Chloroplast thioredoxins affect acclimation of plants to fluctuating light

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MOLECULAR PLANT BIOLOGY

Introduction

In photosynthesis, light reactions convert sun energy to chemical energy that is used to fix CO_2 for the production of sugars in Calvin-Benson-Basshman cycle (CBB) (Fig. 1). In nature, plants face constant changes in light conditions, which is potentially harmful for photosynthetic structures. In order to maintain active and efficient photosynthetic reactions light absorption, conversion into chemical energy and carbon assimilation must be regulated to balance energy capture and consumption and to avoid damages in cellular structures. Efficient regulation of photosynthesis has direct effect on yield of crops.

NADPH-dependent chloroplast tioredoxin reductase (NTRC) controls the activity of photosynthetic enzymes (ATP synthase, CBB), thereby balancing the function of light and carbon fixation reactions. NTRC is an important redox regulator of photosynthetic enzymes especially in the transition from dark to light (sun rise in the morning) and when the light intensity is restricting photosynthesis (shaded conditions).

The aim of this study was to compare the acclimation of *Arabidopsis thaliana* wild type (WT) and NTRC overexpression (OE-NTRC) line in fluctuating light, which mimics light conditions in natural environments.

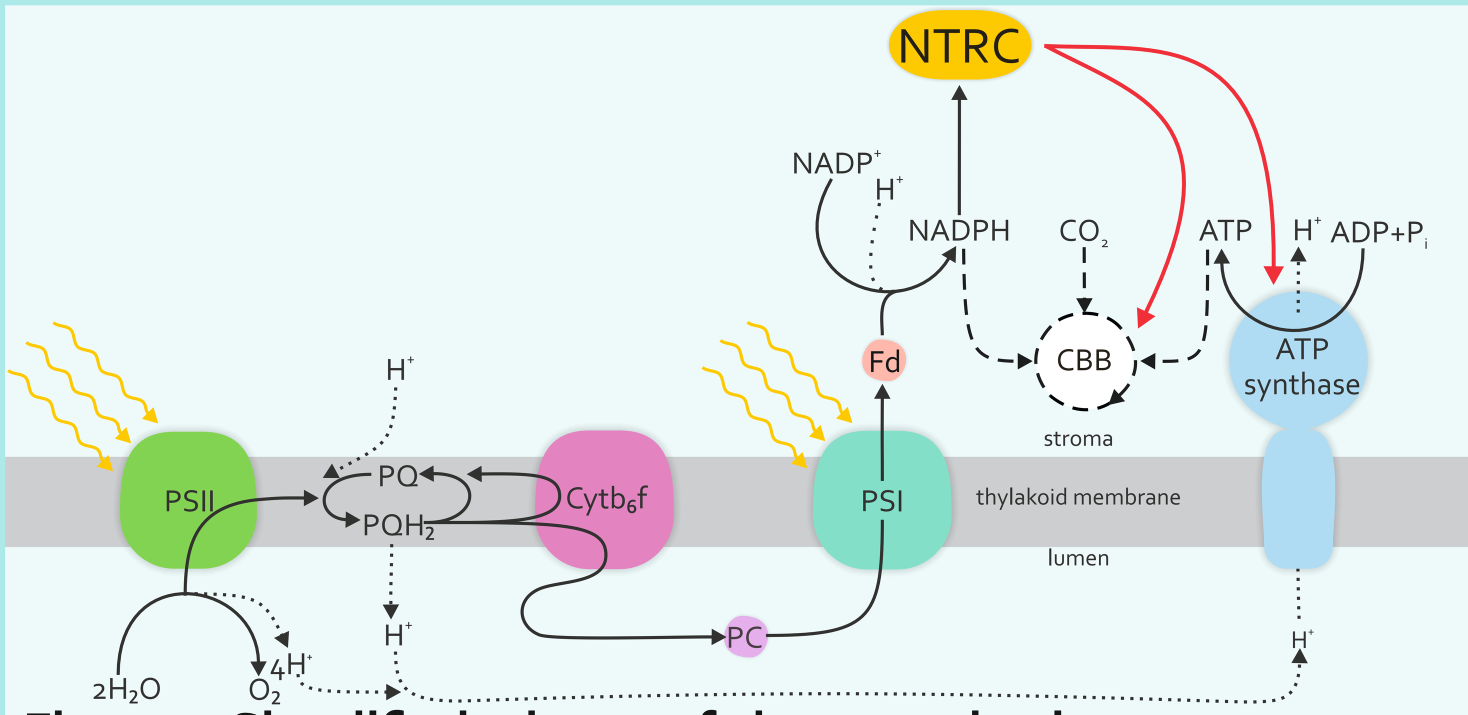


Figure 1. Simplified scheme of photosynthesis. Light reactions absorb light energy that induces a transfer of electrons (solid lines) from water molecules to NADP⁺. The simultaneously formed proton gradient is used to produce ATP. NADPH reduces NTRC that activates both ATP synthase and CBB enzymes (red arrow). With NADPH and ATP CO_2 is fixed into sugars in CBB cycle.

