File S1

The chlorophyll fluorescence CO_2 response curve of plants were measured by the LI-6400XT photosynthesis analyzer and fluorescence leaf chamber (LI-COR, United State) (set PPFD to 400) μ Mol·m^{-2}·s^{-1}). The CO_2 response curve of plants were modified by Tissue et al. (2005) and it was performed using Photosynthetic Assistant software (Version 1.1, Dundee Scientific, Dundee, Scotland). The maximum Rubisco carboxylation rate (Vc), maximum electron transfer rate (Jmax), maximum photosynthetic rate under saturated light intensity and CO_2 (Amax), and respiration rate under light (Rd) are obtained from the CO_2 response curve.

The mesophyll conductance (g_m) is calculated using the "variable electron rate method" (Harley et al., 1992), as follows:

$$g_m = AN/(Ci)\ (\Gamma^*(Jflu + 8(AN + Rd))/(Jflu\ )\ 4(AN + Rd)))$$

Where, AN and C_i was a CO_2 response curve at a saturation light intensity and initial external CO_2 concentration (Ca) of 380 μmol·m^{-2}·s^{-1}, where Γ* was referring to Bernacchi et al. (2002); Jflus was the electron transfer rate and is also measured by the chlorophyll fluorescence CO_2 response curve at an external Ca of 380 μmol·mol^{-1}. The value of KC (1+O/KO) was based on von Camemmer et al. (1994), with a value of 736 μmol·mol^{-1}.

Referring to Grassi and Magnani (2005) and Farquhar et al. (1980), different functional components divide relative photosynthetic limitation into several different factors, namely CO_2 mesophyll conductance limitation (MC_L), stomatal conductance limitation (S_L), and biochemical limitation (B_L). The specific calculation process is as follows:

$$A_N = \frac{V_{c\max}}{Cc + Kc \cdot (1 + O/K_O)} \cdot (1 - \frac{\Gamma^*}{Cc}) - R_d \quad (1)$$

Ignoring slight changes in respiratory function, formula (1) can be rewritten as:

$$dA_N = \frac{\partial A_N}{\partial Cc} \cdot dCc + \frac{\partial A_N}{\partial V_{c\max}} \cdot dV_{c\max} \quad (2)$$

The CO_2 concentration reaching the chloroplast can be represented by the stomatal conductivity of CO_2 (g_{sc}; $g_{sc}=g_{sw}/1.6$), the mesophyll conductivity of CO_2, and photophosphorylation:

$$dCc = \frac{A_N}{g_{sc}} \cdot \frac{dg_{sc}}{g_{sc}} + \frac{A_N}{g_m} \cdot \frac{dg_m}{g_m} - \left(\frac{1}{g_{sc}} + \frac{1}{g_m}\right) \cdot dA_N \quad (3)$$

Meanwhile, AN can be expressed using formula (4):

$$\frac{\partial A_N}{\partial A_{c\max}} = \frac{A_N}{V_{c\max}} \quad (4)$$

Substitute formulas (3) and (4) into formula (2), and the photosynthesis under light saturation can be represented by stomata, mesophyll, and biochemical capacity, resulting in formula (5):

$$\frac{dA_N}{A_N} = S_L + MC_L + B_L = l_s \cdot \frac{dg_{sc}}{g_{sc}} + l_{mc} \cdot \frac{dg_m}{g_m} + l_b \cdot \frac{dV_{c\,max}}{V_{c\,max}} \quad (5)$$

$$l_s = \frac{g_{tot}/g_{sc} \cdot \partial A_N/\partial Cc}{g_{tot} + \partial A_N/\partial Cc} \quad (6)$$

$$l_{mc} = \frac{g_{tot}/g_{mc} \cdot \partial A_N/\partial Cc}{g_{tot} + \partial A_N/\partial Cc} \quad (7)$$

$$l_b = \frac{g_{tot}}{g_{tot} + \partial A_N/\partial Cc} \quad (8)$$

where, g_{tot} is the total conductivity of CO_2 ($1/g_{tot} = 1/g_{sc} + 1/g_m$), S_L, MC_L, B_L were the contributions of stomatal and mesophyll conductivity, as well as were maximum carboxylation efficiency to dA_N/A_N. Ls, lmc, and lb are corresponding relative limits, with values between 0 and 1.

We define that the relative change in assimilation rate under light saturation is the ratio of the actual value of each treatment to the maximum of all treatments, as shown in formula (9):

$$\frac{dA_N}{A_N} \approx \frac{A_{max}^{ref} - A_{max}}{A_{max}^{ref}} \quad (9)$$

Similarly, the relative changes in stomatal conductance, mesophyll conductance, and carboxylation potential were also obtained based on formulas similar to those in Equation (9). Based on the growth and photosynthetic parameters among different treatments, we set 5 μM Cd treatment was used as a control.

Finally, non stomatal limitation is defined as the sum of mesophyll conductance and biochemical limitation ($NS_L = MC_L + B_L$), diffusion limitation is the sum of stomatal conductance limitation and mesophyll conductance limitation ($D_L = S_L + MC_L$), and total limitation value is the sum of stomatal limitation and non stomatal limitation ($T_L = S_L + NS_L$).

References:

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