Integrating conflicting seasonal light and thermal cues in the control of *Arabidopsis* elongation

Pablo Catalán[1], Gabriel Rodriguez-Maroto[1,2], Cristina Nieto,[3] Salomé Prat[4] and Saúl Ares[5]
[1]Grupo Interdisciplinar de Sistemas Complejos (GISC) and Departamento de Matemáticas, Universidad Carlos III de Madrid, Leganés, Spain
[2]Max Planck Institute for Plant Breeding Research, Cologne, Germany
[3]Centro de Recursos Fitogenéticos y Agricultura Sostenible (CRF-INIA), CSIC, Alcalá de Henares, Spain
[4]Centro de Investigación en Agrigenómica (CRAG), CSIC-IRTA-UAB-UB, Cerdanyola, Spain
[5]GISC and Centro Nacional de Biotecnología (CNB) - CSIC, Madrid, Spain

As the summer approaches, plants experience enhanced light inputs and warm temperatures, two environmental cues with an opposite morphogenic impact: temperature stimulates growth, while light inhibits it, since growth occurs mostly during dark periods. Key components of this response are PHYTOCHROME B (phyB), EARLY FLOWERING 3 (ELF3), and CONSTITUTIVE PHOTOMORPHOGENIC 1 (COP1). Here, we used single and double mutant/overexpression lines of the model plant *Arabidopsis thaliana* to study the growth of the hypocotyl under different light and temperature conditions. The hypocotyl is the stem-like part of a plant embryo or seedling. It is located between the cotyledons (seed leaves) and the primary root.

We used this data to fit a mathematical model incorporating known interactions of these regulators [1]. The fitted model recapitulates thermal growth of all lines used, Fig. 1A, and correctly predicts thermal behavior of others not used in the fit, Fig. 1B. While thermal COP1 function is accepted to be independent of diurnal timing, our model shows that it acts at temperature signaling only during daytime. Our thermal model provides a unique toolbox to identify best allelic combinations enhancing climate change resilience of crops adapted to different latitudes.

Our model was fitted using data at two temperatures: 22° and 28°C. We have extended the model introducing an Arrhenius dependence in its parameters. From the values $k(T_1)$ and $k(T_2)$ of a parameter at two different temperatures, we can calculate its value at a temperature T as:

$$k(T) = e^{\frac{T_2 \ln(k(T_2)) - T_1 \ln(k(T_1))}{T_2 - T_1}} \, e^{-\frac{\frac{T_1 T_2}{T_2 - T_1} \ln\left(\frac{k(T_2)}{k(T_1)}\right)}{T}} \tag{1}$$

This extension of the model in [1] allows the study of plant growth around the world under current and potential future conditions. We have calculated the growth of *Arabidopsis*' hypocotyls for the average day lengths and temperatures registered around the world for every month of year 2022, Fig. 1C shows the results for September. Since day lengths is in principle less sensible to climate change than temperature, we have used our model to predict the thermomorphogenic response: the increase in growth as a result of an average increase of 1°C; Fig. 1D shows the results for September 2022. In [1] we have shown that the thermomorphogenetic response significantly depends on the temperature interval and the activity levels of genes in the network. We can now use this information to obtain a more nuanced understanding of how plants integrate conflicting environmental cues to optimize growth.

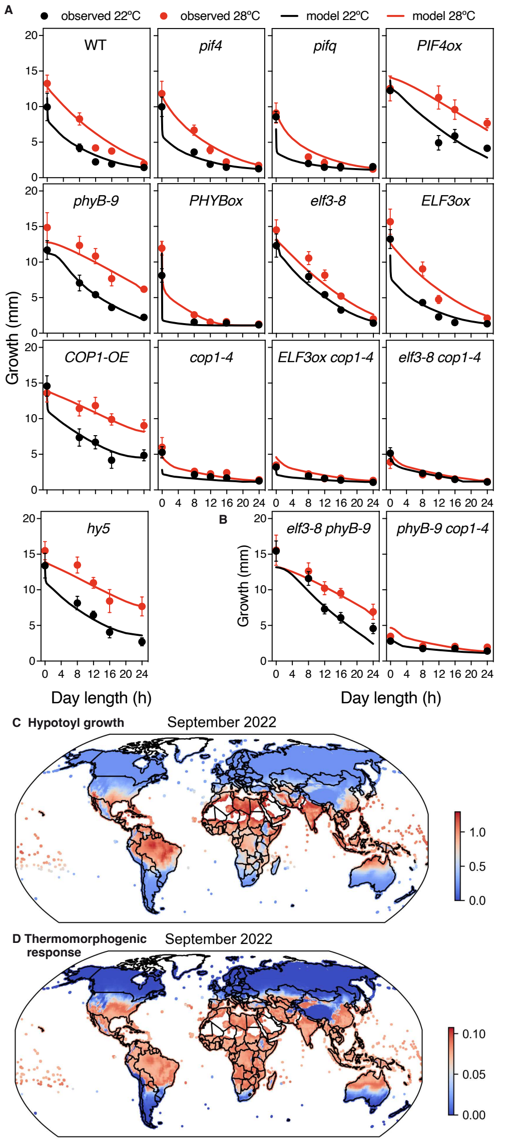

Fig. 1. A: Hypocotyl lengths of the various *Arabidopsis* backgrounds grown at either 22° or 28°C and different day lengths. Curves are model results. In B, the curves are pure predictions: these backgrounds were not used to fit the model. C: hypocotyl growth (mm) in 24 hours predicted by the model with the average day length and temperature conditions around the world in September 2022. D: predicted thermomorphogenic response: growth increase as response to a temperature increase of 1°C.

---

[1] C. Nieto, P. Catalán, L.M. Luengo, M. Legris, V. López-Salmerón, J.M Davire, J.J Casal, S. Ares, and S. Prat, *COP1 dynamics integrate conflicting seasonal light and thermal cues in the control of Arabidopsis elongation*, Science Advances, **8**, eabp8412 (2022).