Changes in oxidative stress defense system in wheat (*Triticum aestivum* L.) and mung bean (*Vigna radiata* L.) cultivars grown with and without mineral nutrients and irradiated by supplemental ultraviolet-B

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Abstract

Field study was conducted to evaluate the inter- and intra-specific variations in sensitivity of two cultivars each of wheat (*Triticum aestivum* L. cv. HD 2329 and HUW 234) and mung bean (*Vigna radiata* L. cv. Malviya Jyoti and Malviya Janpriya) to supplemental levels of UV-B irradiation (sUV-B, 280–315 nm) with and without recommended levels of mineral nutrients. Results showed decrease in photosynthetic pigments and biomass of all the four cultivars due to sUV-B radiation. Antioxidative defense system was activated in all the cultivars after irradiation with sUV-B. SOD, peroxidase and total thiol contents increased, while catalase activity and ascorbic acid contents decreased under sUV-B irradiation. On the basis of biomass, UV-B sensitivity can be arranged in decreasing order as: Malviya Janpriya < Malviya Jyoti < HD 2329 < HUW 234. Application of mineral nutrients (N, P and K) showed significant positive response in all cultivars by ameliorating the negative impact of sUV-B.

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Keywords: Ultraviolet-B radiation; Mineral nutrients; Wheat (*Triticum aestivum* L.); Mung bean (*Vigna radiata* L.); Photosynthetic pigments; Antioxidant defense system; Biomass

1. Introduction

Stratospheric O₃ reduction is one of the pressing global concerns of climate change, which has prompted recent efforts in assessing the potential damage to vegetation due to supplemental levels of ultraviolet-B (sUV-B, 280–320 nm) radiation (Caldwell et al., 1998; Hollosy, 2002; Kakani et al., 2003). Numerous studies have investigated the effects of elevated UV-B on plants, and have shown a diverse range of responses, including changes at the physiological, morphological, biochemical and molecular levels (Caldwell et al., 1995; Jordan, 1996; Allen et al., 1998; Paul, 2001). These studies have shown deleterious effects of UV-B such as reduced photosynthesis, biomass reduction, decreased protein synthesis, damage to nucleic acids and lipids (Jordan, 1996; Jansen et al., 1998; Rathore et al., 2003).

Under light conditions, photoreduction of O₂ in green plants is an unavoidable process that can result in superoxide anion (O₂•−) production. Dismutation of O₂•− by superoxide dismutase (SOD) results in the formation of oxygen and hydrogen peroxide (H₂O₂) and the latter can react with O₂•− to create the highly reactive hydroxyl radical (•OH) via the Haber–Weiss cycle (Bowler et al., 1992). Different species of plants accomplish protection towards stress through different biochemical adjustments but reactive oxygen species (ROS) scavenging is a common response to most stresses. ROS scavenging depends on the detoxification mechanism provided by an integrated system of nonenzymatic reduced molecules like ascorbate and glutathione as well as enzymatic antioxidants like SOD, catalase and peroxidase (Dai...
et al., 1997; Srivalli et al., 2003). At present, our knowledge concerning the role of the antioxidant system in protecting plants under UV-B stress is limited because few studies have been made covering a small number of plant species (Costa et al., 2002; Kakani et al., 2003).

Responses of plants to UV-B vary not only among the species, but also among the cultivars of same species (Tevini, 2000). Variations in responsiveness of different species and cultivars to UV-B were also reported for a variety of plant species (Dai et al., 1994; Smith et al., 2000; Alexieva et al., 2001; Yanqun et al., 2003a,b; Zu et al., 2004). The effects of UV-B on leaves can be mimicked by free radical generators and prevented by antioxidant feeding (Mackerness et al., 1998). Smith et al. (2000) concluded that variations in UV-B sensitivity between different species represent the relative contribution of morphological, physiological and biochemical differences, but variations within species are usually more subtle.

Besides inter and intraspecific variations in UV-B sensitivity, other abiotic factors also alter and/or modify the plant responses as an outcome of the interactions. Under field conditions, plants usually experience several stresses simultaneously. The effect of enhanced UV-B radiation on plants can be modified by other co-occurring stresses or by simply changing environmental factors like atmospheric CO$_2$ (Bjorn et al., 1997), water availability (Manetas et al., 1997) and nutrient availability (Murali and Teramura, 1987; Levizou and Manetas, 2001).