Results

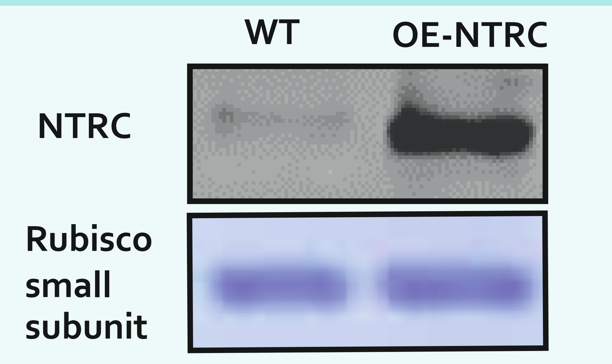


Figure 2. OE-NTRC has 10-30 times more NTRC protein than WT. Rubisco small subunit was used as a loading control.

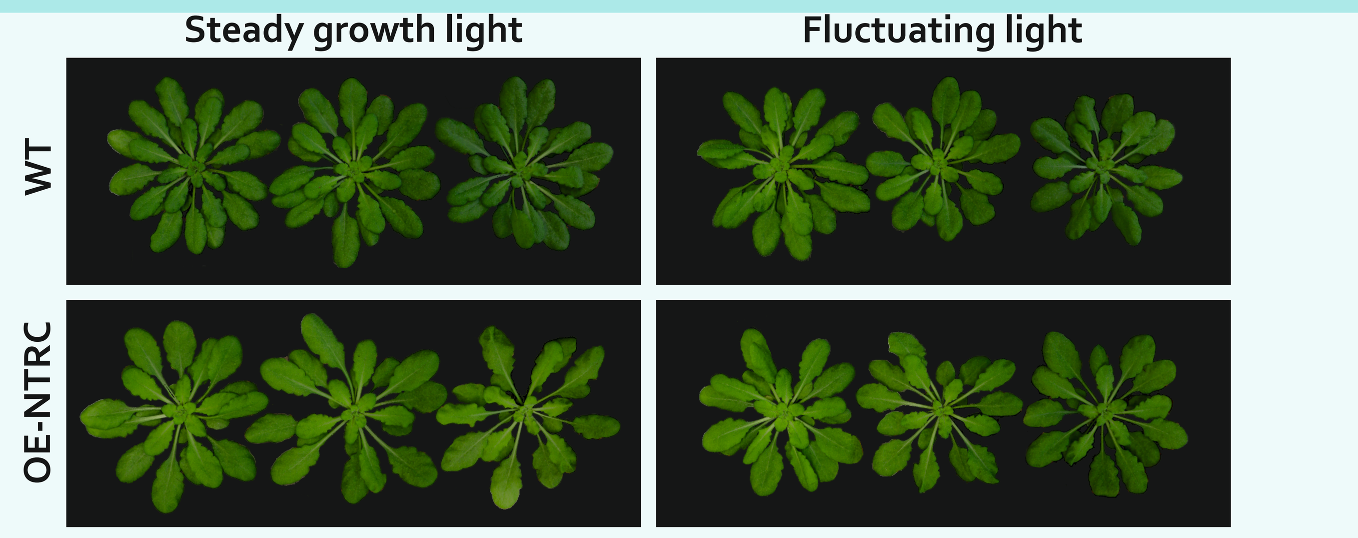
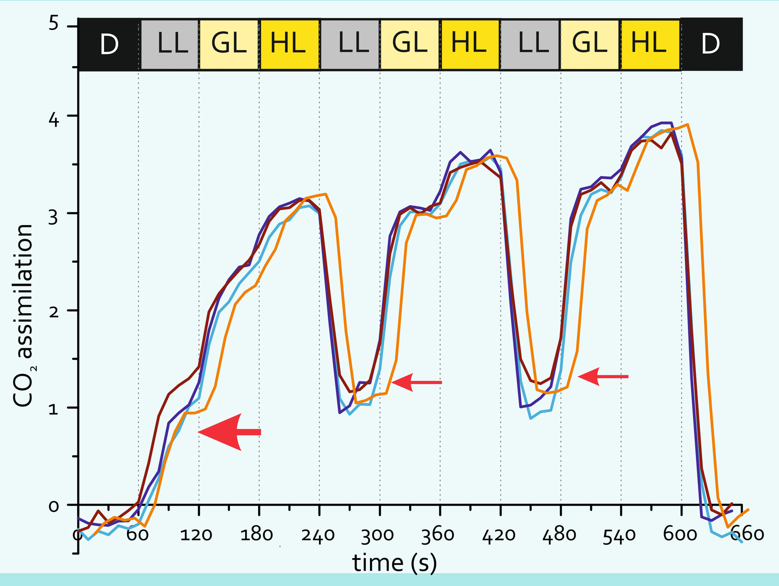


Figure 3. Plants grown under fluctuating light were smaller than plants grown under steady-state light conditions, but no big differences were detected between WT and OE-NTRC lines in 6 weeks.



