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Combined effects of enhanced ultraviolet-B radiation and mineral nutrients on growth, biomass accumulation and yield characteristics of two cultivars of *Vigna radiata* L.

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Abstract: *In a field experiment, the effect of enhanced UV-B radiation (simulating 20% ozone depletion at Allahabad, 20⁰ 47' N latitude) was studied on two cultivars of Vigna radiata L. with various levels of mineral nutrients (N and P). Study showed decrease in total biomass accumulation, harvest index, RSR and yield after exposure with enhanced level of UV-B. RGR and CGR also showed decline after exposure with UV-B. Application of recommended dose of mineral nutrients alleviated the deleterious effect of UV-B and increased plant dry matter vis a vis yield. Both cultivars showed sensitivity to UV-B but cultivar Malviya Janpriya was more responsive to UV-B than Malviya Jyoti.*

Key words: *Biomass, Mineral nutrients, Growth, Ultraviolet-B, Vigna radiata, Yield.*

Introduction

Concern has developed about the effects of ultraviolet-B radiation on living organisms after the discovery of the spring season ozone hole over Antarctica (Cuadra *et al*., 1997). Plant UV-B research in the last 25 years has demonstrated that UV-B radiation has considerable photobiological consequences on growth, development and photosynthesis of plants (McNamara and Hill, 2000). Most of the reports concerning effects of UV-B on plants are from those grown in greenhouse and growth chambers where the irradiance is totally different from the normal sunlight, and therefore the sensitivity of plants may vary (Teramura *et al*., 1991; Dai *et al*., 1995). Furthermore, the effect of UV-B on plants was different not only to species level but also among the cultivars of the same species.

The interaction between UV-B radiation and various environmental stresses was reported in different plants, which altered the UV-B damage (Premkumar and Kulandaivelu, 1996; Tosserams *et al*., 2001). Studies made on interactive effects of UV-B and mineral nutrients are in scanty in comparison to others. Low K supply increased the UV-B susceptibility in *Vigna unguiculata* (Premkumar and Kulandaivelu, 1996) and *Glycine max* (Murali and Teramura, 1985) plants, while at high nutrient it improved growth in *Phlomis fruticosa* (Levizou and Manetas, 2001). When plants have ample water and nutrients, they may able to compensate for, or protect themselves from, detrimental physiological effects of UV-B (Conner and Zangori, 1998).

The present field study was an attempt i) to see relative sensitiveness of two cultivars of *Vigna radiata* L. to enhanced level of UV-B, and ii) to find out cultivar's response pattern against UV-B with and without application of recommended level of nutrients on growth, biomass accumulation and yield.

Materials and Methods

Cultivar Malviya Jyoti and Malviya Janpriya of *Vigna radiata* L. were sown in 24 plots each of 1.0 m^2 at agricultural farm of Allahabad Agricultural Institute of Allahabad city of state Uttar Pradesh, Eastern Gangatic plains of India situated at 24º 47' N latitude and 82º 21' E longitudes, and 96 m above mean sea level. Four border rows were sown round each plot in order to minimize heterogeneity in microclimate. Soil from the experimental field was sampled at a depth of 30 cm and analyzed in soil testing section of Botany Department of the Institute. Soil type was alluvial with pH 8.66, organic carbon 1.79%, N- 540 mg $100g^{-1}$ soil, P- 11.7 mg $100g^{-1}$ soil and K- 91mg $100g^{-1}$ soil. The experiment was conducted as a split plot design with UV-B treatment as a whole plots and fertilizer treatments as the sub plots randomized within the whole plots. Experiment had three factors viz. i) UV-B treatment, ii) recommended dose of fertilizer treatment and iii) plant age. Effect of all the three factors was studied singly and in combination. The fertilizer treatments were (i) without N and P (F_0) and (ii) recommended dose (RD) of N and P (40 kg ha^{-1} N and 60 kg ha^{-1} P) (F_1). A half dose of N and full of P was provided as basal dose and remaining half dose of N was provided as top dressing. For convenience, control plants were designated as F_0C and F_1C for without N and P and RD of N and P, respectively and the corresponding UV-B treated plants as F_0T and F_1T. After germination planted rows were thinned for healthy growth and to maintain the equality. Plots were watered equally as required.

UV-B treatment was started just after emergence of seedlings for 5 hr day^{-1} in the middle of the photoperiod till the maturity of the crop. UV-B was artificially provided by Q Panel UV-B 313 fluorescent lamps (Q Panel, Cleveland, Ohio, USA). Banks of 4 lamps fitted 30 cm apart on a steel frame were suspended above and perpendicular to the planted rows of a

Table – 1: Effect of enhanced UV-B radiation on total biomass and RSR at different growth stages of *Vigna radiata* L. var. Malviya Jyoti and Malviya Janpriya under varying fertility levels (Mean ± 1 S.E, Values within each column followed by the same letter are not significantly different (p<0.05) using Duncan's Multiple Range test and value within parentheses showing percent difference).

