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Photosynthetic characteristics of five rice cultivars grown under increased solar UV-B radiation

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Abstract

The impact of increased solar UV-B radiation on photosynthetic characteristics of rice (*Oryza sativa* L.) cultivars ADT36, IR20, IR50, J13 and MDU4 has been studied. In all the cultivars concentrations of photosynthetic pigments decreased under increased UV-B radiation. Even low enhancement of UV-B reduced the photochemical activities in all the cultivars except MDU4 and changed chlorophyll *a* fluorescence. Enhanced UV-B radiation caused a dose-dependent changes in chloroplast proteins in most of the cultivars.

Additional key words: carotenoids, chlorophyll *a+b*, chlorophyll *a* fluorescence, *Oryza sativa*, photochemical activities, photosystem 1, photosystem 2.

Introduction

Rice responses to increased UV-B (280 - 320 nm) radiation were extensively investigated in the laboratory as well as in the field conditions (Kim *et al.* 1996, Olszyk *et al.* 1996, Dai *et al.* 1997). UV-B radiation has long been known to affect plants from molecular to ecosystem level. However, the effectiveness varies with plant species, cultivars, leaf age, prevailing growth conditions and geographical locations (Ziska 1996, Kulandaivelu *et al.* 1997). Most of studies involving rice cultivars, were carried out in growth cabinets or greenhouses (Teramura *et al.* 1991, Barnes *et al.* 1993, He *et al.* 1994, Sato *et al.* 1994) and only a few in field (Kim *et al.* 1996, Olszyk *et al.* 1996).

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Abbreviations: Chl - chlorophyll; DCPIP - dichlorphenolindophenol; F_v/F_m - variable to maximum fluorescence ratio; MV - methyl viologen; PS1 and PS2 - photosystem 1 and 2; SDS-PAGE - sodium dodecyl sulphate-polyacrylamide gel electrophoresis; UV-B - ultraviolet-B radiation (280 - 320 nm).

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Based on the field observations, it is concluded that rice growth and yield are unaffected by increasing UV-B radiation (Olszyk *et al.* 1996). Further, Ziska (1996) suggested that since tropical plants are already experiencing higher levels of UV-B radiation than temperate plants they should have greater degree of UV-B tolerance. Considering these facts, the present study was aimed at investigating the impacts of increased solar UV-B radiation on different field grown Indian rice cultivars.

Materials and methods

Plant growth: Rice (*Oryza sativa* L.) cultivars ADT36, IR20, IR50, J13 and MDU4 were grown from seeds in pots containing black and red soil in the ratio of 3:1. Seedlings were watered daily and kept under the natural environments. Care was taken to avoid any nutrient and water deficiency. Increased solar UV-B radiation was provided by *Philips TL 20W/12 Sunlamps* (*N.V. Philips Gloelampenfabrieken*, The Netherlands) for 6 h around noon. The seedlings were exposed to 11.0, 12.0 and 14.0 kJ m^{-2} d^{-1} UV-B radiation from May to September 1994. The control seedlings were grown under natural solar radiation (UV-B was 10 kJ m^{-2} d^{-1}).

After 36 d of growth under control and UV-B supplementation, the following analyses were made.

Photosynthetic pigments were extracted in pre-chilled 100 % acetone and the concentrations were determined according to Wellburn and Lichtenthaler (1984).

Electron transport assays: The methods of chloroplast isolation and analysis of photochemical reactions mediated by PS 2 and PS 1 were adopted as described previously (Noorudeen and Kulandaivelu 1982). The rate of PS 2 mediated electron transport ($H_2O \rightarrow$ DCIP) was determined spectroscopically. Actinic light (> 640 nm) was provided at an irradiance of 150 W m^{-2}. The photomultiplier was shielded by a blue (*Corning CS 4-96*) filter. The rate of PS 1 ($DCPIPH_2 \rightarrow$ MV) mediated electron transport was measured using *Hansatech* O_2 electrode.

Chl *a* fluorescence induction kinetics in dark-adapted intact leaves (30 min at 28 °C) was analyzed after excitation with broad band blue light (100 W m^{-2}, 400 - 600 nm, *Corning 5113*) as described earlier (Premkumar *et al.* 1996). The signal was stored in a digital oscilloscope (*Iwatsu SS-5802*) and then transferred to a *Hitachi* recorder.

SDS-PAGE analysis: Polypeptide composition of chloroplasts was analyzed by SDS-PAGE using a 8 - 18 % linear gradient gel system as described by Laemmli (1970). Protein samples were prepared as described previously (Nedunchezhian *et al.* 1995). The molecular masses were calculated using standard molecular mass markers ranging from 14.2 to 66.0 kDa (*Sigma* products).

