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Rev. sci. tech. Off. int. Epiz., 2014, **33** (1s), 10-19

Different UV radiation-induced changes in antioxidant defense system in okra

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Summary
In this paper okra plants were treated by different UV radiation, UV-A, UV-B and UV-C, for 12 days and effects of different UV radiation on activities of antioxidant enzymes including superoxide dismutase (EC. 1.15.1.1, SOD), ascorbate peroxidase (EC 1.11.1.11, APX), guaiacol peroxidase (EC 1.11.1.7, GPX), catalase (EC 1.11.1.6, CAT), and glutathione reductase (EC 1.6.4.2, GR) in leaves, stems, and roots as well as antioxidant compounds including ascorbic acid (AA), anthocyanin, and flavonoid were examined under controlled conditions. The results show an increase in enzymatic and non-enzymatic antioxidants when plants are exposed to UV-B or UV-C radiation while antioxidant enzymes activities and antioxidant compounds did not significantly increase under the UV-A radiation treatments compared to control plants. Our results suggest that increased level of lipid peroxidation products and antioxidant system activity in the UV-B and UV-C treatments may be considered as biomarkers of intensity of UV radiation stress. However, more research is necessary to elucidate the precise role that the antioxidant system plays under UV radiation stress.

Keywords
Antioxidant compounds- Antioxidant enzymes- Okra- Oxidative stress- Ultraviolet radiation

Abbreviations
AA (Ascorbic acid), GSH (Reduced glutathione), GSSG (Glutathione disulfide), H2O2 (Hydrogen peroxide), MDA (Malondialdehyde), ROS (Reactive oxygen species), TBA (Thiobarbituric acid), TCA (Trichloroacetic acid), NBT (Nitroblue etrazolium), FW (Fresh weight), PAL (Phenylalanine ammonia lyase), DHAS (Dehydroascorbate), POX (Peroxidase), UV (Ultraviolet).

Introduction

Increased UV radiation will influence the growth and metabolism of terrestrial plants due to their need for sunlight for photosynthesis (1). Deleterious effects of natural UV radiation on plants is due to reduced photosynthesis, biomass reduction, decreased protein synthesis, impaired chloroplast function, and damage to DNA (2). Previous studies have shown that high levels of antioxidant enzymes and secondary metabolites can lead to increased stress tolerance in some of plants (3-5). However, some questions have still remained unanswered: Do plants enjoy a defense system to encounter the exerted stress in all UV radiations?; by which mechanism each family or one of its species over comes the stress produced by radiation?; which defense system or compound exhibit the most changes in response to stress?, and which plant compound or defense system could be used as marker in identifying the intensity of UV radiation effects?; Therefore, awareness of the mechanisms involved in response to the stresses exerted on different plants is still particularly important and could contribute greatly to managing the plantation and growing of the plants.

Since few have investigated the effect of different UV radiation on antioxidant enzymes and UV-absorbing pigments of Malvaceae family and okra (*Hibiscus esculentus*) is a member of the Malvaceae family, which is a good source of many nutrients including vitamins, protein, amino acids, minerals, and iodine, the aim of the present study was to investigate the effect of different

artificially enhanced UV radiation on the MDA, H2O2, AA, UV-absorbing pigment contents, and antioxidant enzyme (SOD, CAT, APX, GR, GPX) changes of okra which may become a biomarker for assessing the biological impact on Malvaceae family in response to the UV radiation change.

Material and Methods

For culture conditions and treatments, okra seeds cultivar Clemson Spineless (obtained from Bakker brothers Co., Noord- Scharwoude, Holland) were sterilized with 10% sodium hypochlorite for 10 min and thoroughly washed with distilled water. The sterilized seeds were then germinated in an incubator at 25ºC for 4 days. After germination seven homogeneous seedlings were visually selected and transferred to per pot. The soil used in the pots was obtained from the same form and mixed with sand (1:5 v/v). The mixture was autoclaved for 4 h at 121ºC before use (6). Plants were grown in the greenhouse with diurnal regime of 16 h light at 27-29ºC and 8 h dark at 18-20 ºC, light intensity 150 µmol.m-2.s, and relative humidity 30-40% and were fed with half-strength Hogland solution and distilled water for 4 weeks. The plants were grown in 80 pots and after 28 days of growth they divided into 4 sets of 20 pots. One set served as the control, another set received UV radiation for 12 days. UV-B radiation was applied with two (15 w) UV-B lamps (LF-215 m. 312 nm), UV-A radiation was applied with two insecticide lamps (F20/BL-Hitachi, Japan) and UV-C radiation was applied with a germicidal lamp (TUV/G30T8, Philips, Holland). The biologically effective level of UV-A, UV-B and UV-C radiation were 14.5 kJ m2d-1 , 11.3 kJ m-2d-1and 6 kJ m-2d-1 respectively.

