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EDITORIAL

Adaptation of plants to a high CO_2 and high-temperature world

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Global atmospheric CO_2 concentrations (CO_2) have rapidly increased, rising from 280 ppm during the industrial revolution to more than 400 ppm now. The CO_2 are predicted to continue increasing due in part to human activities. Increased atmospheric CO_2 is associated with global warming, and increased frequency and intensity of extreme temperature (IPCC, 2021). Previous studies have demonstrated that plants had a wide range of acclimation and adaptation strategies to cope with the environmental changes (Ainsworth and Rogers 2007; Yamori et al. 2014, 2016). However, considering that the climate is changing at an unprecedented rate, plants may not have sufficient plasticity to deal with the novel environmental pressures. Since climate change is challenging the global agricultural productivity and thus global food and nutrient security, the effects of high CO_2 and global warming on plant growth and yield have attracted considerable attention (e.g., Ray et al. 2019; Zandalinas et al. 2021; Qu et al. 2021). All observed climate change trends are harmful for crop productivity, especially the rise in air temperature (Lobell et al. 2013), which may even balance out the positive effect of elevated CO_2 in C_3 crops (Lobell et al. 2011).

In this special issue, three review articles set the scene from the molecular to the evolutionary scales. In their review of source-sink relationships, Lal et al. (2022) concluded that starch synthesis and remobilization in source tissue, photoassimilate transport via phloem and starch accumulation in the sink tissue are highly responsive to elevated CO_2 and high temperature. In their original research, Sakai et al. (2022) show that alterations in DNA methylation levels of ROS-, GA- and ABA-related gene promoters cause transcriptional changes to induce seed germination in barley seeds exposed to heat stress during grain filling.

A number of contributors highlighted that natural genetic variation influences the response of plant productivity under elevated CO_2 and temperature. Using the whole genome and growth data of *Arabidopsis thaliana* ecotypes, Oguchi et al. (2022) identified two genes associated with enhancement of the growth rate in response to elevated CO_2 conditions. In particular, they found that RNAi lines of AT3G4000 and AT5G50900 showed significantly higher growth rates under elevated CO_2. A wild relative of rice (*Oryza australiensis*) from the Australian savannah revealed greater capacity for thermotolerance in growth and photosynthetic processes and a more robust carbon economy in extreme heat relative to cultivated rice (Phillips et al. 2022). Leaves of a wild rice relative grown at 45 °C had less investment in Rubisco activase, even though CO_2 assimilation was faster than at 30 °C relative to *O. sativa*, reflecting its inferior thermostability. Plants grown at 45 °C responded to CO_2 enrichment in *O. australiensis* but not *O. sativa*, reflecting more robust carboxylation capacity and thermal tolerance in the wild rice relative (Phillips et al. 2022). In two contrasting wheat cultivars, elevated CO_2 improved photosynthesis of control and heat stressed wheat, and improved biomass and grain yield of control plants only, under well-watered conditions. Hence, heat stress under well-watered conditions was not detrimental to leaf photosynthesis or yield but modified the elevated CO_2 response of photosynthesis and yield (Chavan et al. 2022).

Yamori et al. (2022) examined a less well investigated aspect of warming temperatures. They showed that the root zone temperature for optimum photosynthesis and plant growth was affected by air temperature, and that optimization of root zone temperature could lead to improvement of plant production.

Jiang et al. (2021) reviewed the data in the literature on the molecular evolution, comparative genetic, and bioinformatics of the key anion channel gene families. They

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proposed that anion channels are essential players for green plants to respond and adapt to the abiotic stresses associated changing climate. Lv et al. (2022) then showed that the maternal CO_2 environment affected the responses of offspring to elevated CO_2 with regard to stomatal density, photosynthesis and yield of rice cultivated using open-top chambers.

Comparative transcriptomic analysis provides broad and detailed understandings of transcriptional responses to a wide range of temperatures in different plant tissues, and unique regulatory functions of temperature-mediating transcription factors. In their research paper, Sriden et al. (2022) made use of publicly available datasets, gathered and re-analyzed 259 individual transcriptomic profiles from 139 unique experiments of *Arabidopsis thaliana*'s shoot, root, and seedling tissues, subjected to a wide variety of temperature conditions. They comprehensively characterized the transcription patterns of temperature-responsive genes and the effects of key temperature transcription factors on the expression dynamics of their target genes. Finally, Munekage and Taniguchi (2022) discussed the evolutionary impacts of atmospheric CO_2 on the evolution of C_4 photosynthesis in the genus *Flaveria* through anatomical and metabolic modifications acquired through C_3–C_4 intermediate stages.

