Testing the responses and interplay of leaf physiological and morphological traits at elevated CO_2 levels in six common crop species

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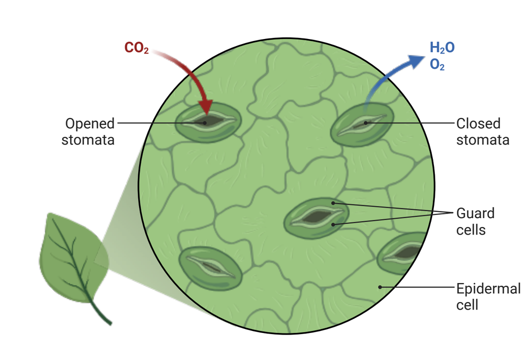
Introduction

Biochemical framework



$$a\,\frac{\partial(E/A)}{\partial\chi} = -b\,\frac{\partial(V_{cmax}/A)}{\partial\chi}$$

Fig. 1 Schematic drawing of stomata and gas exchange. Optimality modelling describes the trade-off of carbon gain versus water loss through the least-cost hypothesis, described in the formula above. A = photosynthesis, E = transpiration, and a and b are unitless cost factors.

Eco-evolutionary optimality (EEO) states that plants adapt or acclimate to their environment, thereby eliminating uncompetitive plant strategies by natural selection. EEO has been proven successful for developing hypotheses and models of the terrestrial biosphere. On a plant leaf level, EEO theory is used to analyze and model plant processes including photosynthesis, gas exchange, and stomatal behavior. Plants regulate their gas exchange by dynamically adjusting their stomata on a short term time scale (opening and closing) and long term time scale (stomatal size and density), which also influences photosynthetic capacity. The operational stomatal conductance (G_{op}) is determined by the opening state of the stomata during typical growth conditions. The anatomical maximum stomatal conductance (G_{smax}) results from the maximum stomatal aperture, stomatal density and pore depth.

Aims:

- **test photosynthesis and gas exchange responses to elevated CO_2**
- **combine biochemical (Fig.1) and morphological (Fig.2) responses in one framework**
- **test optimality model with results**

This poster presents the preliminary results

Morphological framework

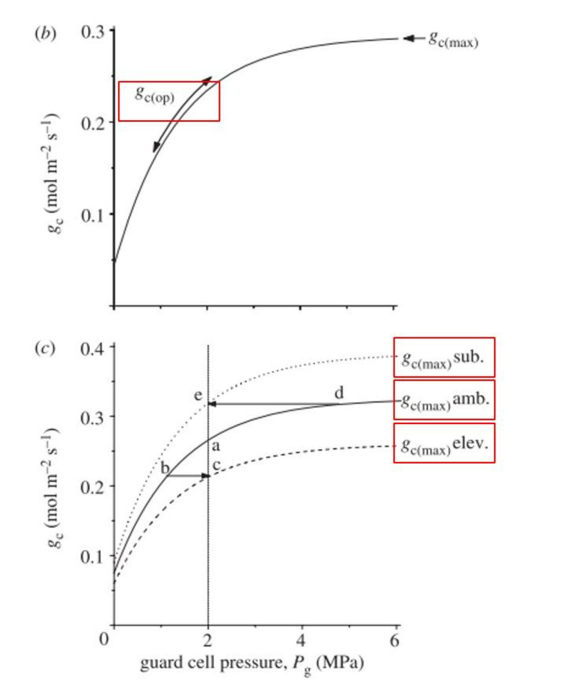
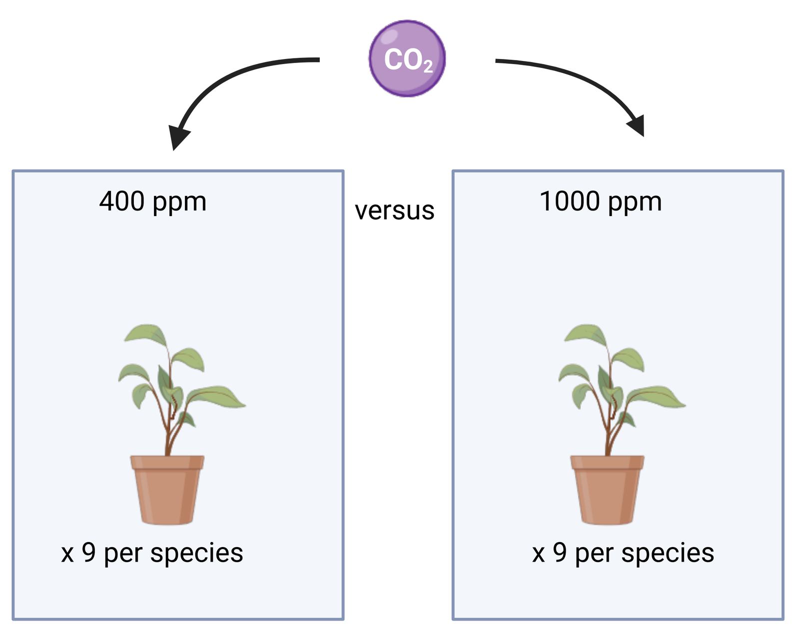