Treatment	Total biomass (g plant^{-1})				RSR (g g^{-1})			
	25 DAS	45 DAS	65 DAS	85 DAS	25 DAS	45 DAS	65 DAS	85 DAS
Malviya Jyoti								
F_0C	0.03±0.009^{c}	0.37±0.017^{a}	1.90±0.14^{b}	2.96±0.27^{a}	0.08±0.011^{a}	0.06±0.007^{a}	0.14±0.017^{b}	0.16±0.014^{a}
F_0T	0.02±0.004^{d}	0.15±0.009^{a}	0.86±0.07^{c}	1.15±0.19^{c}	0.06±0.009^{c}	0.04±0.004^{cd}	0.12±0.011^{b}	0.12±0.016^{c}
	(-33.33%)	(-59.45%)	(-54.73%)	(-61.14%)	(-25%)	(-33.33%)	(-14.28%)	(-25%)
F_1C	0.06±0.006^{a}	0.37±0.024^{a}	3.49±0.16^{a}	3.18±0.31^{a}	0.07±0.012^{b}	0.05±0.006^{b}	0.22±0.027^{a}	0.14±0.011^{bc}
F_1T	0.05±0.004^{b}	0.22±0.016^{a}	2.28±0.11^{b}	2.07±0.24^{b}	0.07±0.014^{b}	0.04±0.003^{d}	0.19±0.019^{a}	0.13±0.009^{c}
	(-16.66%)	(-40.54%)	(-34.67%)	(-37.08%)	(0)	(-20%)	(-13.63%)	(-7.14%)
Malviya Janpriya								
F_0C	0.09±0.006^{b}	1.90±0.11^{b}	2.83±0.27^{b}	3.29±0.47^{b}	0.20±0.017^{ab}	0.52±0.027^{a}	0.22±0.019^{ab}	0.13±0.017^{a}
F_0T	0.05±0.004^{c}	0.71±0.06^{c}	0.91±0.14^{d}	0.92±0.11^{d}	0.19±0.010^{ab}	0.42±0.031^{a}	0.18±0.014^{b}	0.11±0.011^{a}
	(-44.44%)	(-62.63%)	(-67.84%)	(-72.03%)	(-5%)	(-19.23%)	(-18.18%)	(-15.38%)
F_1C	0.13±0.009^{a}	2.10±0.19^{a}	3.79±0.39^{a}	4.11±0.29^{a}	0.15±0.012^{b}	0.39±0.021^{a}	0.23±0.024^{a}	0.13±0.019^{a}
F_1T	0.09±0.004^{b}	1.38±0.11^{b}	2.28±0.24^{c}	2.55±0.31^{c}	0.15±0.011^{b}	0.37±0.018^{a}	0.20±0.011^{ab}	0.12±0.011^{a}
	(-30.76%)	(-34.28%)	(-39.84%)	(-37.95%)	(0)	(-5.12%)	(-13.04%)	(-7.69%)

Malviya Jyoti	Plant age (A)	UV-B treatment (T)	Fertilizer dose (F)	A x T	A x F	T x F	A x T x F
Total biomass	***	***	***	***	***	*	*
RSR	***	***	***	***	***	NS	**
Malviya Janpriya							
Total biomass	***	***	***	***	***	*	NS
RSR	***	**	***	*	***	NS	NS

plot. The 30 cm distance between the top of the plant canopy and UV-B lamps was kept constant. The UV-B irradiance under the lamps was measured at the top of the plant canopy by an ultraviolet intensity meter (UV P Inc. San Gabriel, (A), USA). The readings were converted to UV-B_{BE} values by comparing with the Spectro Power Meter (Scientech, Boulder, USA). Plants under polyester filter lamps received only ambient UV-B (8.6 KJ m^{-2} UV-B_{BE}) on the summer solstice weighted against generalized plant response action spectrum of Caldwell (Caldwell, 1971). The plants beneath cellulose diacetate film received UV-B_{BE} (ambient + 7.1 KJ m^{-2}) that mimicked 20% reduction in stratospheric ozone at Allahabad (20º 47' N) during clear sky condition on the summer solstice normalized at 300m. The ozone column thickness was assumed at 3.0 mm, the albedo 0 and the scatter 1.0. Filters were changed frequently to avoid aging effects on the spectral transmission of UV-B.