The level of lipid peroxidation products was estimated following the method of Heath and Packer (7). 0.2 g fresh weight was homogenized in 5 ml of 1% (w/v) TCA. The homogenate was centrifuged at 8000 g for 10 min at 4ºC. To 1 ml of the aliquot of supernatant 1 ml of 20% TCA containing 0.5% (w/v) TBA was added. The solution was heated for 30 min at 95ºC and then quickly cooled on ice for 10 min. The samples were recentrifuged at 8000 g for 5 min. The absorbance of supernatant was recorded at 532 nm. The lipid peroxides were expressed as µmol TBARS g–1 FW by an extinction coefficient of 155 mM/cm.

The AA content was assayed as per the method of Omaye et al. (8). 1 g of fresh material was homogenized in 5 ml of 10% TCA. The homogenate was centrifuged at 4000 g for 20 min, reextracted twice, and supernatant made up to 10 ml, and was used for assay. To 1 ml of extract, 2 ml of DTC reagent was added and incubated for 3 h at 37 ºC. Then 0.75 ml of ice cold 65% H2SO4 was added, allowed to stand for 30 min at 30ºC, and then resulting color was recorded at 520 nm. The ascorbic acid content was assayed using a standard curve prepared with AA and the results were expressed in mg g-1 FW.

Enzyme extraction was prepared for assay of SOD (EC. 1.15.1.1, SOD) using method of Dhindsa et al. (9). SOD activity assay was based on the method described per Beauchamp and Fridovich (10). The reaction mixture contained 4 ml 50 mM potassium phosphate buffer (pH 7), containing 0.17 mM nitroblue tetrazolium (NBT) salt in ethanol, 13 mM methionine, 0.007 mM riboflavin, 0.1 mM EDTA, and 1 ml enzyme extract. The mixtures were illuminated in glass test tubes by fluorescent lamps for 45 min at 30ºC, and blanks were kept in the dark. The absorbance was recorded at 560 nm, SOD activity was expressed in units (U mg–1protein). About 1 U of SOD activity was defined as the amount of enzyme quantity to cause 50% inhibition of the rate of NBT reduction in the presence of riboflavin in the light.

Enzyme extraction was prepared for assay of CAT, APX, and GPX using modification method of Kang et al. (11). 0.5 g of fresh tissues was homogenized under ice cold in 6 ml of extraction buffer containing, 50 mM Tris-HCl buffer (pH 7.5), 3 mM MgCl2, 1 mM EDTA, and 1% PVP. The homogenate was centrifuged at 5000 g for 20 min. For APX extraction buffer containing 0.2 mM AA was also used. The supernatant was stored at -80ºC and used for the assay of enzymes activities.

Ascorbate peroxidase assay (EC 1.11.1.11, APX) activity assay was performed according to Asada (12). The reaction mixture contained 2.5 ml phosphate buffer (pH 7) containing 0.1 mM EDTA, 0.5 mM AA, 0.2 ml 1% H2O2 and 0.1 ml enzyme extract in final assay volume of 2.8 ml. The H2O2 dependent oxidation of AA was measured by decrease in the absorption at 290 nm (extinction coefficient 2.8 mM/cm).

Guaiacol peroxidase (EC 1.11.1.7, GPX) activity was measured using a modification procedure of Updhyaya (13). The reaction mixture contained 2.5 ml phosphate buffer (pH 7), 1 ml 1% guaiacol, 1 ml 1% H2O2, and 0.3 ml enzyme extract in final assay volume of 4.8 ml. GPX activity was determined in the homogenates by measuring the increase in absorption at 470 nm (extinction coefficient 26.6 mM/cm).

Catalase (EC 1.11.1.6, CAT) activity was measured according to Aebi (14) by measuring the decrease in absorption at 240 nm in a reaction medium containing 2.5 ml phosphate buffer (pH 7.4), 0.1 ml H2O2 and 0.3 ml enzyme extract in final assay volume of 2.9 ml (extinction coefficient 4.7 mM/cm).