Fig. 2 Conceptual framework after Franks et al. (2012). Operational stomatal conductance (Gc(op)) operates on Gc(max) curve by opening/closing the stomata. Subambient or elevated CO2 levels will results in increase in Gc(max) or decrease in Gc(max). Gop will shift along the new curve to return to high sensitivity region (a to b to c for elevated levels, a to d to e for subambient levels).

Methods



Species	*Photosynthesis*	*Class*
Buckwheat	C3	Eudicot
Borlotti bean	C3	Eudicot
Soybean	C3	Eudicot
Common wheat	C3	Monocot
Maize	C4	Monocot
Eucalypt	C3	Eudicot (woody species)

Measurement	*Measurement environment*	*Replicates*
Diurnal cycle	Ambient environment	3-5 per group
ACi curves	Saturating light (1000 PAR)	5 per group
Light response curves	(to check for ACi's)	~2 per group
G_{op}	Ambient environment	8/9 per group
Imprints for G_{smax}	Nail varnish	8/9 per group
LMA	ACi measured leaf	8/9 per group
A_{max}	Ambient + saturating light (1000 PAR)	8/9 per group

Host facility: University of Western Australia, Perth

Two climate controlled growth rooms:

- 12 hours day length
- 700 PAR
- 30 degrees Celsius
- CO_2 concentration: 400 and 1000 ppm
- 6 species (see table A)

Per climate chamber, 9 plants per species were grown in 1 liter pots. Measurements started when first fully mature leaves appeared. Measurements were made with a Licor portable photosynthesis system (LI6400 and LI6800). Imprints of the cuticle for microscope analysis were made with nail varnish., to derive G_{smax}.

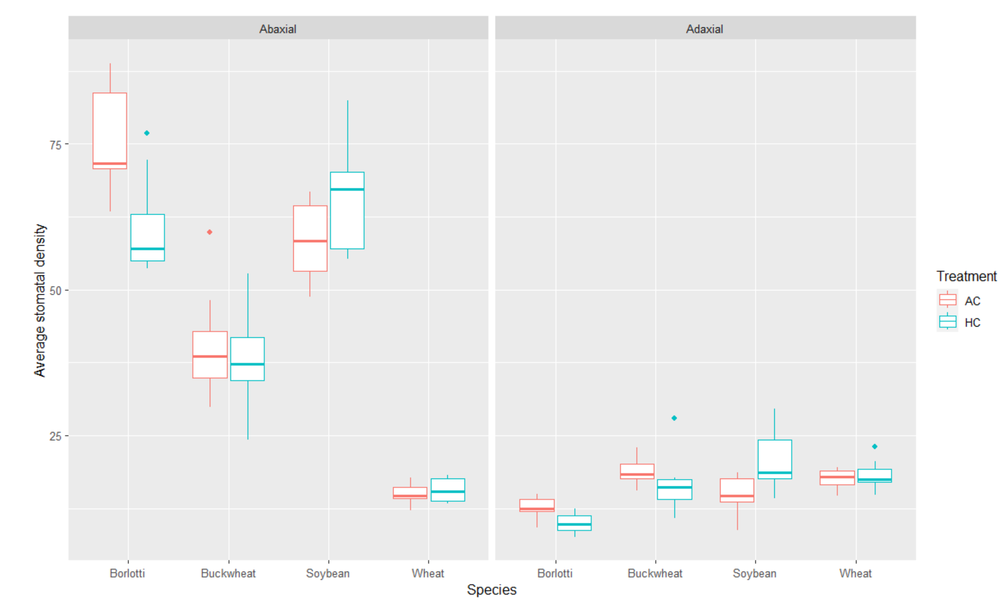
Key concepts:

G_{smax} = anatomical maximum stomatal conductance (theoretical), derived from stomatal density and stomatal size

G_{op} = operational stomatal conductance (tradeoff high sensitivity/water loss), ~0.2*G_{smax}

G_{opt} = optimal stomatal conductance (derived from optimality model)

Morphological prelimary results



Preliminary results of stomatal density for four species, and Gsmax for one species (Borlotti bean).

Fig 3. Boxplot of stomatal density (SD) of four species in micrometer, on the abaxial and adaxial side. There is a significant species effect on SD for adaxial and abaxial side (p < 0.05), but no significant treatment effect on abaxial or adaxial side. AC = ambient CO_2 (400 ppm), HC = elevated CO_2 (1000 ppm)

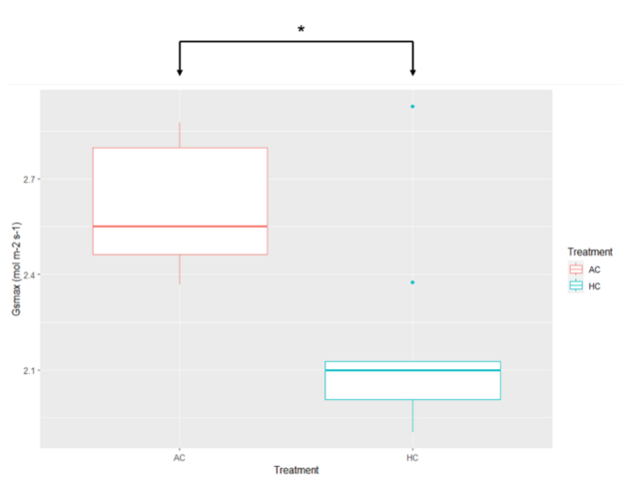


Fig 4. Boxplot of maximum stomatal conductance (Gsmax) of Borlotti bean. There is a significant treatment effect (P < 0.05). AC = ambient CO_2 (400 ppm), HC = elevated CO_2 (1000 ppm).

$$g_{smax} = \frac{\frac{d_w}{v}\cdot D\cdot a_{max}}{l + \frac{\pi}{2}\sqrt{a_{max}/\pi}}$$

--> Stomatal densities and responses to elevated CO_2 levels varied between species, with most variation on the abaxial side. A significant species effect was found, but no significant treatment effect. There is a significant treatment effect on G_{smax} of Borlotti bean. Future results will include G_{smax} of the other species.