The plants were sampled randomly at 25, 45 and 65 days after sowing (DAS). Different plant parts were separated and oven dried at 80º C till the constant weight was achieved. Final harvesting was carried out at 85 DAS and data regarding yield was recorded as g plant^{-1}. Growth indices i.e. root shoot ratio (RSR), specific leaf weight (SLW), relative growth rate (RGR), crop growth rate (CGR) and harvest index (HI) was calculated by the formulae developed by Hunt (1982).

Effects of factors UV-B treatment, fertilizer dose, plant age and their interaction were determined by using SPSS software (SPSS Inc., version 10.0).

Results

An adverse effect of supplemental UV-B radiation was observed on growth and dry matter accumulation in both the cultivars of mungbean. Total biomass reduction was maximal (66.77%) in unfertilized plants of cultivar Malviya Jyoti at 85 DAS (Table 1). Multivariate analysis showed significant differences for all the factors and their interactions in both cultivars. Above ground and below ground biomass of both mungbean cultivars was increased after application of mineral nutrients and exposure with supplemental UV-B resulted a reduction. Above ground biomass was less affected than below ground biomass due to UV-B. It is evidenced by reduction in RSR in both cultivars at all the ages except at 25 DAS with F_1T treatment (Table 1). Reduction in RSR was higher in F_0T plants than F_1T plants at all the ages. Effect of all the factors was statistically significant except interaction between UV-B treatment x fertilizer dose for Malviya Jyoti and UV-B treatment x fertilizer dose and plant age x UV-B treatment x fertilizer dose for Malviya Janpriya (Table 1). Leaf biomass was observed to be more sensitive to UV-B and reduced maximally as compared to pods and shoot biomass. Reduction for dry leaf weight was 66.1 and 44.1% in Malviya Jyoti and 66.4 and 31.8% in Malviya Janpriya under F_0T and F_1T treatments, respectively at 85 DAS (Table 2). Leaf thickness measured as SLW was surprisingly decreased in UV-B treated plants at both the nutrients levels of both the cultivars (Table 2). Cultivar Malviya Janpriya showed less RGR comparative to cultivar Malviya Jyoti at early sampling

Table – 2: Effect of enhanced UV-B radiation on dry leaf weight and SLW at different growth stages of *Vigna radiata* L. var. Malviya Jyoti and Malviya Janpriya under varying fertility levels (Mean ± 1 S.E, Values within each column followed by the same letter are not significantly different (p<0.05) using Duncan's Multiple Range test and value within parentheses showing percent difference).

Treatment	Dry leaf weight (g plant^{-1})				SLW (g cm^{-2})			
	25 DAS	45 DAS	65 DAS	85 DAS	25 DAS	45 DAS	65 DAS	85 DAS
Malviya Jyoti								
F_0C	0.30±0.017^{c}	2.32±0.21^{bc}	5.50±0.47^{b}	5.22±0.61^{b}	0.0021±0.001^{ab}	0.0053±0.0006^{a}	0.0053±0.0003^{a}	0.0092±0.001^{b}
F_0T	0.14±0.011^{d} (-53.33%)	1.07±0.17^{e} (-53.87%)	2.58±0.31^{d} (-53.09%)	1.77±0.24^{d} (-66.09%)	0.002±0.000^{b} (-4.76%)	0.0045±0.0004^{b} (-15.1%)	0.0051±0.0001^{b} (-3.77%)	0.0034±0.001^{d} (-63.04%)
F_1C	0.50±0.024^{a}	2.76±0.34^{a}	6.66±0.53^{a}	6.85±0.39^{a}	0.0027±0.0002^{a}	0.004±0.0002^{b}	0.005±0.0003^{a}	0.0105±0.003^{a}
F_1T	0.35±0.027^{b} (-30%)	2.03±0.19^{cd} (-26.44%)	4.65±0.44^{c} (-30.18%)	4.19±0.28^{c} (-44.13%)	0.0025±0.0001^{ab} (-7.41%)	0.0039±0.0002^{b} (-2.5%)	0.0049±0.0004^{b} (-2%)	0.0063±0.002^{c} (-40%)
Malviya Janpriya								
F_0C	0.32±0.011^{c}	1.71±0.24^{ab}	6.11±0.47^{b}	7.50±0.72^{b}	0.0041±0.0002^{c}	0.0035±0.0003^{a}	0.0101±0.0008^{a}	0.0220±0.004^{a}
F_0T	0.15±0.014^{d} (-53.12%)	0.63±0.18^{d} (-63.15%)	1.81±0.28^{d} (-70.37%)	2.52±0.39^{c} (-66.4%)	0.0037±0.0003^{d} (-9.76%)	0.0034±0.0001^{b} (-2.86%)	0.0093±0.0004^{b} (-7.92%)	0.0064±0.001^{c} (-70.9%)
F_1C	0.57±0.029^{a}	2.14±0.31^{a}	7.53±0.21^{a}	10.80±0.42^{a}	0.0063±0.0004^{a}	0.0034±0.0004^{a}	0.0082±0.0003^{c}	0.0135±0.001^{b}
F_1T	0.40±0.017^{b} (-29.82%)	1.35±0.19^{bc} (36.91%)	4.66±0.37^{c} (-38.11%)	7.37±0.30^{b} (-31.75%)	0.006±0.0001^{b} (-4.76%)	0.0033±0.0002^{b} (-2.94%)	0.008±0.0005^{c} (-2.44%)	0.0121±0.002^{b} (-10.37%)

