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LIGHT AND HIGH TEMPERATURE EFFECTS ON DYNAMICS OF REGULATION OF NONRADIATIVE DISSIPATION WITHIN PHOTOSYSTEM II

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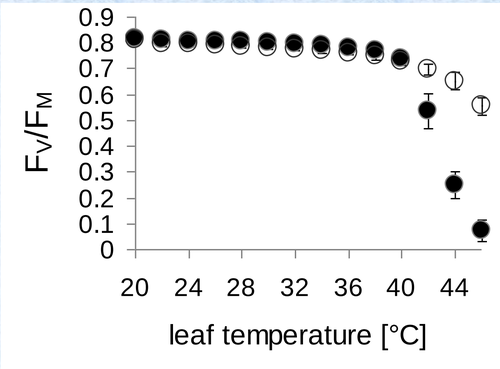
INTRODUCTION

Whereas zeaxanthin dependent nonradiative dissipation of absorbed light within photosystem II (NRD) has been extensively studied as a crucial protective process mitigating oxidative damage to thylakoid membranes under high-light stress at optimum or low temperatures, considerably less information is available on the role of NRD at elevated temperatures. Although the opinion prevails that NRD contribution to PS II protection at elevated temperatures is lesser than that of cyclic electron transport and/or photorespiration (D´Ambrosio et al. 2006, Kaňa et al. 2008), there is increasing evidence that NRD induction and relaxation are facilitated at elevated temperature, thus providing more prompt regulation of PS II function (Zhang et al. 2011, Ilík et al, 2010).

Thermostability of PS II function in dark adapted leaves/needles

The measurements of temperature dependencies of both potential *(F_V/F_M)* and actual (P) quantum yields of PS II photochemistry on leaves exposed to linear heating were adopted as a rapid tool for PS II thermostability evaluation.

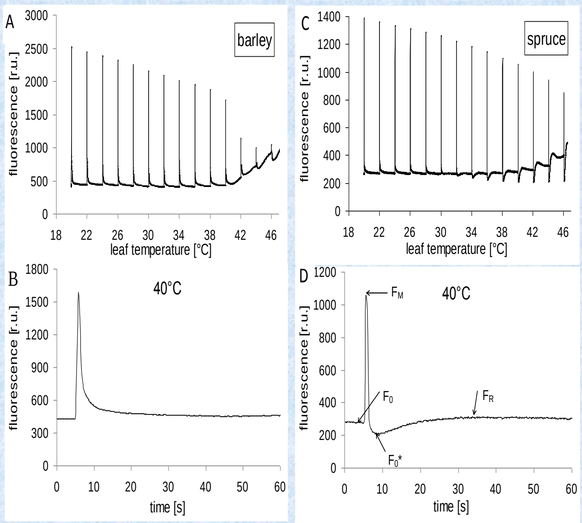


PS II thermostability of dark adapted Norway spruce needles is considerably higher than in barley leaves.

Why?

Fig. 1: Temperature dependence of maximum efficiency of PS II photochemistry (F_V/F_M) measured on overnight dark-adapted barley leaves (full symbols) and spruce needles (empty symbols) exposed to linear heating 1°C/min (for detailed description of experimental conditions see Fig.2).

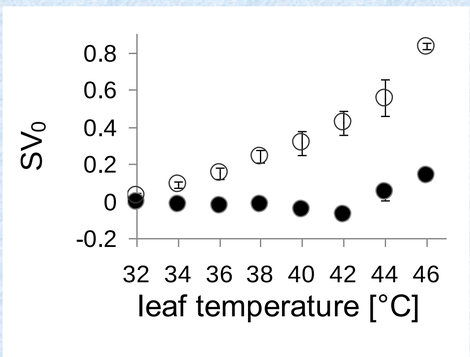
ANSWER (Part I): Because of accelerated induction of nonradiative dissipation of absorbed light (NRD) in Norway spruce needles at elevated temperatures



Barley leaves: a typical response of Chl a fluorescence after saturation pulse application at temperatures up to 40 °C (Fig. 2 A,B) => saturation pulses did not induced NRD within LHC II.

Spruce needles: starting at 32 °C, the fluorescence signal after saturation pulse rapidly decreased below the F_0 level denoted hereafter as F_0*; Fig. 2 C,D); *(F_0 quenching is usually attributed to light-induced conformational change of PS II supercomplex that reduces the efficiency of excitation energy transfer from LHC II and increases NRD (NPQ))* => rapid induction of NRD by short light pulses was observed in spruce needles at elevated temperatures.