Fig. 1. Age wise changes in total chlorophyll content of control and sUV-B exposed *Triticum aestivum* L. (cv. HD 2329 and HUW 234) and *Vigna radiata* L. (cv. Malviya Jyoti and Malviya Janpriya) cultivars with and without nutrients (bars represent ± S.E.).
Most studies have examined the responses of individual species and/or their varieties to UV-B grown under unrealistic and unbalanced UV-B, UV-A and photosynthetically active radiation (Caldwell et al., 1995; Middleton and Teramura, 1994) in growth chambers and greenhouses (Fiscus and Booker, 1995), or under balanced UV-B radiation in the field, but at diverse locations with dissimilar environmental conditions (Rozema et al., 1997). Therefore, the present study was conducted in the field under the natural level of PAR at two different doses of UV-B irradiation i.e. ambient and ambient + supplemental (7.1 kJ m\(^{-2}\), simulating 20% ozone depletion at Allahabad, 24°47'N) on two cultivars each of wheat and mung bean with and without the recommended level of mineral nutrients to evaluate its effect on photosynthetic pigment, biomass and antioxidative response among cultivars. We hypothesized that sUV-B radiation leads to production of ROS, which causes reduction in photosynthetic pigments and also affect several biochemical processes. Insufficient removal of ROS by ascorbic acid, SOD and thiols will affect various metabolic processes, causing a reduction in biomass. Further, plants may develop resistance against sUV-B irradiation by nutrient’s application to mitigate its negative impact via more activation of the antioxidant defense system.

### 2. Materials and methods

#### 2.1. Plant materials and growth conditions

The study was performed at the agricultural farm of Allahabad Agricultural Institute of Allahabad city of state Uttar Pradesh, Eastern Gangetic plains of India situated at 24°47’N latitude and 82°21’E longitude, and 96 m above mean sea level. Soil type was alluvial with pH 7.62, organic carbon 1.64%, N 690 mg 100 g\(^{-1}\) soil, P 16.4 mg 100 g\(^{-1}\) soil and K 136.2 mg 100 g\(^{-1}\) soil. Genetically similar seeds of two cultivars each of wheat (Triticum aestivum L. cv. HD 2329 and HUW 234) and mung bean (Vigna radiata L. cv. Malviya Jyoti and Malviya Janpriya) were sown separately under field conditions in 24 plots of size 1 m × 1 m in respective growing seasons. After germination, plants were thinned in each row (spaced 30 cm apart) for uniformity in growth to one plant every 15 cm. Plants were watered uniformly. Four border rows were sown round each plot in order to minimize heterogeneity in microclimate.

#### 2.2. Experimental design and nutrient application

The experimental design was a split plot with UV-B treatments as whole plots and fertilizer treatments as the sub plots randomized within the whole plots. Each treatment was replicated three times. The experiment had three factors (i) sUV-B treatment, (ii) fertilizer treatments and (iii) plant age. Effects of all the three factors were studied singly and in combination. The different fertilizer treatments were: recommended dose of nutrients (\(F_1\)), and without nutrients application (\(F_0\)). The recommended dose (RD) of N, P and K for wheat were 80, 40 and 40 kg ha\(^{-1}\), respectively and for mung bean 20 and 50 kg ha\(^{-1}\) of N and P, respectively. N, P and K were applied as urea, single superphosphate and muriate of potash, respectively. A half dose of N and full doses of P and K were given.

### Table 1

<table>
<thead>
<tr>
<th>Cultivars</th>
<th>Parameters</th>
<th>Factor</th>
<th>Plant age (A)</th>
<th>UV-B treatment (T)</th>
<th>Fertilizer dose (F)</th>
<th>A × T</th>
<th>A × F</th>
<th>T × F</th>
<th>A × T × F</th>
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<td>5.20***</td>
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<td>0.45NS</td>
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<td>Thiol</td>
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<td>HUW 234</td>
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<td>4.92*</td>
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<td>Total chlorophyll</td>
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<td>20.95***</td>
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<td>40.78***</td>
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<td>2.78NS</td>
<td>13.27***</td>
<td>0.13NS</td>
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<td>96.30***</td>
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<td>10.09**</td>
<td>1.12NS</td>
<td>0.01NS</td>
<td>0.01NS</td>
<td>0.17NS</td>
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</table>

NS: not significant.