Malviya Jyoti	Plant age (A)	UV-B treatment (T)	Fertilizer dose (F)	A x T	A x F	T x F	A x T x F
Dry leaf weight	***	***	***	***	***	***	***
SLW	***	***	***	***	***	***	NS
Malviya Janpriya							
Dry leaf weight	***	***	***	***	***	**	**
SLW	***	***	NS	***	*	***	***

Table – 3: Variance ratio of *Vigna radiata* L. cultivars Malviya Jyoti and Malviya Janpriya grown with varying treatments at different plant age.

Cultivars	Parameters	Plant age (A)	UV-B treatment (T)	Fertilizer dose (F)	A x T	A x F	T x F	A x T x F
Malviya Jyoti	RGR	***	NS	NS	NS	NS	NS	NS
	CGR	***	***	***	**	**	**	NS
	Grain plant^{-1}	-	***	***	-	-	**	-
	HI	-	*	**	-	-	NS	-
Malviya Janpriya	RGR	***	**	NS	NS	**	NS	NS
	CGR	***	***	***	***	***	***	NS
	Grain plant^{-1}	-	***	***	-	-	NS	-
	HI	-	**	***	-	-	NS	-

***= p < 0.001, ** = p < 0.01, * = p < 0.05, NS= Not significant

time (25-45 DAS) at both nutrient levels but found higher at 45-65 and 65-85 DAS. CGR also showed similar pattern. RGR and CGR showed decline between two plant ages after exposure with enhanced UV-B at all the sampling intervals and reduction was less in the plants supplemented with mineral nutrients (Fig. 1). Significant effect of UV-B treatment was observed on RGR and CGR in cultivar Malviya Janpriya and on CGR in cultivar Malviya Jyoti (Table 3).

Seed yield and harvest index (HI) were observed higher in both cultivars with application of mineral nutrients (Fig 2). Supplemental UV-B resulted in lesser yield in both cultivars at both the fertility regimes. Reduction in economic yield due to enhanced UV-B was higher in Malviya Janpriya in comparison to Malviya Jyoti. Reduction in seed yield was 62.4 and 31.6% in Malviya Jyoti and 71.6 and 40.3% in Malviya Janpriya at F_0T and F_1T, respectively. Multivariate analysis showed significant effect of all the factors except interaction between UV-B treatment x fertilizer dose for HI in both cultivars and for seed yield in cultivar Malviya Janpriya (Table 3).

Discussion

Exposure of mungbean cultivars to supplemental UV-B caused reduction in total biomass. UV-B induced damage to photosynthetic function can manifest itself in less biomass,

