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Effects of UV-Radiation on Photosynthetic Pigments and UV Absorbing Compounds in *Capsicum longum* (L.)

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Abstract: The objective of this study was to evaluate the effects of UV radiation on photosynthetic pigments and UV absorbing compounds of pepper plants (*Capsicum longum* L.) in the greenhouse. Pepper plants were grown in a uniform environment and after 35 days they were exposed to UV-A and UV-C radiation for 15 and 8 days, respectively. Changes in photosynthetic pigments, chlorophyll and carotenoids and UV absorbing compounds, flavonoids and anthocyanins were measured. In this study it was found that the content of Chl-a and Chl-b slightly decreased in UV-R exposed plants and although this reduction was not significant, the total chlorophyll (Chl-T) amount decreased significantly especially in UV-C exposed plants. Carotenoids concentration was also reduced in UV-R exposed plants and this reduction was significant in UV-C exposed plants. UV absorbing compounds were increased. Concentration of flavonoids was significantly increased in both UV-A and UV-C treatments. Although anthocyanin concentration was also increased in UV-R exposed plants, this rise was not significant. UV-C radiation significantly reduced number of leaves per plant, but no significant effect was found on leaf numbers of UV-A treated plants. The fresh weight was significantly decreased in shoot of UV-C treated plants but there was no significant change in fresh weight in UV-A treated plants. In the root of UV-R treated plants no significant changes were observed in fresh weight.

Key words: Anthocyanin, *Capsicum longum* L., carotenoids, chlorophyll, flavonoids, UV-radiation

INTRODUCTION

Ultraviolet radiation (UVR) is the part of the non-ionizing region of the electromagnetic spectrum which comprises approximately 8-9% of the total solar radiation (Frederick, 1993). UV is traditionally divided into three wavelengths: UV-C (200-280 nm) is extremely harmful to living organisms, but not relevant under natural conditions of solar irradiation; UV-B (280-320 nm) is of particular interest because although this wavelength represents only approximately 1.5% of the total spectrum, but can induce a variety of damaging effects in plants; UV-A (320-400 nm) represents approximately 6.3% of the incoming solar radiation and is the least hazardous part of UV radiation (Hollosy, 2002).

Projections indicate that solar ultraviolet-B (UV-B) radiation will reach peak levels on the earth's surface in the next few years (Kakani *et al*., 2003). However, it is expected that UV-B radiation could fall to pre-ozone depletion levels by 2050 if the Montreal protocol were fully implemented by the member countries (Van der Leun *et al*., 1998).

UV radiation is readily absorbed by biomolecules such as amino acids, polypeptides and nucleic acids (Hollosy, 2002). Enhanced UV radiation causes a significant reduction in plant growth and photosynthetic capacity (Ziska *et al*., 1993; Teramura and Sullivan, 1994) and pigment levels (Strid and Porra, 1992; Sullivan and Rozema, 1999).

Increased UV radiation has also been shown to alter the biotic relationships of higher plants as demonstrated by the changes in plant disease susceptibility and the balance of competition between plant species. The influence of UV on growth appears to be mediated by phytohormones, either through photodestruction or enzymatic reactions. Overall, the effectiveness of UV varies both among species and among cultivars of a given species. Of those plants which have been tested, a large proportion exhibit reduced plant growth (plant height, dry weight, leaf area, etc.), photosynthetic activity and flowering. Photosynthetic activity may be reduced by direct effects on the photosynthetic process or metabolic pathways, or indirectly through effects on photosynthetic pigments or stomatal function. Plants sensitive to UV may also respond by accumulating UV-absorbing compounds in their outer tissue layers, which presumably protect sensitive targets from UV damage. The key enzymes in biosynthetic pathways of these compounds have been shown to be specifically induced by UV irradiation via gene activation (Teramura *et al*., 1991).

