Rubisco activation limits photosynthesis in wheat

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Rationale:

Light available for photosynthesis fluctuates continuously in the field, as clouds cross the sun and as the movement of the sun causes shadows to move across leaves. Transgenic manipulations to allow more rapid relaxation of non-photochemical quenching during sun-shade transitions increased productivity in the field by 14-20% [1]. Rubisco activation is a key limit on photosynthesis during induction following shade-sun transitions [2]. This suggests there may also be potential to increase photosynthesis and crop productivity by speeding up Rubisco activation.

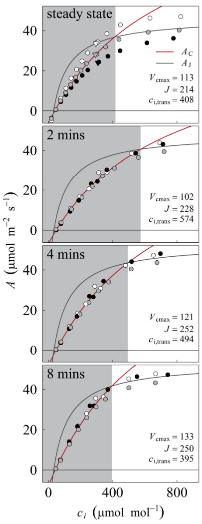
Key findings:

1) Dynamic A/c_i analysis shows that V_{cmax} is the slowest relaxing biochemical limitation during photosynthetic induction in flag-leaves of wheat
2) Modelling diurnal CO_2 assimilation using photosynthetic light responses and kinetics for V_{cmax} shows that V_{cmax} kinetics limit flag leaf photosynthesis by as much as 21%

Dynamic A/c_i analysis

- Flag leaf photosynthesis of wheat, cv. Highbury, was carboxylation-limited at steady state (Fig. 1).
- A/c_i response curves at 10 s time intervals showed that photosynthesis was limited by V_{cmax} for longer than J (Fig. 2).
- Time constants were obtained for increases in V_{cmax} in the light: $\tau_{act} \simeq$ 180 s; and decreases in the shade, $\tau_{de\text{-}act} \simeq 300$ s.

Fig. 1 A/c_i responses illustrating biochemical limitations to photosynthesis in flag leaves of wheat, cv. Highbury. Carboxylation-limited region (shaded), and A/c_i components (A_C, A_J) are shown for steady state conditions (PPFD, 1200 µmol m^{-2} s^{-1}; T_{leaf}, 25 °C; and VPD_{leaf}, 1 kPa) and snapshots 2, 4 and 8 min after transition from shade (30 min, 50 µmol m^{-2} s^{-1} PPFD) to saturating light (1200 µmol m^{-2} s^{-1}). Dynamic responses were obtained following Soleh et al. [3], by repeating measurements at $[CO_2]$ of 50, 100, 200, 300, 400, 500, 600, 800 and 1000 µmol mol^{-1}.



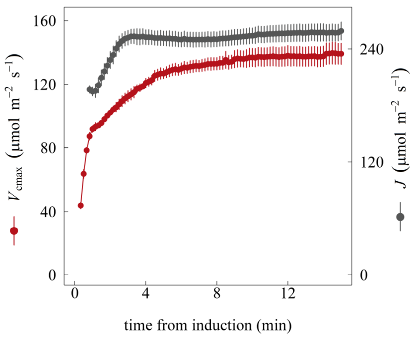


Fig. 2 Dynamic response to shade-sun transitions for biochemical factors limiting photosynthesis in flag leaves of wheat, cv. Highbury. Rubisco carboxylation rate, V_{cmax}, and electron transport rate, J, determined at 10 s intervals after transition from 30 mins deep shade (PPFD, 50 µmol m^{-2} s^{-1}) to saturating light (1200 µmol m^{-2} s^{-1}). Activation and de-activation time constants (τ) for V_{cmax} were determined using the exponential $y = y_{sat} - (y_{sat} - y_0)e^{t/\tau}$ [4].

Impact on diurnal CO_2 assimilation

Impacts of V_{cmax} kinetics on gross CO_2 assimilation at steady state c_i (A^*) were estimated by comparing two scenarios: 1) immediate responses of A^* to PPFD; and 2) A^* responses with kinetics similar to V_{cmax}.

- V_{cmax} kinetics decreased diurnal photosynthesis by 21% (Fig. 3).

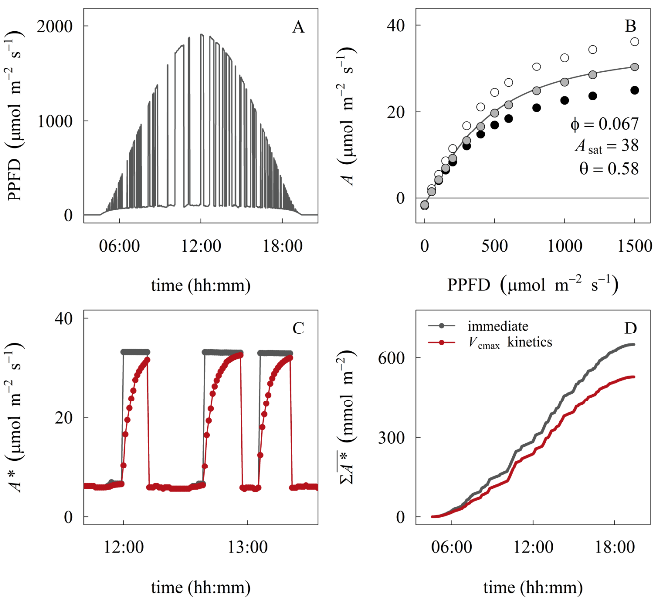


Fig. 3 Impact of Rubisco activation kinetics on integrated gross CO_2 assimilation ($\overline{A^*}$). (A) A minute-by-minute simulation of PPFD in the second layer of a crop canopy on a clear-sky day [5] and (B) photosynthetic light response curves, were used to model (C) A^* during a diurnal period, and (D) the impact on cumulative potential CO_2 uptake ($\sum \overline{A^*}$).

A^* was integrated following [4], as

$$\overline{A^*} = A_f^* t - (A_f^* - A_i)\tau + (A_f^* - A_i)\tau e^{-t/\tau}$$

A_f^* and A_i are predicted final and initial values for A^*:

A_i was initially 0, then $A_i = A_f^* - (A_f^* - A_i)e^{-t/\tau}$ from the previous interval

$A_f^* = \phi I + A_{sat} - \sqrt{(\phi I + A_{sat})^2 - 4\theta\phi I A_{sat}}/2\theta$ (non-rectangular hyperbola) fit to photosynthetic light response curves (B).

τ is the relevant time constant

scenario 1: $\tau = 0$

scenario 2: $\tau = \tau_{act}$ with ↑ PPFD, or $\tau_{de\text{-}act}$ with ↓ PPFD

t is the time interval (~60 s).

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References
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