Results and discussion

In all rice cultivars content of Chl *a* and Chl *b* decreased. The highest decrease in pigment content was observed in cv. IR50 and lower in cvs. ADT36, MDU4 and J13 (Table 1). In IR20, seedlings receiving highest supplemental UV-B (14.0 kJ m^{-2} d^{-1}) alone showed reduction in the level of Chl *a*, while Chl *b* was decreased under both 20 and 40 % UV-B enhancements. The concentrations of carotenoids were decreased in all supplemental UV-B radiation treatments. In J13, although the level of carotenoids showed similar decreased pattern as observed for Chl, the extent of reduction was less in carotenoids. In contrast, 40 % UV-B supplementation showed a 2-fold decrease in the carotenoid content in MDU4 when compared with Chl *a* and Chl *b*. Similar findings of decreased Chl content in rice cultivars at early stages of vegetative growth were reported by Kim *et al.* (1996). On the contrary, Teramura *et al.* (1991) observed an increase in Chl content in some rice cultivars which received increased solar UV-B radiation equivalent to 20 % ozone depletion.

Table 1. Changes in the content of Chl *a*, Chl *b* and carotenoids [g kg^{-1}(f.m.)] in leaves of 5 rice cultivars grown under UV-B enhancement from 10 to 11, 12 and 14 kJ m^{-2} d^{-1} for 36 d. Means ± SE, $n = 5$.

Parameter	Cultivar	10	11	12	14
Chl *a*	ADT 36	2.621 ± 0.380	2.569 ± 0.410	2.837 ± 0.260	2.428 ± 0.430
	IR20	1.986 ± 0.130	1.898 ± 0.110	1.762 ± 0.380	1.630 ± 0.270
	IR50	2.689 ± 0.260	2.456 ± 0.190	1.879 ± 0.410	1.753 ± 0.320
	MDU4	3.214 ± 0.730	2.900 ± 0.630	2.552 ± 0.470	2.622 ± 0.140
	J13	2.052 ± 0.020	1.739 ± 0.270	1.537 ± 0.140	1.427 ± 0.120
Chl *b*	ADT 36	0.906 ± 0.011	0.887 ± 0.081	0.894 ± 0.012	0.815 ± 0.023
	IR20	0.628 ± 0.014	0.603 ± 0.021	0.531 ± 0.021	0.712 ± 0.017
	IR50	0.765 ± 0.021	0.719 ± 0.010	0.566 ± 0.016	0.546 ± 0.013
	MDU4	1.103 ± 0.026	1.146 ± 0.012	1.104 ± 0.011	1.024 ± 0.019
	J13	0.643 ± 0.030	0.529 ± 0.016	0.486 ± 0.024	0.463 ± 0.015
Carotenoids	ADT 36	0.591 ± 0.062	0.570 ± 0.039	0.554 ± 0.028	0.567 ± 0.041
	IR20	0.446 ± 0.014	0.421 ± 0.026	0.398 ± 0.029	0.319 ± 0.016
	IR50	0.640 ± 0.029	0.567 ± 0.018	0.464 ± 0.020	0.420 ± 0.031
	MDU4	0.731 ± 0.041	0.673 ± 0.049	0.668 ± 0.051	0.623 ± 0.032
	J13	0.454 ± 0.032	0.425 ± 0.017	0.380 ± 0.024	0.401 ± 0.019

Both 10 and 20 % UV-B enhancements considerably stimulated the photochemical activities of MDU4, while 40 % enhancement in solar UV-B radiation had an inhibitory effect (Table 2). In all other rice cultivars the photochemical activities were progressively reduced by increased UV-B radiation. The decline in photosynthesis in the leaves of UV-B treated plants has been previously reported in a variety of plant species (Yerkes *et al.* 1989, Wilson and Greenberg 1993) and also in some rice cultivars (Teramura *et al.* 1991, Kumagi and Sato 1992). On contrary to the present study, Kim *et al.* (1996) found no or little UV-B effects on photosynthetic capacity of three rice cultivars. This difference could be due to the latitudinal difference and the environmental conditions during the experimental period. Similar to the present study, Dai *et al.* (1994) and Caasilit *et al.* (1997) observed that some of the rice cultivars exhibited sensitivity to UV-B radiation.

Table 2. Changes in PS 2 [nmol(DCPIP red.) kg^{-1}(Chl) s^{-1}] and PS 1 [nmol(O_2) kg^{-1}(Chl) s^{-1}] photochemical activities and F_v/F_m ratio in leaves of 5 rice cultivars grown under UV-B enhancement from 10 to 11, 12 and 14 kJ m^{-2} d^{-1} for 36 d. Means ± SE, n = 5.