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UV radiation above ambient may inhibit plant growth, development and reproduction and depress photosynthesis (Teramura and Sullivan, 1994; Rozema *et al*., 1997; Jansen *et al*., 1998). However, plant sensitivity to UV differs between species and even varieties (Reed *et al*., 1992; Barnes *et al*., 1993; Correia *et al*., 1998). It is modified by plant growth rate (Eichhorn *et al*., 1993), growth form (herbs cf. trees) and functional type (Gwynn-Jones *et al*., 1999). Also, air temperature (Mark and Tevini, 1997), atmospheric carbon dioxide concentrations (Sullivan, 1997) and soil nitrogen (Hunt and McNeil, 1998; Correia *et al*., 2000) and moisture (Sullivan and Teramura, 1990) contents may affect plant sensitivity to UV (Musil *et al*., 2002).

The aim of the present study was to screen a variety of parameters, considered to play an important role in plant protection against UV radiation, to get an encompassing view of the way that important crop plants stands when exposed to enhanced levels of UV radiation. We have analyzed changes in chlorophyll and carotenoid pigments, flavonoids and anthocyanin contents, in pepper exposed to UV radiation. The number of leaves and fresh weight of shoot and root was also measured.

MATERIALS AND METHODS

Plant material: This study was conducted in biology Department of Urmia University during June and July 2007. Red pepper, *Capsicum longum* L., commonly called chili, is a member of the Solanaceae family. Seeds of chili (obtained from Artan Co., Iran) were sterilized with 10% sodium hypochlorite for 10 min then soaked in distilled water. The percentage of germination was about 90%.

The soil used for pots was obtained from a field and mixed with sand (1:5 v/v). The mixture was autoclaved before use, at 121°C for 4 h. The germinated seeds were grown in 45 pots measuring 20 cm in diameter in greenhouse. After 35 days of growing in a uniform condition they were divided into three sets, one set served as control, 2nd set received UV-C radiation, which was produced by a UV-C germicidal lamp (TUV/G30T8-Philips, Holland) that provided an irradiation dose of approximately 17.2 kJ m^{-2} day^{-1} for 8 days and 3rd set exposed to UV-A radiation which was produced by two insecticide UV-A lamps (F20T9/BL-Hitachi, Japan) that produced an irradiation dose of approximately 18.9 kJ m^{-2} day^{-1} for 15 days.

Plants were grown at 35/26°C (day/night) under 14 h light and 10 h dark periods and were alternately watered with half strength Hoagland's solution and distilled water.

Flavonoids assays: For extraction of flavonoids, 0.1 g leaf material was ground in 10 mL methanol then 1 mL of extract added to 1 mL of Aluminium trichloride ($AlCl_3$) 2% in ethanol. The volume of extract was reached to 25 mL by adding ethanol. After centrifugation at 3000 x g for 10 min, the absorbance of the supernatant was recorded at three wavelengths: 270, 300 and 330 nm (Markantonuts *et al*., 1993).

Pigment assays: For analysis of chlorophyll and carotenoid contents 0.1 g leaf material was ground in 2 mL acetone 80% then extract was centrifuged at 2700 x g for 10 min. The absorbance of the supernatant was recorded at three wavelengths: 663, 647 and 470 nm by spectrophotometer (Lichtenthaler and Wellburn, 1983).

Anthocyanin assay: For analysis of anthocyanin amount, 0.1 g leaf material was ground in 10 mL acidified methanol (99 methanol and 1% HCl by volume). Samples were then centrifuged at 6000 x g for 10 min and the supernatant of each sample incubated in the dark at room temperature for 24 h. Samples were then pipetted into spectrophotometer cuvette and the absorbance was recorded at 550 nm (Fulcki and Francis, 1968).

Statistical analyses: Values presented in the text indicate mean values ±SEM of three separate experiments. The significance of differences between control with UV-C and UV-A exposed material was analyzed using the Tukey MRT for comparison of means at the level of significance of $p<0.05$.