Fig. 2, Typical examples of continuous recording of Chl a fluorescence obtained during the measurement of F_V/F_M dependence on temperature for barley leaf segment (A) and spruce needles (C) [dark adapted samples, pre-acclimated at 20 °C for 10 min, ***subjected to linear heating 1°C/min under weak measuring light (< 0.1 μmol m^{-2} s^{-1})****, saturation pulses were applied after increase of leaf temperature by 2 °C]. Zoomed response of Chl a fluorescence to saturation pulse at 40 °C for barley leaf segment (B) and spruce needles (D).*



SV_0 was used to quantify an effect of increasing temperature on rapidly inducible (by one saturation pulse) NRD localized within LHC II:

In barley leaves slight SV_0 occurred only at temperatures above 44 °C (only in some experiments) that resulted in almost complete irreversible PS II inactivation of barley PS II.

In spruce needles SV_0 increased gradually within the temperature range 32-46 °C; SV_0 value of 0.8 at 46 °C. The observed degree of SV_0 is higher than in needles (acclimated to similar low light and temperature conditions) exposed to saturating continuous light at 20 °C for 10 min (Štroch et al., 2008).

Fig 3: Effect of temperature on the Stern-Volmer quenching of initial Chl a fluorescence induced in dark adapted leaves by saturation pulse [quantified as $SV_0=F_0/F_0$-1], see Fig. 2D] for barley leaves (full symbols) and spruce needles (empty symbols).* N= 5-6

Dynamics of NRD relaxation during short period of darkness in light adapted state

In barley leaves the fluorescence quenching did not considerably relaxed during 5s darkness period (used for F_0´ estimation) and negligible fluorescence induction was observed after re-switching on the actinic light (F_{MI}) at temperatures below 40 °C.

In spruce needles relaxation of NRD during short interuption of actinic irradiance was gradually accelerated at temperatures above 20 °C.

=> **Dynamics of both NRD induction and relaxation revealed higher sensitivity to elevated temperatures in spruce needles than barley leaves.**

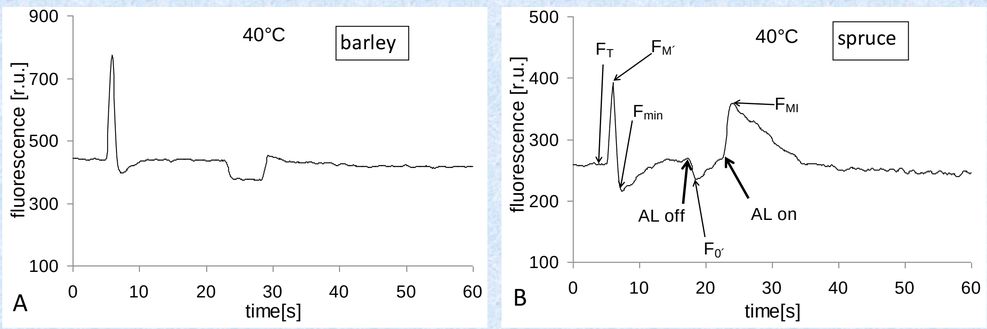


Fig. 5: Response of Chl a fluorescence to saturation pulse followed by 5s interruption of actinic irradiance at 40 °C for barley leaf segment (A) and spruce needles (B) exposed to moderate actinic light (250 μmol·m^{-2}·s^{-1}) during linear heating.

CONCLUSION

In some higher plant species (eg. Norway spruce) the dynamics of regulatory processes (eg. NRD induction and relaxation) can be significantly stimulated and accelerated at elevated temperatures (in the case of V deepoxidation at least by an order faster as expected from publications).

Main hypotheses: The temperature dependence of thylakoid membrane fluidity (that can be different due to different lipid composition) belongs to factors that determine the extent and dynamics of PS II regulation (and its variability among plant species). Particularly MGDG composition can be crucial with respect to observed stimulation of V deepoxidation (MGDG in spruce needles contains octadecatetraenoic acid (18:4 FA) Wolfenden and Wellburn 1991).

⇒ We suggest that increased fluidity of certain domains of thylakoid membrane contributes both to considerably facilitated V deepoxidation at elevated temperatures, to rapid regulation of PS II (structure and function) and to higher PS II thermostability (and photostability).

FURTHER PERSPECTIVES:

1, To elucidate features of thylakoid membranes that determine different dynamics (and extent) of regulation of light utilization in PS II among different species

2, To evaluate the ecophysiological significance (advantage) of the rapid regulation of PS II function at elevated temperatures.

This research will continue within the GA CR project „Impact of temperature and photosynthetically active radiation on dynamics of regulation of photosystem II function in higher plants“ (2013-2016).

