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Effects of supplemental UV-B and drought stress on photosynthetic activity of sessile oak (*Quercus petraea L.*)

I Mészáros[1], *R Láposi*[1], *Sz Veres*[1], *E Bai*[1], *Gy Lakatos*[2], *A Gáspár*[1], *O Mile*[1]
[1]*Department. of Botany, Debrecen University, Debrecen, Hungary, H-4010 P.O. Box14.*
[2]*Department of Applied Ecology, Debrecen University, Debrecen, Hungary H-4010*
Tel:+ 36-52-512-900 ; Fax.: +36-52-512-943 immeszaros@tigris.klte.hu

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Abstract
Enhanced UV-B radiation and water stress may have direct and indirect effects on physiology of plants. In the present study we investigate the responses of sessile oak seedlings grown from seeds to supplementary UV-B radiation and water stress. Seedlings of sessile oak showed relatively high and rapidly developing susceptibility to the enhanced UV-B radiation which appeared in lowering the chlorophyll content and maximum (Fv/Fm) and actual photochemical efficiency of PSII (ΔF/Fm') during the treatment prior to the onset of water stress. With increasing water stress, seedlings grown without UV-B exhibited more significant further decreases in Fv/Fm values than UV-B treated plants. Both UV-B radiation and water stress increased non-photochemical quenching with a parallel enhancement of zeaxanthin formation.

Introduction

Increased ultraviolet-B (UV-B, 280-320 nm) radiation due to depletion of stratospheric ozone, is an increasing potential damaging factor to vegation (Caldwell et al. 1995, Gwynn-Jones et al. 1997). Furthermore, increased dought stress as a consequence of global climate change may have dramatic influence on plants in many regions too.The long-lived trees are likely endangered by the environmental changes at much higher degree than annual crops and other herbaceous plants because the effects may accumulate and even small changes in the environment factors will have detrimental influence over the life time of trees. This study evaluates the effect of combined UV-B stress and water stress on seedlings of *Quercus petraea*, an important deciduous tree species in the European temperate region.

Materials and methods

One year old seedlings were grown and acclimated under white light of 300 μmol m^{-2} s^{-1}) for 2 weeks and then treated with 150 μW cm^{-2} of UV-B radiation for 4 weeks. The UV-B radiation was provided by flurescence tubes (UV-B 313, Q-Panel, Cleveland, OH) for 8 hours centered into the middle of the 14 hour light period . The tubes were wrapped with 0.1 mm cellulose acetate film (Courtaulds, Chemicals, Derby, UK). Then a set of seedlings both in control and UV-B chambers were exposed to water stress by withholding water for 2 weeks. Photosynthesis activity and occurrence of photoinhibition of PSII were analyzed by means of PAM 2000 fluorometer (WALZ, Germany). Photosynthetic pigments were measured by spectrophotometry (*Shimadzu UV/VIS*) and HPLC (UV/VIS HPLC, Jasco, Japan). Leaf water content was calculated after drying samples at 105 ^{o}C, leaf water potential was determined by HR33T dew point microvoltmeter (Wescor, USA) using leaf disc chamber. Mesophyllum succulence index was calculated as the ratio of water content to total chlorophyll content (g H_2O mg^{-1} chl).

Results

Exposure of seedlings to UV-B radiation for four weeks reduced the total chlorophyll content by 15-20 % (Fig.1**).** UV-B treatment increased the total carotenoid content per chlorophyll basis (Fig.2). The supplemental UV-B influenced the composition of carotenoid pool with increasing the concentration of VAZ cycle pigments and β-carotene. Water stress also enhanced the carotenoid pool which became larger in the presence of supplementary UV-B.