RESULTS AND DISCUSSION

Leaf pigments: The content of chlorophyll-a (Chl-a) and chlorophyll-b (Chl-b) slightly decreased in UV-R exposed plants and this reduction was not significant, but the total chlorophyll (Chl-T) amount decreased more noticeably and it was significant in UV-C exposed plants (Table 1). It has been reported that the effect of UV-R on Chl a/b ratios varies among growth conditions and species (Hollosy, 2002). Carotenoids concentration was also reduced in UV-R exposed plants and this reduction was significant in UV-C exposed plants (Table 2). Total chlorophyll and carotenoid concentration reduction has been reported in

Table 1: Mean±SE of Chl-a, Chl-b and Chl-T amount (μg g^{-1} FW) in plants exposed to UV radiation in comparison with the control

Treatments	Chl-a	Chl-b	Chl-T
Control	4.307±0.14d	8.123±0.05c	12.43±0.15a
UV-A	4.257±0.17d	7.987±0.14c	12.36±0.12ab
UV-C	3.193±1.10d	7.96±0.22c	11.87±0.31b

Means followed by the same letter are not significantly different; Tukey Multiple Range Test at p = 0.05

Table 2: Mean±SE of carotenoids amount (μg g^{-1} FW) in plants exposed to UV radiation in comparison with the control

Treatment	Amount
Control	2.043±0.018a
UV-A	1.993±0.024a
UV-C	1.903±0.018b

Means followed by the same letter are not significantly different; Tukey Multiple Range Test at p = 0.05

Arabidopsis which were exposed to UV-R (Jenkins *et al*., 1997). It has been observed that the concentration of chl-a has increased after UV exposure in the red alga *Palmaria decipiens* (Poppe *et al*., 2002). No significant differences have been detected in total chlorophyll concentration in bean plants (Antonelli *et al*., 1997) and potato (Santos *et al*., 2004) that were exposed to supplemental UV radiation. It has been also reported that the concentration of chl-a and chl-b has been significantly decreased in *Barleria obtusa* and *Vigna unguiculata* plants that were exposed to UV radiation (Musil *et al*., 2002). This is attributed to increased photo-degradation of chlorophylls (Strid and Porra, 1992) and lower rates of chlorophyll synthesis resulting from reduced expression of genes encoding chlorophyll-binding proteins (Strid *et al*., 1994) or to breakdown of structural integrity of chloroplasts (Cassi-Lit *et al*., 1997; He *et al*., 1994; Tevini *et al*., 1991). Concentrations of carotenoids has been significantly ($p<0.01$) increased in leaves of two species, the *Colophospermum mopane* tree ecotypes alba and leslie and in the shrub *Phylica pubescens* (Musil *et al*., 2002). These may represent a biochemical response to alleviate UV stress since carotenoids function in the photo-protection of photosynthetic systems by dissipating excess excitation energy through the xanthophyll cycle (Demmig-Adams and Adams, 1992).

UV absorbing compounds: In this study we found that exposure to UV radiation caused an increase in the UV absorbing compounds. Concentration of flavonoids has been significantly increased in both UV-A and UV-C treatments in comparison with the control (Table 3). Anthocyanin concentration has also been increased in UV-R exposed plants, but this rise was not significant (Table 4). There is evidence that flavonoids reduce damage from UV radiation because they act as UV filters, reducing the penetration of potentially damaging UV radiation. Mutants of *Arabidopsis* lacking flavonoid production are hypersensitive to UV radiation whereas an *Arabidopsis* mutant possessing constitutive elevated accumulation of flavonoids and other phenolics is tolerant to lethal UV level (Bieza and Lois, 2001; Li *et al*., 1993). Plant capability to accumulate UV absorbing compounds and the readiness of this accumulation has been correlated with UV tolerance (Gonzalez *et al*., 1998). Flavonoids strongly absorb light in the range of 220-380 nm and are known to be photostable (Stapleton