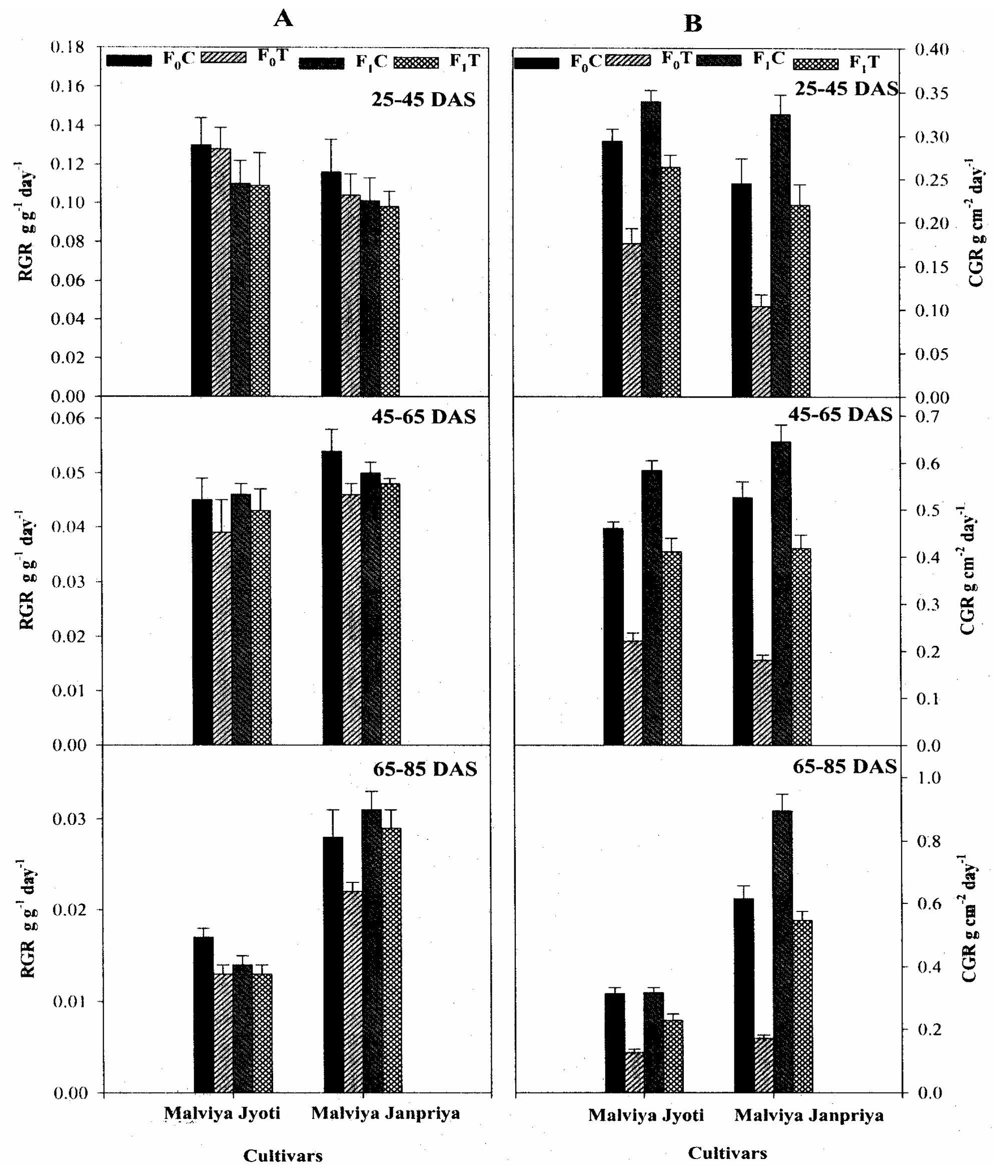

Fig. 1: Effect of enhanced UV-B radiation on RGR (A) and CGR (D) of *Vigna radiata* L. (cultivar Malviya Jyoti and cultivar Malviya Janpriya) at different age intervals with different nutrients level.

however it may also be influenced by UV-B without being mediated by changes in photosynthesis (Tevini, 2000). Tosserams *et al.* (2001) reported that biomass production of *Plantago lanceolata* plants grown limited nutrient supply was not affected by UV-B. Reduction in dry matter yield and grain yield might be associated with stunted growth and changed morphology with supplemental UV-B radiation (Teramura, 1980; Barnes *et al.,* 1990). Reduction in shoot biomass accumulation is a good measure to UV-B sensitivity since this reflects the cumulative effect of many small disruptions in plant function (Smith *et al*., 2000). The response of diverse species to sub optimal nutrient levels has shown some support for this hypothesis (Shipley and Keddy, 1988). Present investigation showed more damaging effect of supplemental UV-B on different shoot parts of cultivar Malviya Janpriya than Malviya Jyoti suggesting higher sensitivity of former cultivar. The effect of UV-B on the shoot was direct, while on the root was indirect and interacted with other co-occurring factors. In the present study higher reduction in root biomass than shoot biomass was observed resulting in less RSR. A possible explanation for this may be the reduction in allocation of photosynthates to roots and nodules of mungbean plants (data not given). Deckmyn and Impens (1995) found variable RSR in field condition and reduced RSR in indoor experiment of bean plants after elevated UV-B exposure. Ziska *et al* (1993) showed that tropical plants of *Manihot esculentum* grown under supplemental UV-B radiation produced significantly less root biomass resulting in a significant increase in the shoot root ratio.