ANSWER (Part II): …… that is zeaxanthin dependent

		Chl *a+b* [g kg^{-1}]	Car *x+c* [g kg^{-1}]	Chl *a/b*	DEPS
BARLEY	before heating	1.261±0.053	0.271±0.010	3.177±0.041	0.051±0.011
	after heating	1.131±0.032	0.320± 0.020	3.637±0.086	0.298±0.006
SPRUCE	before heating	1.280±0.179	0.262±0.032	3.102±0.067	0.097±0.013
	after heating	1.310±0.230	0.263±0.049	3.071±0.058	0.684±0.048

Table I. The content of chlorophylls (Chl a+b) and carotenoids (Car x+c) expressed per unit fresh leaf weight, Chl a/b ratio and the deepoxidation state of the xanthophyll cycle pigments (DEPS = [Z+A]/[V+A+Z]) in dark adapted barley leaves and spruce needles before the measurement of F_V/F_M dependence on the temperature (before heating) and immediately after the linear heating of leaves to 46 ° C (after heating).

After measurement of the temperature dependence of F_V/F_M:

1, some degradation changes (probably LHC II degeradation as indicated from changes in pigment composition) occurred in barley leaves but not in Spruce needles (LHC II, not in each experiment);

2, the deepoxidation state of the xanthophyll cycle pigments increased to considerably higher extent in NS needles than in barley leaves. DEPS values around 0.7 are the same as the light saturated DEPS level typical for low light acclimated needles at 20 °C (at least 10 min at saturating irradiance; Kurasová et al., 2003; Štroch et al., 2008).

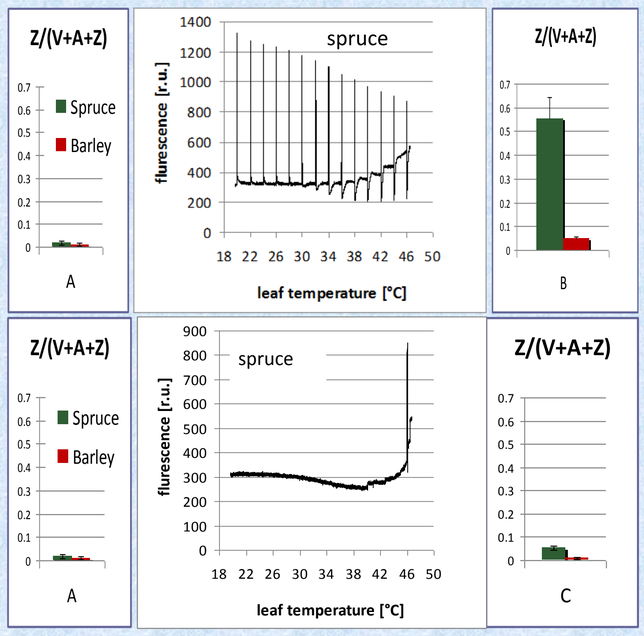


Fig. 4. Rel. amount of zeaxanthin before the given linear heating (A-left) of NS needles and barley leaves, after the measurement of temperature dependence of F_V/F_M (upper panel, B-right), and after the linear heating under weak measuring irradiance with saturation pulse applied at 46 °C (lower panel, C-right). A typical trace of Chl a flurescence during corresponding heating protocol is presented for spruce needles in the middle section needles.

Particularly the second deepoxidation step from anteraxanthin to zeaxanthin was stimulated in Norway spruce needles at elevated temperatures (as compared to barley leaves).

When only one saturation pulse was apllied at *46 °C, both the relative amount of zeaxanthin and the extent of NRD induced after the saturation pulse were dramatically reduced in spruce needles (but still a detectable amount of Z was coverted after single saturation pulse, but not in barley leaves). =>*

1, In spruce needles efficient violaxanthin deepoxidation at elevated temperatures can be caused by short (<1s) saturation pulses.

2, The extent of rapidly inducible NRD is zeaxanthin dependent.

References

D'Ambrosio N, Arena C, De Santo AV (2006) *Environ Exp Bot* 55: 248-257
Ilík P, Kotabová E, Špundová M, Novák O, Kaňa R, Strzalka K. (2010) *Photochem Photobiol* 86:722-726.
Kaňa R, Kotabová E, Prášil O. (2008) *Physiol Plant* 133:794-806.
Kurasová I, Kalina J, Urban O, Štroch M, Špunda V (2003) *Photosynthetica* 41: 513-23.
Štroch M, Kuldová K, Kalina J, Špunda V. (2008) *J Plant Physiol* 165: 612-22.
Wolfenden J, Wallburne AR (1991) *New Phytol* 118: 323-329.
Zhang R, Kramer DM, Cruz JA, Struck KR, Sharkey TD (2011) *Photosynth Res* 108:171-181

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