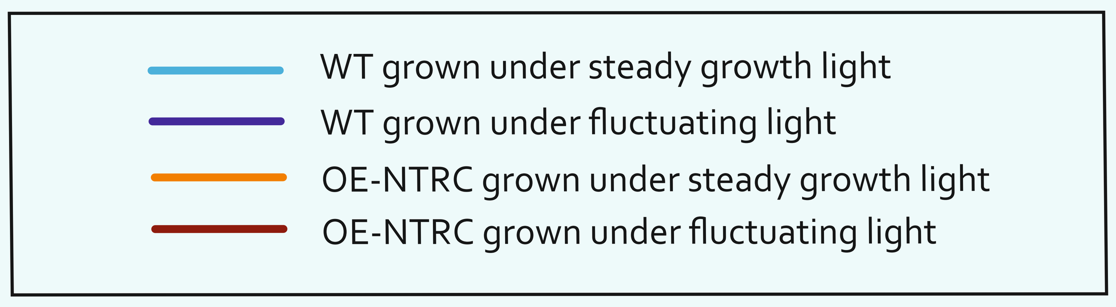


Figure 4. OE-NTRC lines assimilate CO_2 slightly better during low light periods (red arrows).

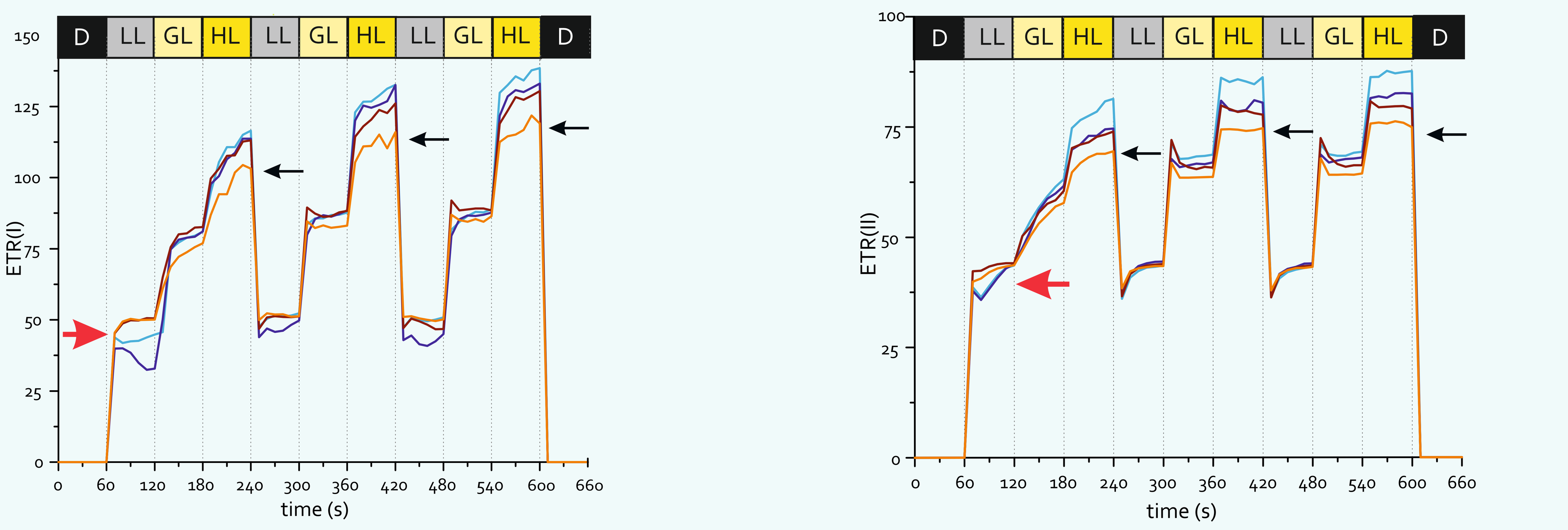


Figure 5. OE-NTRC lines have higher activity of PSII (ETR(II)) and PSI (ETR(I)) at the first low light period (red arrows), whereas the activities remain lower in OE-NTRC plants exposed to high light (black arrows).