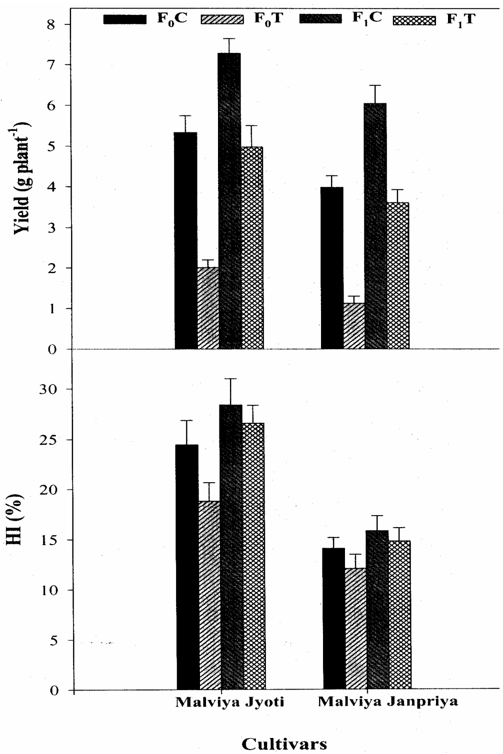

Fig. 2: Effect of enhanced UV-B radiation on yield (A) and HI (B) of *Vigna radiata* L. (cultivar Malviya Jyoti and Malviya Janpriya) with different nutrients at final harvest.

In order to perform their function as photosynthetic organs, leaves must cope with excess heat and potentially damaging UV radiation (Dillenburg *et al*., 1995). Sharma *et al.* (1991) reported reduction in dry weight of pod, leaf and stem in UV-B exposed *Vigna radiata* var. Wilczek and is conformity of the present investigation. Hunt and McNeil (1998) reported UV-B induced reduction of leaf mass, leaf area and plant height in nitrogen supplemented *Cucumis sativus* L. plants. Plants have been shown to adapt to UV-B radiation environment by increasing their specific leaf weight (Vu *et al.,* 1982). But in present investigation, less SLW in UV-B treated plants was reported but was found more in nutrient amended plants. Krizek *et al.* (1997) also reported similar pattern in four cultivars of *Cucumis sativus* L. Increased leaf and epidermal thickness can decrease the penetration of UV-B to more sensitive layers (Day, 1993; Santos, 2003). Hunt and McNeil (1998) found significant increase in leaf thickness of *Cucumis* sativus with increased N supply at additional UV-B dose.

Reduction in RGR and CGR in mungbean cultivars showed less production efficiency and may partially revealed the way in which inhibition of growth took place by enhanced UV-B, even with addition of fertilizers. Rozema *et al.* (1991) reported 32-47% and 22-39% reduction in RGR of wheat (*Triticum aestivum*) and maize (*Zea mays*), respectively. However, Zavala and Botto (2002) could not found any consistent pattern in plant RGR and higher RGR of tubers for plants grown under ambient UV-B than those grown under solar UV-B exclusion in *Raphanus sativus*. Less RGR may be explained as, due to influence of photosynthetic response to enhanced UV-B (Cen and Bornman, 1990).

Reduction in seed yield is a common characteristic of UV-B sensitive species (Tevini *et al*., 1989). Ambasht and Agrawal (2003) reported decline in seed yield of *Glycine max* due to UV-B exposure singly and in combination with ozone. Significant reduction in grain yield of *Triticum aestivum* after UV-B enhancement was observed by Yue *et al.* (1998) but Demchik and Day (1996) found no reduction in seed yield of *Brassica rapa*. Reduced HI of present investigation is a result of changes in dry matter allocation to different plant parts in enhanced UV-B exposed plants. UV-B radiation resulted in obvious shift in dry matter allocation patterns; a lower proportion of dry matter was allocated in to grains (Yue *et al.,* 1998). Contrary to this Deckmyn and Impens (1995) reported an increased HI of UV-B exposed *Phaseolus vulgaris* plants. Reduction in HI of UV-B exposed plants was accounted by larger decrease in grain yield and less reduction in aboveground dry matter yield (Yue et al., 1998). Murali and Teramura (1985) showed that decreased P supply reduced allocation of biomass to leaves and stem but increased allocation to roots, simultaneously; exposure with UV-B radiation increased allocation to leaves but decreased that to stem and root.

Results of the present study showed beneficial effect of mineral nutrients (N & P) by increasing growth and yield *vis a vis* alleviating adverse effect of UV-B in both the cultivars of mungbean. Levizou and Manetas (2001) observed that at high nutrient level (N, P & K) supplemental UV-B radiation improved the growth in *Phlomis fruticosa*, indicating a strong interaction between treatments. UV-B and relative nutrient addition rate have mainly an additive effect in *Betula pendula*, as leaves responded to increasing UV-B by synthesizing metabolites (e.g. flavonols), which are important UV-B filters (Rosa *et al*., 2001). Carbon/nutrient balance hypothesis of Bryant *et al* (1983) proposes that the relative availability of carbon and nutrient resources in the local environment greatly influences the amount of carbon based secondary plant compounds found in plant tissues by mediating plants carbohydrate storage. Fajer *et al.* (1992) predicted from the present hypothesis that under low nutrient conditions there is reduction in photosynthesis. This leads to the accumulation of carbohydrate concentrations in excess of those needed for plant growth, which will drive the additional synthesis of carbon based secondary compounds.