* Significant at \(p < 0.05\).

** Significant at \(p < 0.01\).

*** Significant at \(p < 0.001\).
as basal dose and another half dose of N was given as a top dressing.

2.3. sUV-B treatment

sUV-B was artificially provided by Q Panel UV-B 313 fluorescent lamps (Q Panel, Cleveland, Ohio, USA). Banks of 4 lamps (120 cm long) fitted 30 cm apart on a steel frame were suspended above and perpendicular to the planted rows of each plots. The 30 cm distance between the top of the plant canopy and UV-B lamps was kept constant. UV-B treatment was started just after germination for 5 h day$^{-1}$ in the middle of the photoperiod till the maturity. The UV-B irradiance at the top of the plant canopy under the lamps was measured with an ultraviolet intensity meter (UVP Inc., San Gabriel, USA). The readings were converted to UV-BBE values by comparing with the Spectro Power Meter (Scientech, Boulder, USA). Plants under 0.13 mm polyester filter lamps received only ambient UV-B ($8.6 \text{ kJ m}^{-2} \text{ UV-BBE}$) on the summer solstice weighted against generalized plant response action spectrum of Caldwell (1971). The plants beneath 0.13 mm cellulose diacetate film received UV-BBE (ambient + $7.1 \text{ kJ m}^{-2}$) that mimicked 20% reduction in stratospheric ozone at Allahabad (20° 47′ N) during clear sky condition on the summer solstice (Green et al., 1980) normalized at 300 m. Cellulose diacetate and polyester films used to transmit UV-B (cut off ca. 292 nm) and exclude UV-B (cut off ca. 318 nm). 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. For convenience, control plants were designated as $F_0$ for those grown without fertilizer, $F_1$ grown at the rec-

Fig. 2. Age wise changes in carotenoid content of control and sUV-B exposed *Triticum aestivum* L. (cv. HD 2329 and HUW 234) and *Vigna radiata* L (cv. Malviya Jyoti and Malviya Janpriya) cultivars with and without nutrients (bars represent ± 1 S.E.).
ommended dose of fertilizer, with the corresponding sUV-B treated plants designated as $F_0T$, $F_1T$.

2.4. Plant Analysis

Wheat plants were sampled in triplicate at 35, 55 and 75 days after sowing (DAS) and mung bean plants were sampled at 25, 45 and 65 DAS for biochemical analysis and biomass estimation. Final harvest was carried out at complete maturity i.e. 120 DAS for wheat cultivars and 85 DAS for mung bean cultivars for estimation of biomass.

For the estimation of chlorophyll and carotenoid contents, 0.1 g leaf samples (third leaf below the apex of the stem) were placed in 10 ml of cold 80% acetone in a stoppered tube overnight in a refrigerator at 4°C. It was then homogenized and centrifuged at 6000 × g for 15 min. Absorbance of leaf extract was measured on a UV–vis. spectrophotometer (Systronics, model 117, India) at 480 and 510 nm wavelengths for carotenoids and 645 and 663 nm wavelengths for chlorophyll determination. The amount of total chlorophyll and carotenoid were calculated by using the formulae developed by MacLachalan and Zalik (1963) and of Duxbury and Yentsch (1956), respectively. The methods of Keller and Schwager (1977) and Fahey et al. (1978) were used for the extraction and determination of ascorbic acid and total thiol contents, respectively.

![Graph showing age-wise changes in ascorbic acid content of control and sUV-B exposed Triticum aestivum L. (cv. HD 2329 and HUW 234) and Vigna radiata L. (cv. Malviya Jyoti and Malviya Janpriya) cultivars with and without nutrients (bars represent ± 1S.E.).](image-url)
Superoxide dismutase (SOD) activity was measured by the method of Beauchamp and Fridovich (1971). Catalase and peroxidase enzyme activities were determined using the methods of Kar and Mishra (1976) and Britton and Mehley (1955), respectively.

