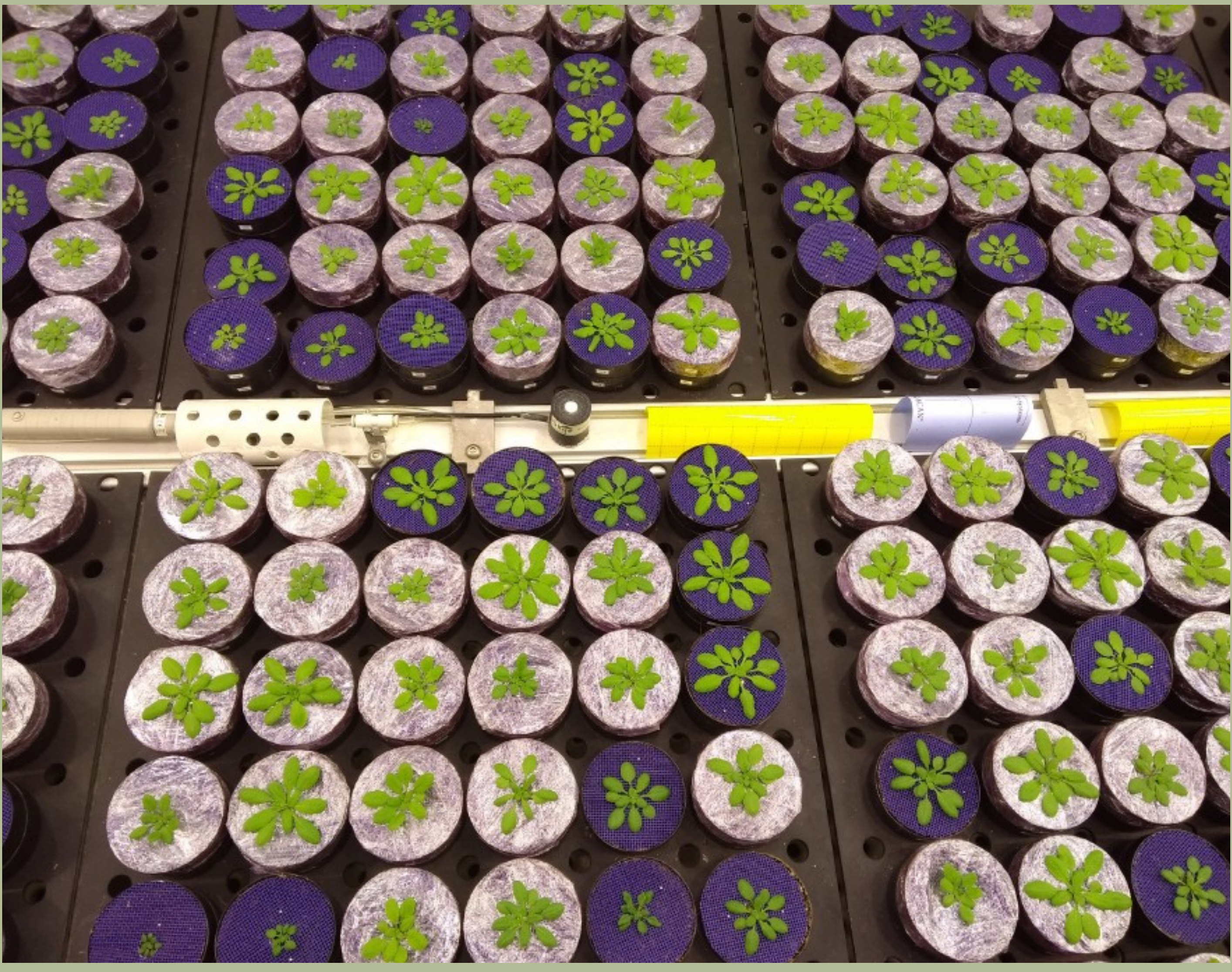

Figure 2: Arabidopsis plants in the PHENOPSIS phenotyping platform.

References

Bertolino, L. T., Caine, R. S. and Gray, J. E. (2019) 'Impact of Stomatal Density and Morphology on Water-Use Efficiency in a Changing World', *Frontiers in Plant Science*, 10.

Engineer, C. B. *et al.* (2016) 'CO2 Sensing and CO2 Regulation of Stomatal Conductance: Advances and Open Questions', *Trends in Plant Science*, 21, pp.16–30.

Franks, P. J. *et al.* (2013) 'Sensitivity of plants to changing atmospheric CO 2 concentration: from the geological past to the next century', *New Phytologist*, 197, pp.1077–1094.

Gray, S. B. *et al.* (2016) 'Intensifying drought eliminates the expected benefits of elevated carbon dioxide for soybean', *Nature Plants*, 2, p.16132.

Hetherington, A. M. and Woodward, F. I. (2003) 'The role of stomata in sensing and driving environmental change', *Nature*, 424, pp.901–908.

IPCC (2013) Climate Change 2013: The Physical Science Basis. Available at: www.ipcc.ch/site/assets/uploads/2018/03/WG1AR5_SummaryVolume_FINAL.pdf.

Leakey, A. D. B. *et al.* (2019) 'Water Use Efficiency as a Constraint and Target for Improving the Resilience and Productivity of C3 and C4 Crops', *Annual Review of Plant Biology*, 70, pp.781–808.

Morison, J. I. L., Baker, N. R., Mullineaux, P. M. and Davies, W. J. (2008) 'Improving water use in crop production', *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363, pp.639–658.

Porter, J. R. (2014) Climate Change 2014: *Impacts, Adaptation, and Vulnerability*. Available at: https://www.ipcc.ch/report/ar5/wg2/.

PROJECT SUMMARY

The multidisciplinary MSCA-IF project "STOCOVAR" combines ecophysiology, cellular physiology, genetics and high-throughput phenotyping to decipher how plants respond to rising atmospheric CO_2, opening new avenues to select and develop crop cultivars that will perform better in a changing global climate.

PROJECT LEAD PROFILE

Dr Aude Coupel-Ledru received her doctorate in plant physiology and genetics from the French University of Montpellier SupAgro in 2015. After two postdocs at INRAe (France) and the University of Bologna (Italy), she was awarded a Marie-Sklodowska Curie Individual Fellowship to carry out her research at the University of Bristol (United Kingdom).

PROJECT PARTNERS

The STOCOVAR project is based at the School of Biological Sciences of the University of Bristol, taking advantage of its state-of-the-art cellular physiology and molecular genetics resources. Collaboration partners include groups from France, China and the UK.

CONTACT DETAILS

Dr Aude Coupel-Ledru

Life Sciences Building, School of Biological Sciences, University of Bristol, 24 Tyndall Avenue, BS8 1TQ Bristol, UK

aude.coupel-ledru@bristol.ac.uk

www.researchgate.net/profile/Aude_Coupel-Ledru

FUNDING

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie Individual Fellowship (MGA MSCA-IF) grant agreement No.740222.