The study concludes that enhanced UV-B has manifested its effect in the form of significant reduction in biomass, its allocation and seed yield in both cultivars of *Vigna radiata* L. Application of recommended dose of mineral nutrients alleviates the deleterious affect of supplemental UV-B. Cultivar, Malviya Janpriya was affected more to UV-B than cultivar Malviya Jyoti showing intraspecific variations in the UV-B sensitivity.

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References

Ambasht, N. K. and M. Agrawal : Interactive effects of ozone and ultraviolet-B singly and in combination on physiological and biochemical characteristics of soybean plants. *J. Plant Biol*., **30**, 37-45 (2003).

Barnes, P. W., S. D. Flint and M. M. Caldwell : Morphological responses of crop and weed species of different growth forms to ultraviolet-B radiation. *Amer. J. Bot*., **77**, 1354-1360 (1990).

Bryant, J. P., F. S. Chapin and D. R. Klein: Carbon/nutrient balance of boreal plants in relation to vertebrate herbivory. *Oikos*, **40**, 357-368 (1983).

Caldwell, M. M.: Solar ultraviolet radiation and the growth and development of higher plants. *In*: Photophysiology Vol. 6, (*Ed:* A. C. Giese). Academic Press, New York. pp. 131-171 (1971).

Cen, Y. P. and J. F. Bornman: The response of bean plants to UV-B radiation under different irradiance of background visible light. *J. Exp. Bot*., **41**, 1489-1495 (1990).

Conner, J. K. and L. A. Zangori: Combined effects of water, nutrients and UV-B stress on female fitness in *Brassica* (Brassicaceae). *Amer. J. Bot*., **85(7)**, 925-931 (1998).

Cuadra, P., J. B. Harborne and P. G. Waterman: Increases in surface flavonols and photosynthetic pigments in *Gnaphaliun luteo-album* in response to UV-B radiation. *Phytochem*., **45(7)**, 1377-1383 (1997).

Dai, Q., S. Peng, A. Q. Chavez and B. S. Vergara: Effect of enhanced UV-B radiation on growth and production of rice under green house and field conditions. *In* : Climate change and rice (*Eds:* S. Peng, K. T. Inagram, H. U. Neue and L. H. Ziska). Springer-Verlag, Berlin. pp. 242-257 (1995).

Day, T. A.: Relating UV-B radiation screening effectiveness of foliage to absorbing compounds concentration and anatomical characteristics in a diverse group of plants. *Oecolog*., **95,** 542-550 (1993).

Deckmyn, G. and I. Impens : UV-B increases the harvest index of bean (*Phaseolus vulgaris* L.). *Plant Cell Environ*., 1**8**, 1426-1433 (1995).

Demchik, S. M. and T. A. Day: Effect of enhanced UV-B radiation on pollen quantity, quality and seed yield in *Brassica rapa* (Brassicaceae). *Amer. J. Bot*., **83 (5),** 573-579 (1996).

Dillenburg, L. R., J. H. Sullivan and A. H. Teramura: Leaf expansion and development of photosynthetic capacity and pigments in *Liquidamber styraciflue* (Hamamelidaceae)- effects of UV-B radiation. *Amer. J. Bot*., **82(7),** 878-885 (1995).

Fajer, E. D., M. D. Bowers and F. A. Bajjaz: The effect of nutrients and enriched CO_2 environments on production of carbon based allelochemicals in *Plantago*: a test of the corbon/nutrient balance hypothesis. *Amer. Nature*, **140**, 707-723 (1992).

Hunt, J. E. and D. L. McNeil: Nitrogen status affects UV-B sensitivity of cucumber. *Austr. J. Plant Physiol*., **25,** 79-86 (1998).

Hunt, R.: Plant growth analysis. University Park Press, Baltimore, USA (1982).

Krizek, D. T., R. M. Mirecki and S. J. Britz: Inhibitory effects of ambient levels of solar UV-A and UV-B radiation on growth of cucumber. *Physiol. Plant*., **100**, 886-893 (1997).

Levizou, E. and Y. Manetas: Combined effects of enhanced UV-B radiation and additional nutrients on growth of two Mediterranean plant species. *Plant Ecol*., **154**, 181-186 (2001).

McNamara, A. E. and W. R. Hill: UV-B irradiance gradient affects photosynthesis and pigments but not food quality of periphyton. *Fresh Water Biol*., **43**, 649-662 (2000).