For total biomass, randomly sampled plants were oven dried at 80°C till a constant weight was achieved. Care was also taken to avoid sampling of plants from the edge of treated plots and there were no border rows between the sampled plants.

2.5. Statistical analysis

Differences between control and UV-B exposed plants were determined by DMRT through SPSS software (SPSS Inc., Version 10.0). Multivariate analysis was done to identify significant effects and interactions among plant age, sUV-B and mineral nutrients.

3. Results

3.1. Photosynthetic pigments

Total chlorophyll contents reduced in wheat and mung bean cultivars after exposure to sUV-B irradiation except at 75 DAS in wheat cultivar grown without fertilizers. In fact they showed slight increment in the chlorophyll contents. However, nutrient amended and sUV-B exposed plants showed a lower percentage of chlorophyll damage than sUV-B exposed plants grown without additional nutrients as compared to their respective controls except in wheat cultivar HD2329 at 75 DAS and both the cultivars of mung bean at 65 DAS (Fig. 1). Maximum chlorophyll contents were noticed at F1 treatment in both the crop plants at all ages except at 65 DAS in mung bean cultivars. Reductions in chlorophyll contents due to sUV-B were ranged from 10.9 to 31.1% in wheat cultivars and from 5.1 to 23.4% in mung bean cultivars. Mul-
tivariate analysis showed significant effect due to plant age, sUV-B and fertilizer on chlorophyll content in both cultivars of wheat and mung bean except Malviya Janpriya for sUV-B (Table 1). Carotenoid contents were also affected adversely by sUV-B in fertilizer amended and non-amended plants of both cultivars of wheat and mung bean (Fig. 2). Mineral nutrients amended and sUV-B exposed plants showed more carotenoid contents than their respective controls. Analysis of variance showed significant variations in carotenoids due to plant age, sUV-B and fertilizer dose of both cultivars of wheat and mung bean except cultivar Malviya Jyoti for sUV-B (Table 1).

3.2. Metabolites

Foliar ascorbic acid contents increased at successive growth stages of both the crops. Application of mineral nutrients increased ascorbic acid contents in all cultivars at all plant ages (Fig. 3). Exposure to sUV-B irradiation resulted in decrease of ascorbic acid contents in both wheat and mung bean cultivars at all sampling dates. Percent decreases of ascorbic acid contents were less in fertilizer amended and sUV-B treated plants. Maximum decrease in ascorbic acid contents was found in mung bean cultivar Malviya Janpriya at 45 DAS in fertilizer amended (15.1%) and non-amended

![Graph showing changes in superoxide dismutase activity](image)

Fig. 5. Age wise changes in superoxide dismutase of control and sUV-B exposed *Triticum aestivum* L. (cv. HD 2329 and HUW 234) and *Vigna radiata* L (cv. Malviya Jyoti and Malviya Janpriya) cultivars with and without nutrients (bars represent ± 1 S.E.).
3.3. Enzyme activity

Activity of peroxidase and SOD increased, while catalase activity decreased in sUV-B exposed cultivars of wheat and mung bean plants. Maximum increase in SOD activity due to sUV-B was observed in fertilizer amendment plants (Fig. 5). Catalase activity was higher in mineral nutrient amended plants as compared to the control ones ($F_0$) at all the plant ages. Minimum activity of catalase was observed in mung bean cultivar Malviya Janpriya at 25 DAS and wheat cultivar HD2329 at 75 DAS at $F_0T$ treatment (0.014 μM H$_2$O$_2$ decomposed min$^{-1}$ g$^{-1}$ fresh leaf) (Fig. 6). Maximum peroxidase activity was found at $F_1T$ treatment in all the cultivars (Fig. 7). Analysis of variance for catalase and peroxidase activity showed significant variations in both cultivars of
wheat and mung bean due to plant age, UV-B treatment and fertilizer dose (Table 2). In the present study a clear cut antagonistic interaction was observed between nutrients and sUV-B as ample nutrients supply compensate for/or protect themselves from physiological and biochemical effects of sUV-B.