Biochemical preliminary results

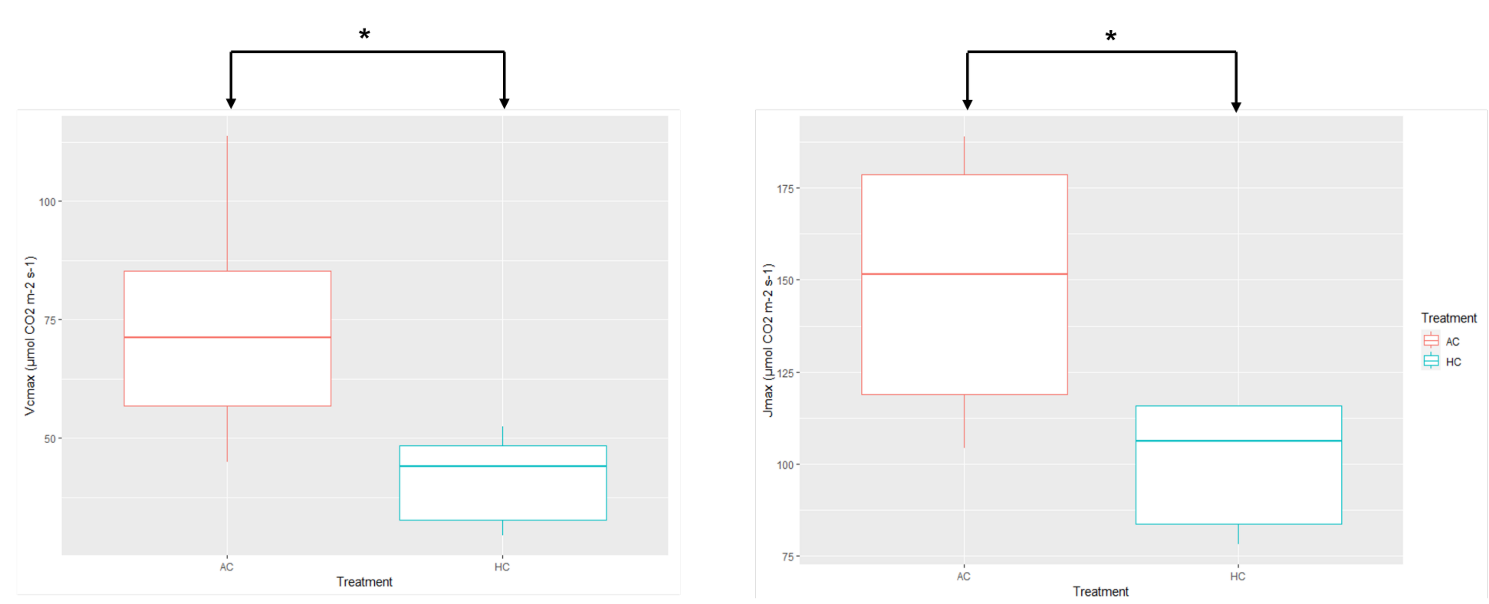


Fig 5. Boxplot of maximum carboxylation rate (V_{cmax}) and maximum electron transport rate (J_{max}) of Borlotti bean. There is a significant treatment effect on both SD and GCL (p < 0.05). AC = ambient CO_2 (400 ppm), HC = elevated CO_2 (1000 ppm)

Biochemical preliminary results (continued)

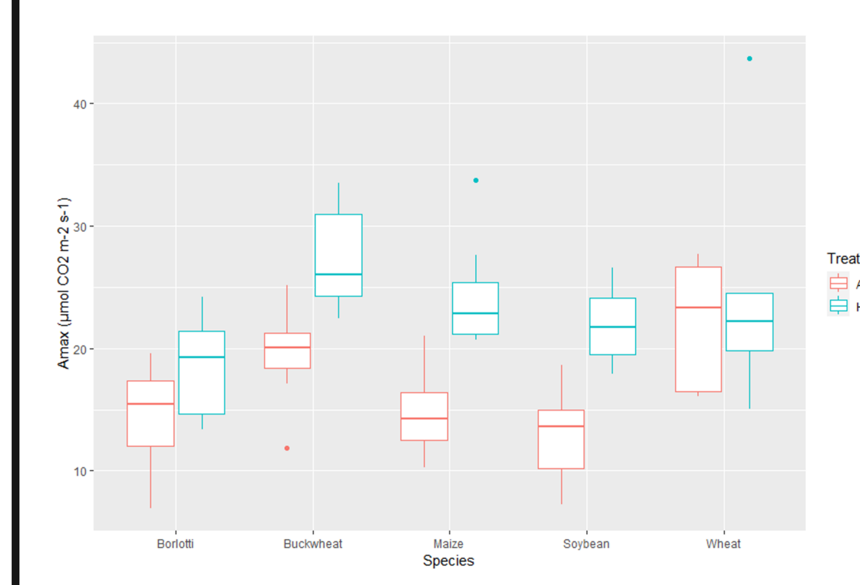


Fig. 6. Boxplot of maximum photosynthetic capacity (Amax) of five species, showing a significant (P < 0.05) treatment effect, and a significant species effect (P < 0.05). AC = ambient CO_2 (400 ppm), HC = elevated CO_2 (1000 ppm)