Murali, N. S. and A. H. Teramura: Effects of ultraviolet – B irradiance on soyabean VI. Biomass and concentration and uptake of nutrient at varying P supply. *J. Plant Nutr*., **8**, 177-192 (1985).

Premkumar, A. and G. Kulandaivelu : Influence of ultraviolet-B enhanced solar radiation on growth and photosynthesis of potassium deficient cowpea seedlings. *Photosynthetica*, **32,** 521-528 (1996).

Rosa, T. M. De La, R. J. Tiitto, T. Lehto and P. J. Aphalo: Secondary metabolites and nutrients concentration in silver birch seedlings under five levels of daily UV-B exposure and two relative nutrient addition rates. *New Phytol*., **150,** 121-131 (2001).

Rozema, J., J. V. De Staay, V. Costa, J. T. Pereira, R. Broekman, G. Lenssen and M. Stroetemga: Effect of solar UV-B radiation on growth of mungbean (*Vigna radiata* L. Wilczek) plants. *In*: Impact of global climatic changes on photosynthesis and plant productivity. (*Eds:* Y. P. Abrol *et al.*). Oxford and IBH Publishing Co.Pvt. Ltd., New Delhi. pp. 163-174 (1991).

Santos, I.: UV-B radiation and the biochemical and ultrastructural responses of plants. *In*: Advances in plant physiology Vol. 5 (*Eds:* A. Hemantaranjan). Scientific Publisher, India, Jodhpur. pp. 159-180 (2003).

Sharma, A., Y. P. Abrol and U. K. Sengupta: Effect of solar UV-B radiation on growth of mungbean (*Vigna radiata* L. Wilczek) plants. *In*: Impact of global climatic changes on photosynthesis and plant productivity. (*Eds:* Y. P. Abrol *et al.*). Oxford and IBH Publishing Co.Pvt. Ltd., New Delhi. pp. 175-180 (1991).

Shipley, B. and P. A. Keddy: The relationship between relative growth rate and sensitivity to nutrient stress in twenty eight species of emergent macrophytes. *J. Ecol*., **76**, 1101-1110 (1988).

Smith, J. L., D. J. Burritt and P. Bannister: Shoot dry weight, chlorophyll and UV-B absorbing compounds as indicators of plant sensitivity to UV-B radiation. *Ann. Bot*., **86**, 1057- 1063 (2000).

Teramura, A. H.: Effects of ultraviolet-B irradiances on soybean I. Importance of photosynthetically active radiation in evaluating ultraviolet-B irradiance effects on soybean and wheat growth. *Physiol. Plant*., **48**, 333- 339 (1980).

Teramura, A. H., L. H. Ziska and A.E. Sztein: changes in growth and photosynthetic capacity of rice with increased UV-B radiation. *Physiol. Plant*., **83**, 373-380 (1991).

Tevini, M., A. H. Teramura, G. Kulandaivelu, M. M. Caldwell and L. O. Bjorn: Terrestrial plants. *In*: Environmental effects pannel report, pursuant to article 6 of the Montreal protocol on substances that deplete the ozone layer under the auspices of the United Nations Environment Programme. pp. 25-37 (1989).

Tevini, M.: UV-B effects on plant. *In*: Environmental pollution and plant responses. (*Eds:* S. B. Agrawal and M. Agrawal). Lewis Publishers, Boca Raton, USA. 83-98 (2000).

Tosserams, M., J. Smet, E. Magendans and J. Rozema: Nutrient availability influences UV-B sensitivity of *Plantago lanceolata*. *Plant Ecol*., **154**, 159-168 (2001).

Vu, C. V., L. H. Allen Jr. and L. A. Garrard: Effect of UV-B (ultraviolet-B) radiation (280-320 nm) on photosynthetic constituents and processes in expanding leaves of soybean (*Glycine max* L. Merr.). *Environ. Exp. Bot*., **22/4**, 465-471 (1982).

Yue, M., Y. Li and X. Wang: Effects of enhanced ultraviolet-B radiation on plant nutrients and decomposition of spring wheat under field conditions. *Environ. Exp. Bot*.,**40**, 187-196 (1998).

Zavala, J. A. and J. F. Botto: Impact of solar UV-B radiation on seedling emergence, chlorophyll fluorescence, and growth and yield of radish (*Raphanus sativus*). *Funct. Plant Biol*., **29**, 797-804 (2002).

Ziska, L. H., A. H. Teramura, J. H. Sullivan and A. McCoy: Influence of ultraviolet-B radiation on photosynthetic and growth characteristic in field-grown cassava (*Monihot esculunta* Crantz.). *Plant Cell Environ.,* **16,** 73-79 (1993).

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