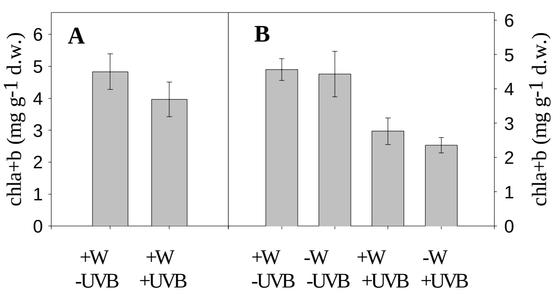

Fig. 1.
Effects of UV-B and water stress on chlorophyll content and chl a/b ratio at Sampling time 1 after four-week UV-B exposure (A) and Sampling time 2 after withholding of water for 2 weeks at Sampling time 1 with the simultaneous continuation of UV-B treatment (B) (n=5)

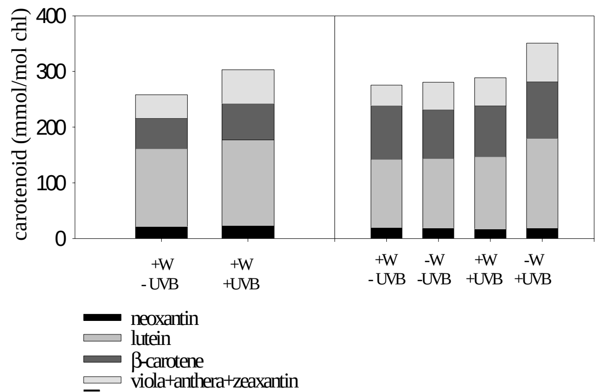

Fig. 2.
Effects of UV-B and water stress on carotenoid composition at Sampling time 1 after four-week UV-B exposure (left part) and Sampling time 2 after withholding of water for 2 weeks (right part) (n=5)

The treatment by UV-B did not affect significantly the leaf water relations of well watered seedlings and more or less have an improvement in water content and water potential which is reflected in the increase of Sm index too (Table 1).

Table 1: Leaf water content, leaf water potential and mesophyllum succulence index at Sampling time 1 after four-week UV-B exposure and sampling time 2 after withholding of water for 2 weeks at Sampling time 1 with the simultaneous continuation of UV-B treatment (n=10)

Treatment	Leaf age	Sampling time 1			Sampling time 2		
		WC % (d.w.)	Ψ (mPa)	Sm	WC % (d.w.)	Ψ (mPa)	Sm
+W -UVB	Old	134.6±35.7	1.47±0.23	0.25±0.03	108.7±15.7	1.9±0.11	0.23±0.01
	Young	150.4±18.2	1.38±0.13	0.42±0.23	129.9±12.6	1.4±0.04	0.51±0.15
+W +UVB	Old	142.8±51.0	1.26±0.08	0.34±0.07	114.9±14.9	1.9±0.12	0.40±0.13
	Young	159.3±19.9	1.53±0.29	0.55±0.16	141.8±30.8	1.7±0.27	0.69±0.11
-W -UVB	Old				53.4±19.6	4.7±0.17	0.12±0.06
	Young				69.7±15.8	4.2±0.17	0.22±0.09
-W +UVB	Old				57.1±18.2	5.3±0.25	0.21±0.03
	Young				67.2±14.0	3.7±0.29	0.32±0.04

When water was withheld from seedlings for two weeks under growth chamber conditions 45-50 % decrease in leaf water content and multifold decreases in water potential values occurred. The dehidration of leaf tissues was stronger in older than younger leaves but in case of latter one the presence of supplementary UV-B significantly moderated the effect of water stress. UV-B treatment alone resulted in a statistically significant increase of Sm. During water stress there were 40-50 % decrease in the values of Sm (Table 1).
The maximum photochemical efficiency of PSII (Fv/Fm) progressively decreased during the UV-B treatment (Table 2). After 4 weeks of UV-B treatment the Fv/Fm values were reduced by 20 an 25 % as compared to the control seedlings. There were larger decrease (50-55 %) in the actual photochemical activity (ΔF/Fm'). The decreases of both chlorophyll fluorescence parameters became more severe when seedlings were subjected to water stress. This was also observed in case of RFD values too.