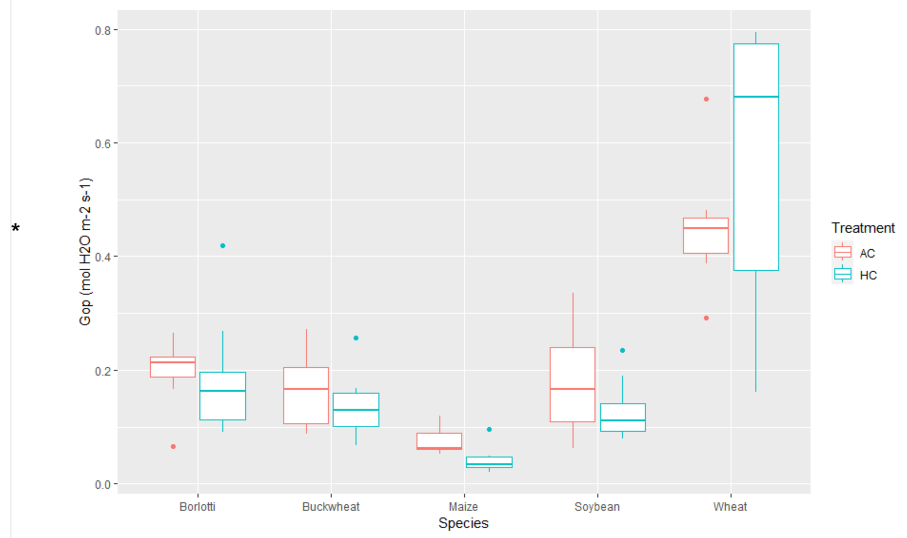
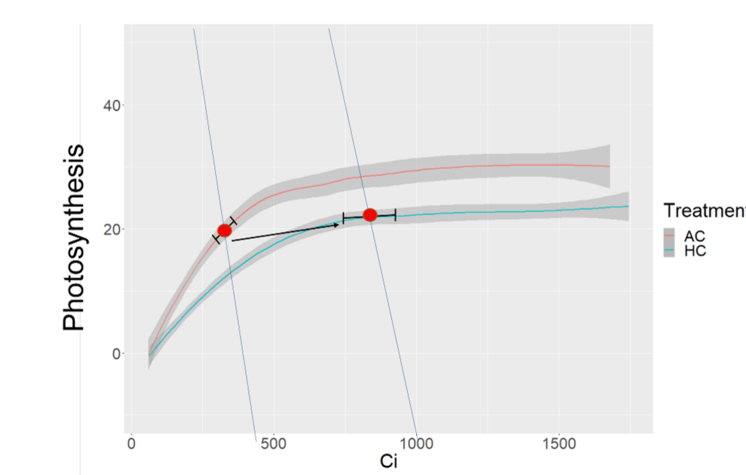


Fig. 7. Boxplot of operational stomatal conductance (Gop) of five species, showing a significant species effect (P < 0.05), but no significant treatment effect. AC = ambient CO_2 (400 ppm), HC = elevated CO_2 (1000 ppm)

→ So, A_{max} significantly increases at elevated CO_2 levels. G_{op} slightly decreases, but not significantly. Both traits have a significant species effect.

Combining biochemical and morphological responses: preliminary conceptual framework

See fig. 8. The two curves represent ACi curves for a theoretical plant at ambient (AC) and elevated (HC) CO_2 levels. At elevated CO_2 levels, V_{cmax} and J_{max} decrease. G_{op} decreases due to stomata closing (blue diagonal line), but photosynthesis at G_{op} (operational A_{max}, red points) will still be at the same or slightly higher rate. So, at a much higher internal CO_2 levels (Ci), photosynthesis only increases slightly.



Further analysis

- Analysis of the other species' G_{smax} and LMA of all species
- Compare species responses statistically
- Compare to p-model simulations
- Interpret in optimality context

Conclusions

Plants adapt their biochemistry and morphology at elevated CO_2 levels. Photosynthesis traits, V_{cmax} and J_{max} decrease (Borlotti bean), while operational maximum photosynthesis rates increase (all species). Morphologically, stomatal density responses varies between the species, and remaining analyses should reveal patterns in G_{smax} responses, as well as patterns in biochemical responses. This shows that different morphological and biochemical strategies can results in the same enhances photosynthetic rate at elevated CO_2. It should also be noted that responses in morphology may be more consistent between species on longer timescales.

Outlook

- Connect this research to herbarium analysis to compare the results on different (longer) timescales
- Use results to test and improve the P-model
- Use results to identify/ confirm potential plant physiological constraints in the P-model (based on paper 1 of thesis

Literature

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