Parameter	Cultivar	10	11	12	14
PS 2	ADT 36	121.91 ± 1.10	115.82 ± 2.76	109.08 ± 0.87	98.33 ± 1.92
	IR20	57.32 ± 1.92	52.24 ± 0.63	43.43 ± 1.59	32.86 ± 1.42
	IR50	86.47 ± 0.66	79.17 ± 0.75	65.91 ± 0.54	59.30 ± 0.48
	MDU4	102.76 ± 1.59	134.12 ± 1.35	149.87 ± 2.19	85.43 ± 1.62
	J13	147.99 ± 8.85	138.02 ± 2.60	129.63 ± 4.63	83.02 ± 7.67
PS 1	ADT 36	311.78 ± 3.24	287.25 ± 3.79	263.14 ± 4.18	247.09 ± 2.73
	IR20	142.73 ± 0.63	134.48 ± 1.76	119.92 ± 0.91	92.15 ± 2.78
	IR50	168.43 ± 3.87	152.52 ± 2.91	139.31 ± 1.85	125.90 ± 1.42
	MDU4	307.50 ± 3.98	422.33 ± 1.91	453.51 ± 1.96	275.07 ± 1.85
	J13	276.03 ± 6.65	260.17 ± 8.75	246.01 ± 9.28	203.79 ± 10.3
F_v/F_m	ADT 36	0.709 ± 0.003	0.667 ± 0.101	0.617 ± 0.003	0.581 ± 0.005
	IR20	0.260 ± 0.006	0.245 ± 0.006	0.212 ± 0.005	0.160 ± 0.006
	IR50	0.359 ± 0.005	0.332 ± 0.002	0.311 ± 0.006	0.263 ± 0.005
	MDU4	0.543 ± 0.002	0.609 ± 0.007	0.565 ± 0.009	0.576 ± 0.006
	J13	0.461 ± 0.002	0.452 ± 0.005	0.417 ± 0.009	0.413 ± 0.005

The variable to maximum fluorescence ratio (F_v/F_m) ratio (an indicator of PS 2 efficiency) exhibited a dose response decrease to UV-B supplementation with a maximum reduction at 40 % UV-B enhancement. Various extent of F_v/F_m decrease in different cultivars suggested that the stability of water oxidation system and energy redistribution between the photosystems were affected to various extents by increased solar UV-B radiation (Lingakumar and Kulandaivelu 1993). Although 40 % UV-B enhancement reduced photochemical activities in MDU4, it induced increase in fluorescence yield and the reason for such increase is presently unknown.

Under increased solar UV-B radiation the content of polypeptides isolated from chloroplasts of cv. ADT36 was severely reduced. In IR50, the content of 55 and 33 kDa polypeptides decreased marginally, however, 47 and 43 kDa polypetides showed drastic reduction (Fig. 1). A 10 % solar UV-B enhancement did not produce any significant impact on chloroplast proteins in IR20. Both 20 and 40 % solar UV-B enhancements equally reduced the content of 47 and 17 kDa chloroplast polypeptides in J13. In contrast to these observation, the chloroplast polypeptides of MDU4 and IR20 were stable even under 40 % UV-B enhancement. Decrease in 17, 23 and 33 kDa polypeptides which are associated with inner lumenal surface of thylakoid membranes (Enami *et al.* 1991), indicates their poor stability under solar UV-B supplementations (Nedunchezhian and Kulandaivelu 1993) and therefore results in a loss of PS 2 activity (Nedunchezhian *et al.* 1995).

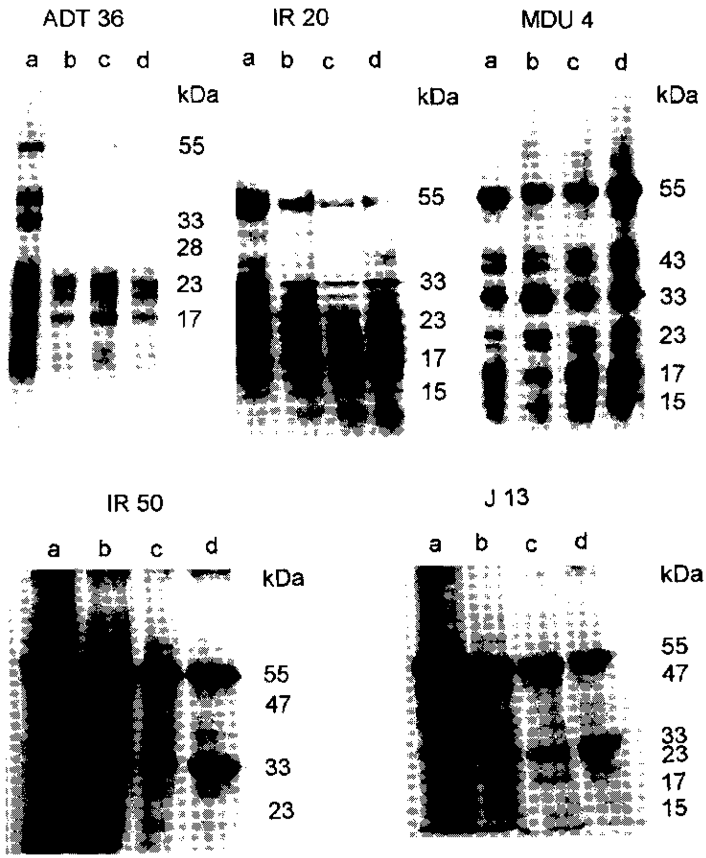

Fig. 1. Changes in the chloroplast proteins of 5 rice cultivars grown under UV-B enhancement from 10 (*lane a*) to 11 (*lane b*), 12 (*lane c*), and 14 (*lane d*) kJ m^{-2} d^{-1} for 36 d.

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