Table 2: Chlorophyll fluorescence parameters and de-epoxidation state of xanthophyll cycle of seedlings at Sampling time 1after four-week UV-B exposure and sampling time 2 after withholding of water for 2 weeks at Sampling time 1 with the simultaneous continuation of UV-B treatment (n=10)

Treatment	Sampling time 1					Sampling time 2				
	Fv/Fm	ΔF/Fm'	NPQ	RFD	DEEPS	Fv/Fm	ΔF/Fm'	NPQ	RFD	DEEPS
+W -UVB	0.764 ±0.045	0.553 ±0.030	0.54 ±0.17	2.5 ±0.07	0.09 ±0.04	0.758 ±0.048	0.502 ±0.013	0.44 ±0.012	2.0 ±0.18	0.15 ±0.09
+W +UVB	0.599 ±0.047	0.248 ±0.013	0.61 ±0.12	1.4 ±0.09	0.32 ±0.018	0.627 ±0.084	0.314 ±0.016	0.65 ±0.041	1.6 ±0.12	0.43 ±0.08
-W -UVB						0.691 ±0.013	0.225 ±0.056	0.77 ±0.043	1.4 ±0.19	0.67 ±0.08
-W +UVB						0.540 ±0.015	0.124 ±0.011	0.49 ±0.046	0.76 ±0.17	0.72 ±0.06

With increasing water stress, seedlings grown without UV-B, exhibited more significant further decreases in Fv/Fm values than UV-B treated plants. Both UV-B radiation and water stress increased non-photochemical fluorescence quenching which took place in close correlation with the larger activity of xanthophyll cycle and degree of zeaxanthin formation (DEEPS, Table 2).

Discussion

In last decades many studies were performed to study the influence of UV-B radiation on plants which showed that the resistance and susceptibility to UV-B radiation is highly species and ecotype dependent character and change largely when other stresses are present (Tevini 1994). Our repeated experiments showed that under the light conditions of growth chamber seedlings of sessile oak showed relatively high and rapidly developing susceptibility to the enhanced UV-B radiation as compared to UV-B experiments performed under the natural light conditions (Mészáros et al. 2000). This differential effects of UV-B on photosynthesis activity were observed for many species (Teramura and Ziska 1996). In this study seedlings of sessile oak showed different susceptibility to water stress in the presence and absence of supplemental UV-

B under the experimental conditions. Although all treatment have influenced the photosynthetic apparatus of seedlings, some chlorophyll fluoresecence parameters responded especially sensitively to UV-B and water stress (Table 2). The reduction in chlorophyll content might be due to the inhibition of biosynthesis or degradation of pigments under UV-B exposure (Strid and Porra 1992) and was only slightly affected when water was withheld (Fig.1). Concerning the effects of UV-B on chlorophyll content the results on different species are very diverse and unambigous tendency can not be stated. The supplementary UV-B had a clear efffect on carotenoid content, seedlings responded with increasing the total carotenoid pool and water stress resulted in further inceases. This points to the photoprotection role of carotenoids (Demmig-Adams and Adams 1992). Among the carotenoids the size of xanthophyll cycle pool was very responsive to UV-B (Fig.2). Further increase of VAZ cycle pool was observed when UV-B irradiation was followed by water stress treatment. Concerning the effects of UV-B on the xanthophyll cycle pigments and enzymes the data available are contradictory (Teramura and Ziska 1996). In contrast to papers presenting results on the inhibition of the cycle activity in this study we have shown that not only the pool size but the activity of xanthophyll cycle were enhanced in seedlings of sessile oak exposed to UV-B and water stress and formation of zeaxanthin took place in correlation with the development of non-photochemical fluorescence quenching (Table 2). Chlorophyll fluorescence analysis showed UVB-induced decreases in the ratio of variable to maximum fluorescence under both dark-adapted (Fv/Fm) and steady state photosynthesis conditions (ΔF/Fm') in presence of actinic light (Table 2). Well-watered seedlings did not show further decreases in Fv/Fm until the end of UV-B experiment which indicated that the repair mechanism of PSII balanced the damage of PSII. Concerning the changes of Sm of sessile oak the antagonistic effect of UV-B and water stress was shown (Table 1). Although strong dehidration also takes place in in the UV-B treated plants there are effective mechanisms in their leaf tissues for protecting the structure and functioning of photosynthesis apparatus. Our results suggest that UV-B radiation may cause the hardening of oak seedlings and thereby improve the tolerance to water stress.

Acknowledgments
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