3.4. Biomass

Biomass of both cultivars of wheat and mung bean increased with successive growth stages. Application of mineral nutrients also increased biomass of the plants at each stage of growth (Fig. 8). All plants were negatively influenced by the treatment with sUV-B, but inhibition in biomass accumulation was less in nutrients applied plants than their respective controls (plants grown without recommended dose of nutrients). Mung bean cultivar Malviya Janpriya showed higher sensitivity to sUV-B, showing maximum reduction in biomass Variations in biomass were significant due to plant age, UV-B treatment, fertility level and interactions between plant age × sUV-B and plant age × fertility levels in both wheat and mung bean cultivars (Table 2). The results clearly showed that better nutrient availability may reduce the potential damage caused by sUV-B, indicating strong interactions between the treatments.

4. Discussion

Results of the present investigation showed a negative influence of sUV-B radiation on photosynthetic pigments and
broadleaf plants after 60 days of UV-B exposure. Contrary to this, a 27% reduction in carotenoid content in A. thaliana exposed to UV-B was not significant, showing adaptation of cultivars to UV-B. Ambasht and Agrawal (1998) reported a 25% reduction in carotenoid content in primary leaves of barley after exposure to UV-B. Liu et al. (1995) reported increased reduction was non-significant showing adaptation of cultivars to sUV-B radiation. Liu et al. (1995) reported increased turnover of glutathione due to sUV-B. Thiol content in all the cultivars after sUV-B exposure resulted in an increase of chlorophyll content in both UV-B exposed and unexposed plants, which may be due to availability of higher N for synthesis of pigments. N limitation reduced chlorophyll content (Rousseau and Reid, 1990). Carotenoids protect chlorophyll from photodestruction, thus reduction in carotenoids could have serious consequences for UV-B radiation effects on chlorophyll pigments. In the present investigation, significant reduction of carotenoids was observed only at early age, but afterwards reduction was non-significant showing adaptation of cultivars to sUV-B radiation. Liu et al. (1995) reported increased carotenoid content in primary leaves of barley after exposure to UV-B. Ambasht and Agrawal (1998), however, reported a 27% reduction in carotenoid content in Sorghum vulgare plants after 60 days of UV-B exposure. Contrary to this, increment in carotenoid content may represent a biochemical response to alleviate UV-B stress because of its role in the photoprotection of the photosynthetic system by dissipating excess excitation energy through the xanthophylls cycle (Demmig-Adams and Adams, 1992). Higher concentration of carotenoids was found in both sUV-B exposed and unexposed plants under elevated mineral nutrients.

Ascorbate is a major primary antioxidant, reacting directly with hydroxyl radicals, superoxide and singlet oxygen, and is also a powerful secondary antioxidant, reducing the oxidized form of tocopherol. Increase of foliar ascorbic acid concentration in sUV-B exposed plants suggested a defense strategy of cultivars to sUV-B stress. The destruction of H2O2 is the important function of the plant peroxidases that use ascorbic acid as a hydrogen donor. Increment in peroxidase activity along with ascorbic acid content suggested a higher potential of H2O2 destruction vis-a-vis greater protection to the plants.

Carotenoids protect chlorophyll from photodestruction, thus reduction in carotenoids could have serious consequences for UV-B radiation effects on chlorophyll pigments. In the present investigation, significant reduction of carotenoids was observed only at early age, but afterwards reduction was non-significant showing adaptation of cultivars to sUV-B radiation. Liu et al. (1995) reported increased carotenoid content in primary leaves of barley after exposure to UV-B. Ambasht and Agrawal (1998), however, reported a 27% reduction in carotenoid content in Sorghum vulgare plants after 60 days of UV-B exposure. Contrary to this, increment in carotenoid content may represent a biochemical response to alleviate UV-B stress because of its role in the photoprotection of the photosynthetic system by dissipating excess excitation energy through the xanthophylls cycle (Demmig-Adams and Adams, 1992). Higher concentration of carotenoids was found in both sUV-B exposed and unexposed plants under elevated mineral nutrients.