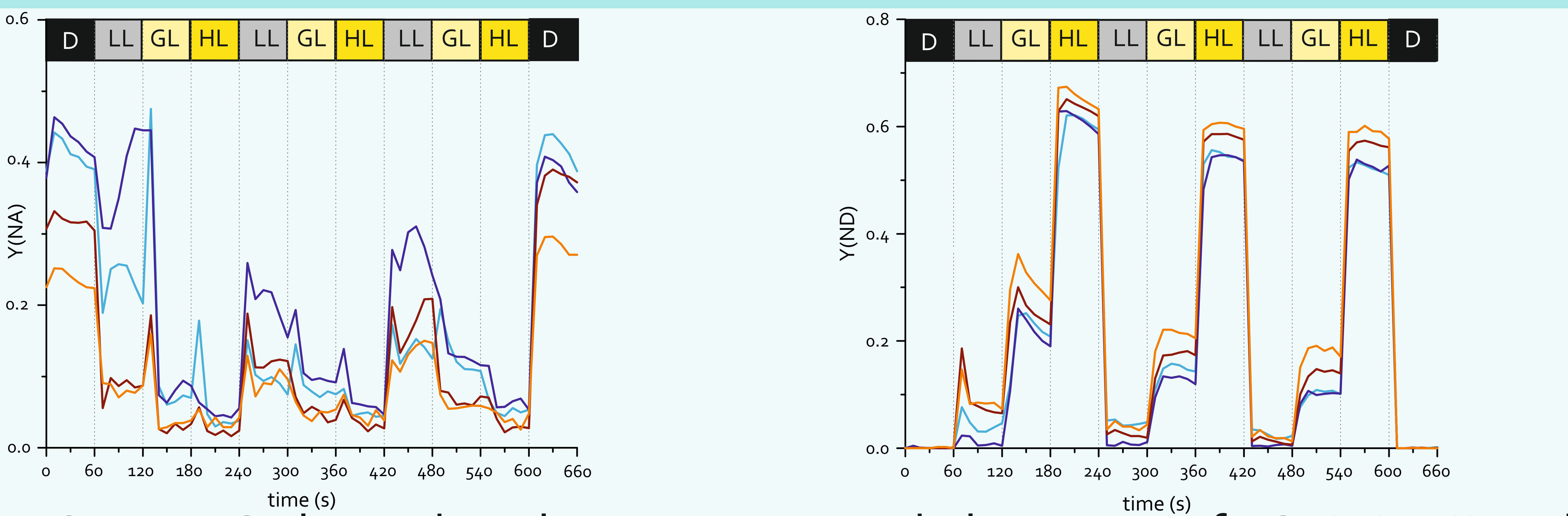


Figure 6. OE-NTRC plants show lower acceptor side limitation of PSI (Y(NA)) and higher donor side limitation of PSI than WT plants during the first exposure to LL,GL,HL -period. WT grown under steady-state light have strongest Y(NA). OE-NTRC lines have higher donor side limitation of PSI than WTs.

Materials and methods

Six-week-old *A. thaliana* WT and OE-NTRC grown in either steady-state growth light (GL) or fluctuating light conditions were used for experiments.

Steady-state growth conditions (LL low light; GL growth light)

Light type	Intensity μmol photons $m^{-2}s^{-1}$	Duration (min)	Repetition (times)
LL	50	30	1
GL	200	30	
GL	200	360	1
GL	200	30	1
LL	50	30	
Dark	0	960	1

Fluctuating light conditions
(LL low light; GL growth light; HL high light)

Light type	Intensity μmol photons $m^{-2}s^{-1}$	Duration (min)	Repetition (times)
LL	50	30	1
GL	200	30	
LL	50	1	24
GL	200	1	
HL	600	1	
LL	50	1	
GL	200	11	
GL	200	30	1
LL	50	30	
Dark	0	960	1

Photosynthetic parameters and CO_2 assimilation were measured with DUAL–KLAS –NIR and GFS-3000 (Heinz Walz GmbH, Germany). Soluble proteins were isolated and separated on SDS-PAGE, electroblotted to the membrane and NTRC was detected with specific polyclonal antibody. Total proteins on membrane were stained with Coomassie Blue for loading control.

Conclusions

OE-NTRC plants are able to more efficiently use light energy in photosynthesis (lower Y(NA)) of PSI in (Fig. 6) that improves photosynthesis, especially under low light (=shaded) conditions (Fig. 4). This is due to the permanently active CBB enzymes in OE-NTRC chloroplasts (Nikkanen et. al 2016).

The better capacity of OE-NTRC to use light energy in comparison to WT plants was strengthened in plants grown under fluctuating light (Fig. 6), suggesting that higher amount of NTRC in chloroplasts improves the acclimation capacity of plants to natural environmental light conditions.

Nikkanen, L., Toivola, J. and Rintamäki, E. (2016) Plant, Cell and Environment, 39: 1691–1705.