Studies on plant responses to high CO_2 and high temperature can help us tackle the global food problem. Breeding crops for a changing future climate requires the identification of key growth and physiological traits that contributes to enhance crop productivity. Moreover, understanding the genetic variation in plant responses to high CO_2 and high temperature would also assist in selecting plants for greater ability of adaptation to climate stress. Although changes in plant growth at high CO_2 and high temperature are well documented across C_3 and C_4 species, the physiological and molecular mechanisms are still not clearly understood since these growth traits are highly complicated. The comprehensive research would improve crop productivity in a future high CO_2 and high temperature. Therefore, the aim of this Special Issue is to better elucidate the physiological and molecular adaptive mechanisms of plants to a high CO_2 and high-temperature world.

We want to thank the authors for their truly valuable reviews and exciting research studies. We appreciate their contribution which has enriched this field. The editors hope that the readers will find these papers enjoyable to read and useful to their own research. We also acknowledge all the peer reviewers and staff at PMB for their valuable input and contributions.

References

Ainsworth EA, Rogers A (2007) The response of photosynthesis and stomatal conductance to rising [CO2]: mechanisms and environmental interactions. Plant Cell Environ 30(3):258–270

Chavan SG, Duursma RA, Tausz M et al (2022) Moderate heat stress prevented the observed biomass and yield stimulation caused by elevated CO_2 in two well-watered wheat cultivars. Plant Mol Biol. https://doi.org/10.1007/s11103-022-01276-7

Climate IPCC (2021) Climate Change, The Physical science basis: working group i contribution to the sixth assessment report of the intergovernmental panel on climate change, climate change 2021: The Physical Science Basis Cambridge University Press. United Kingdom and New York, NY, USA

Jiang W, Tong T, Chen X et al (2021) Molecular response and evolution of plant anion transport systems to abiotic stress. Plant Mol Biol. https://doi.org/10.1007/s11103-021-01216-x

Lal MK, Sharma N, Adavi SB et al (2022) From source to sink: mechanistic insight of photoassimilates synthesis and partitioning under high temperature and elevated [CO_2]. Plant Mol Biol. https://doi.org/10.1007/s11103-022-01274-9

Lobell DB, Schlenker W, Costa-Roberts J (2011) Climate trends and global crop production since 1980. Science 333:616–620

Lobell DB, Hammer GL, McLean G, Messina C, Roberts MJ, Schlenker W (2013) The critical role of extreme heat for maize production in the United States. Nat Clim Change 3:497

Lv C, Hu Z, Wei J et al (2022) Transgenerational effects of elevated CO_2 on rice photosynthesis and grain yield. Plant Mol Biol. https://doi.org/10.1007/s11103-022-01294-5

Munekage YN, Taniguchi YY (2022) A scheme for C_4 evolution derived from a comparative analysis of the closely related C_3, C_3–C_4 intermediate, C_4-like, and C_4 species in the genus *Flaveria*. Plant Mol Biol. https://doi.org/10.1007/s11103-022-01246-z

Oguchi R, Hanada K, Shimizu M et al (2022) Enhanced growth rate under elevated CO_2 conditions was observed for transgenic lines of genes identified by intraspecific variation analyses in *Arabidopsis thaliana*. Plant Mol Biol. https://doi.org/10.1007/s11103-022-01265-w

Phillips AL, Scafaro AP, Atwell BJ (2022) Photosynthetic traits of Australian wild rice (*Oryza australiensis*) confer tolerance to extreme daytime temperatures. Plant Mol Biol. https://doi.org/10.1007/s11103-021-01210-3

Qu Y, Sakoda K, Fukayama H, Kondo E, Suzuki Y, Makino A, Terashima I, Yamori W (2021) Overexpression of both Rubisco and Rubisco activase rescues rice photosynthesis and biomass under heat stress. Plant Cell Environ 44:2308–2320

Ray DK, West PC, Clark M, Gerber JS, Prishchepov AV, Chatterjee S (2019) Climate change has likely already affected global food production. PloS One 14(5):e0217148

Sakai Y, Suriyasak C, Inoue M et al (2022) Heat stress during grain filling regulates seed germination through alterations of DNA methylation in barley (*Hordeum vulgare* L.). Plant Mol Biol. https://doi.org/10.1007/s11103-022-01278-5

Sriden N, Charoensawan V (2022) Large-scale comparative transcriptomic analysis of temperature-responsive genes in *Arabidopsis thaliana*. Plant Mol Biol. https://doi.org/10.1007/s11103-021-01223-y

Yamori W, Shikanai T (2016) Physiological functions of cyclic electron transport around photosystem I in sustaining photosynthesis and plant growth. Annu Rev Plant Biol 67:81–106

Yamori W, Hikosaka K, Way DA (2014) Temperature response of photosynthesis in C3, C4, and CAM plants: temperature acclimation and temperature adaptation. Photosynth Res 119(1):101–117

Yamori N, Levine CP, Mattson NS et al (2022) Optimum root zone temperature of photosynthesis and plant growth depends on air temperature in lettuce plants. Plant Mol Biol. https://doi.org/10.1007/s11103-022-01249-w

Zandalinas SI, Fritschi FB, Mittler R (2021) Global warming, climate change, and environmental pollution: recipe for a multifactorial stress combination disaster. Trends Plant Sci 26(6):588–599