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Increase of thiol content in all the cultivars after sUV-B exposure was observed in the present study. Ascorbate and glutathione are closely related, since both are constituents of the antioxidative ascorbate-glutathione cycle, which detoxifies hydrogen peroxide through a series of enzyme reactions. Galatro et al. (2001) reported increased thiol content in soybean leaves with increasing UV-B intensity. Massi et al. (2002) also reported increased levels of cysteinyl-glycine (low molecular weight thiol) in maize, which is a possible degradation product of glutathione, pointing towards an increased turnover of glutathione due to sUV-B.

Superoxide dismutase, peroxidase and catalase are key enzymes of the antioxidant defense system. SOD accelerates the conversion of superoxide to hydrogen peroxide, while catalase and peroxidase catalyse H2O2 breakdown. In the present investigation, activities of SOD and peroxidase increased, while catalase decreased. Activation of enzymes

**Table 2**

F-ratios and levels of significance of three way ANOVA test for metabolites and biomass of Triticum aestivum L. (cv. HD 2329 and HUW 234) and Vigna radiata L. (cv. Malviya Jyoti and Malviya Janpriya) plants

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<tr>
<th>Cultivars</th>
<th>Parameters</th>
<th>Factor</th>
<th>Plant age (A)</th>
<th>UV-B treatment (T)</th>
<th>Fertilizer dose (F)</th>
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<td>Superoxide dismutase</td>
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<td>10.56 *</td>
<td>7.23 *</td>
<td>0.33 NS</td>
<td>0.52 NS</td>
<td>0.14 NS</td>
<td>0.01 NS</td>
<td>0.01 NS</td>
</tr>
<tr>
<td></td>
<td>Catalase activity</td>
<td>687.62 ***</td>
<td>69.62 ***</td>
<td>64.62 ***</td>
<td>0.93 NS</td>
<td>2.69 NS</td>
<td>2.59 NS</td>
<td>0.13 NS</td>
<td>0.13 NS</td>
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<tr>
<td></td>
<td>Peroxidase activity</td>
<td>429.56 ***</td>
<td>456.58 ***</td>
<td>129.71 ***</td>
<td>26.69 ***</td>
<td>53.82 ***</td>
<td>4.25</td>
<td>3.89</td>
<td>3.89</td>
</tr>
<tr>
<td></td>
<td>Total biomass</td>
<td>947.79 ***</td>
<td>13.65 ***</td>
<td>222.24 ***</td>
<td>8.51 **</td>
<td>126.12 ***</td>
<td>0.03 NS</td>
<td>0.02 NS</td>
<td>0.02 NS</td>
</tr>
<tr>
<td>Malviya Jyoti</td>
<td>Superoxide dismutase</td>
<td>39.6 ***</td>
<td>172.13 ***</td>
<td>38.29 ***</td>
<td>3.18 NS</td>
<td>0.95 NS</td>
<td>5.77</td>
<td>0.46 NS</td>
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<td></td>
<td>Catalase activity</td>
<td>26.41 ***</td>
<td>16.88 ***</td>
<td>151.95 ***</td>
<td>0.04 NS</td>
<td>0.31 NS</td>
<td>2.23 NS</td>
<td>0.04 NS</td>
<td>0.04 NS</td>
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<tr>
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<td>Peroxidase activity</td>
<td>410.73 ***</td>
<td>178.94 ***</td>
<td>99.1 ***</td>
<td>14.54 ***</td>
<td>4.09</td>
<td>7.84</td>
<td>1.38 NS</td>
<td>1.38 NS</td>
</tr>
<tr>
<td></td>
<td>Total biomass</td>
<td>1050.6 ***</td>
<td>69.67 ***</td>
<td>107.04 ***</td>
<td>31.21 ***</td>
<td>34.87 ***</td>
<td>1.89 NS</td>
<td>0.70 NS</td>
<td>0.70 NS</td>
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<td>Malviya Janpriya</td>
<td>Superoxide dismutase</td>
<td>8.13 ***</td>
<td>48.06 ***</td>
<td>0.89 NS</td>
<td>0.62 NS</td>
<td>0.10 NS</td>
<td>3.29 NS</td>
<td>0.03 NS</td>
<td>0.03 NS</td>
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<tr>
<td></td>
<td>Catalase activity</td>
<td>91.45 ***</td>
<td>15.56 ***</td>
<td>70.62 ***</td>
<td>0.21 NS</td>
<td>0.56 NS</td>
<td>2.38 NS</td>
<td>0.09 NS</td>
<td>0.09 NS</td>
</tr>
<tr>
<td></td>
<td>Peroxidase activity</td>
<td>96.8 ***</td>
<td>120.71 ***</td>
<td>136.03 ***</td>
<td>0.88 NS</td>
<td>4.46</td>
<td>20.82 ***</td>
<td>0.34 NS</td>
<td>0.34 NS</td>
</tr>
<tr>
<td></td>
<td>Total biomass</td>
<td>370.64 ***</td>
<td>20.89 ***</td>
<td>21.92 ***</td>
<td>17.18 ***</td>
<td>16.63 ***</td>
<td>0.23 NS</td>
<td>0.21 NS</td>
<td>0.21 NS</td>
</tr>
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</table>