Table 3: Mean±SE of flavonoid absorbance in plants exposed to UV radiation in comparison with the control

Treatment	270 nm	300 nm	330 nm
Control	0.267±0.014g	0.271±01.0f	0.279±0.007e
UV-A	0.278±0.007e	0.288±0.018d	0.299±0.01c
UV-C	0.314±0.01b	0.317±0.011a	0.319±0.006a

Table 4: Mean±SE of shoot anthocyanin content (μM g^{-1} FW) under UV treatment

Treatment	Content
Control	3.747±0.165a
UV-A	3.930±0.09a
UV-D	4.257±0.136a

Means followed by the same letter(s) are not significantly different; Tukey Multiple Range Test at p = 0.05

and Walbot, 1994). Pigments that absorb UV radiation strongly are considered to play a major role in protecting plants from UV damage. It has been reported that flavonoid and anthocyanin concentrations of pea plants subjected to UV radiation was increased. Anthocyanin was also significantly increased by UV radiation in these plants (Nogués *et al*., 1998). It has been reported that cotton plants were not sensitive to UV levels at optimum temperatures but were more sensitive to UV radiation at both low and high temperatures as indicated by the increase in UV absorbing compounds (Reddy *et al*., 2004). In *Impatiens capensis* it has been observed that exposure to UV radiation stimulated the production of both anthocyanins and flavonoids. Anthocyanins induced by the UV exposure appear to be a response to stressful growth conditions, rather than an adaptive response (Dixon, *et al*., 2001). In potato plants it has been shown that UV exposure caused accumulation of constitutive flavonoids and the induction of two new flavonoid types (Santos *et al*., 2004). It has been reported that flavonoid concentrations were significantly ($p<0.01$) altered in leaves of three species *Colophospermum mopane* tree ecotypes alba, chota and ovifolia and the herb *Glycine max* had increased concentrations and the shrub *Hermania saccilifera* had a decreased flavonoid concentration (Musil *et al*., 2002). Plants sensitive to UV may also respond by accumulating UV-absorbing compounds in their outer tissue layers, which presumably protect sensitive targets from UV damage. The key enzymes in biosynthetic pathways of these compounds have been shown to be specifically induced by UV irradiation via gene activation (Teramura *et al*., 1991).

Leaf numbers: UV-C radiation significantly reduced number of leaves per plant, but no significant effect was found on leaf numbers of UV-A exposed plants (Table 5). It has been reported that in pea plants (Nogués *et al*., 1998) and cotton (Kakani *et al*., 2003) UV radiation did not significantly affect the number of leaves, but in *Impatiens capensis* (Dixon, *et al*., 2001) the reduction of node numbers has been observed.

Table 5: Mean±SE of leaf number in plants exposed to UV radiation as compared with the control

Treatment	Leaf No.
Control	13.00±0.577a
UV-A	12.67.0±0.333a
UV-C	10.67±0.333b

Table 6: Mean±SE of fresh weight of root and shoot (g^{-1} plant) in plants exposed to UV radiation as compared with the control

Treatment	Root	Shoot
Control	4.157±0.265a	0.387±0.002c
UV-A	3.853±0.139a	0.385±0.007c
UV-C	1.437±0.27a	0.251±0.007c

Means followed by the same letter(s) are not significantly different; Tukey Multiple Range Test at p = 0.05

Biomass: The fresh weight was significantly decreased in shoot of UV-C treated plants but in UV-A treated plants there was no significant change in fresh weight. In the root of UV-R treated plants no significant changes were observed in fresh weight (Table 6). In bean plants (Antonelli *et al*., 1997) and *Impatiens capensis* (Dixon *et al*., 2001) also it has been shown that UV radiation exposure caused the reduction of biomass.

CONCLUSION

The study shows that pepper plants are sensitive to UV-R and this finding give an insight into the physiological changes during UV exposure and indicate the sensitivity of these plants to UV-C more than UV-A radiation.

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