NS: not significant.
* Significant at p < 0.05.
** Significant at p < 0.01.
*** Significant at p < 0.001.
was more in wheat as compared to mung bean cultivars, suggesting a strong antioxidative scavenging capability of the former. Costa et al. (2002), however found reduction in SOD activity leading to $O_2^{•−}$ accumulation, which therefore could be responsible for decrease of chlorophyll in sUV-B exposed sunflower cotyledons. Inhibition of catalase activity may also be ascribed to enzyme consumption to detoxify $H_2O_2$ or enzyme inactivation (Ambasht and Agrawal, 2003). Similar findings were also reported by Agrawal (2002) in *Vicia faba*. Alexieva et al. (2001) reported increments of catalase and peroxidase activities in pea plants upon UV-B exposure while increase of catalase and decrease of peroxidase activity was observed for wheat plants.

Though, the antioxidant defense system was activated in all the cultivars, reductions in biomass were observed in all cultivars due to sUV-B exposure. Change in biomass accumulation is an important measure to assess sUV-B sensitivity, since this parameter reflects the cumulative effect of many small disruptions in plant function. Reduction in biomass due to sUV-B was of lower magnitude in plants supplemented with mineral nutrients. Musil and Wand (1994) found similar results for the winter ephemeral *Dimorphotheca pluvialis* during the early developmental stage upon UV-B exposure. However, interaction between nutrient availability and UV-B was not present in mature leaves. The present investigation showed more damaging effect of sUV-B on biomass of mung
bean cultivar Malviya Janpriya suggesting its higher sensitivity to sUVR. However, this cultivar did not show the highest decline in chlorophyll content. Ghisi et al. (2002) also found reduced fresh and dry weights of UV-B exposed barley plants, but the reduction was not correlated with decline in photosynthesis rate. Quaggiotti et al. (2004) observed no difference in biomass, while Ambasht and Agrawal (1995) found higher biomass in UV-B treated Zea mays as compared to their respective controls. Teramura et al. (1991) showed significant reduction in total biomass in 6 out of 16 rice cultivars screened for UV-B sensitivity.

The activation of the free radical scavenging system due to sUVR highlighted the differential role of each component in the UV-B stress acclimation process in wheat and mung bean cultivars. This coordinated defense mechanism helped the plants to recover in terms of growth after stress cycle. sUVR stress showed an increase in tested enzymes along with total thiols and ascorbic acid. Further, these antioxidants increased with application of nutrients, increasing the resistance of both cultivars. Lavola et al. (2003) revealed that high nutrient availability increases the resources in seedlings and thereby, the growth and the investment for protection would be greater under the high nutrient than moderate nutrient level.

5. Conclusion

Wheat cultivars HD 2329 and HUW 234 and mung bean cultivars Malviya Jyoti and Malviya Janpriya are sensitive to sUVR. Inter- and intra-specific variations were present in tested cultivars in response to sUVR radiation and it was well correlated with free radical scavenging capacity of tested cultivars. However, adaptations or acclimation to photooxidative stress is multifactorial and many factors are involved in the overall defense strategy of the plants. Application of recommended dose of mineral nutrients showed significant positive response by ameliorating the negative effects of sUVR radiation by increasing the levels of antioxidants. To understand the exact mechanism of tolerance more detailed investigations are required under field conditions on growth, physiological and biochemical responses and genetic control to sUVR radiation.

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References