Glutathione reductase (EC 1.6.4.2, GR) activity was measured using modification of the procedure of Foyer and Halliwel (15) by following the decrease in absorption

at 340 nm due to NADPH oxidation. The reaction mixture contained 50 mM phosphate buffer (pH 7) with 2.5 mM MgCl2, 0.5 mM GSSG, 0.2 mM NADPH, and 0.3 ml enzyme extraction in final assay volume of 2.8 ml (extinction coefficient 6.2 mM/cm).

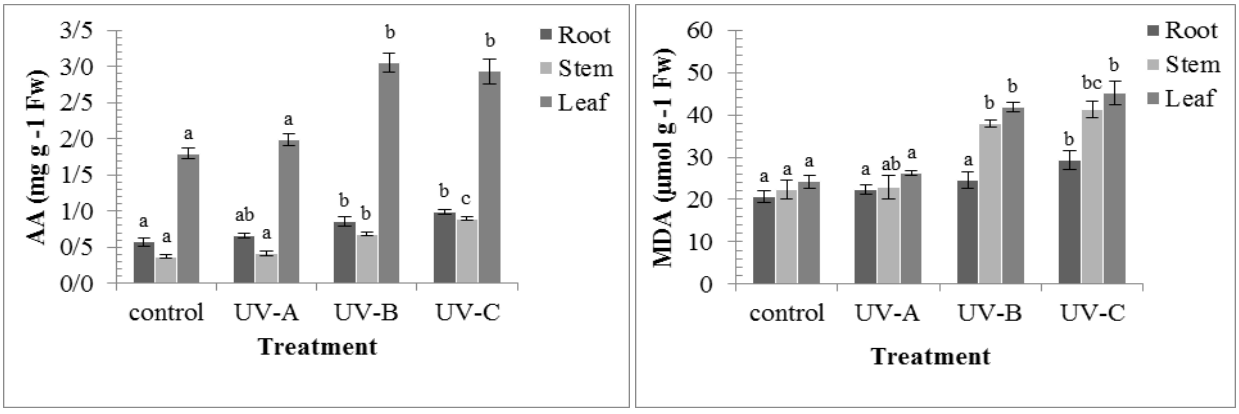
The contents of H2O2 production was measured colorimetrically using the method of Jana and Choudhuri (16). The intensity of yellow color developed was recorded at 410 nm and the amount of H2O2 was calculated using a standard curve prepared with (H2O2) and the results were expressed in µmol (H2O2) g-1 Fw-1.

The anthocyanin content was determined according to the method described by Fulcki and Francis (17). The control and treated leaves (0.1 g) were homogenized in 10 ml of acidified methanol (1:99, HCl: methanol). The homogenate was centrifuged at 6000 g for 10 min. Extract was incubated at room temperature in dark for 24 h. Then, the absorption was read at 550 nm. The total flavonoid content was determined according to the aluminum chloride colorimetric method described by Chang et al. (18). The control and treated leaves (0.1 g) were homogenized in 1 ml deionized water. This solution (0.5 ml) was mixed with 1.5 ml of 95% ethanol, 0.1 ml of 10% aluminum chloride, 0.1 ml of 1 M potassium acetate, and 2.8 ml of deionized water. After incubation at room temperature for 40 min, the reaction mixture absorption was measured at 415 nm. Then the absorbance was read at 415 nm.

For statistical analysis, each value was the mean of four replicate experiments (±SE). The data were statistically analyzed using (ANOVA), followed by Duncan, s multiple range test. Standard error of mean was also calculated for presentation in figures.

Results

UV had a significant effect on AA content in okra plants. In the leaves, stems, and roots of plants treated with UV-B, the AA content significantly increased to respectively 41.31, 44.77, and 32.94% and with UV-C treatment significantly increased to respectively 38.9, 58.42, and 42.4% of the controls. But in the different parts of plants treated with UV-A, AA content increased by 9.59, 9.75, and 12.30%, respectively, not significantly compared to the control plants (Figure 1.a). MDA content in both leaves and stems of the plants treated with UV-B significantly increased by 42.30 and 41.53%, respectively, but in the root of plants treated with UV-B, the MDA content increased by 15.78%, not significantly compared to the control plants. UV-C treatments also increased MDA content in the three parts of the treated plants significantly (46.43, 46.2, and 30% respectively in leaves, stems, and roots), but in UV-A treated plants there was no significant increase (7.4, 3.4 and 7.35% respectively in leaves, stems, and roots in comparison with the controls) (Figure 1.b).

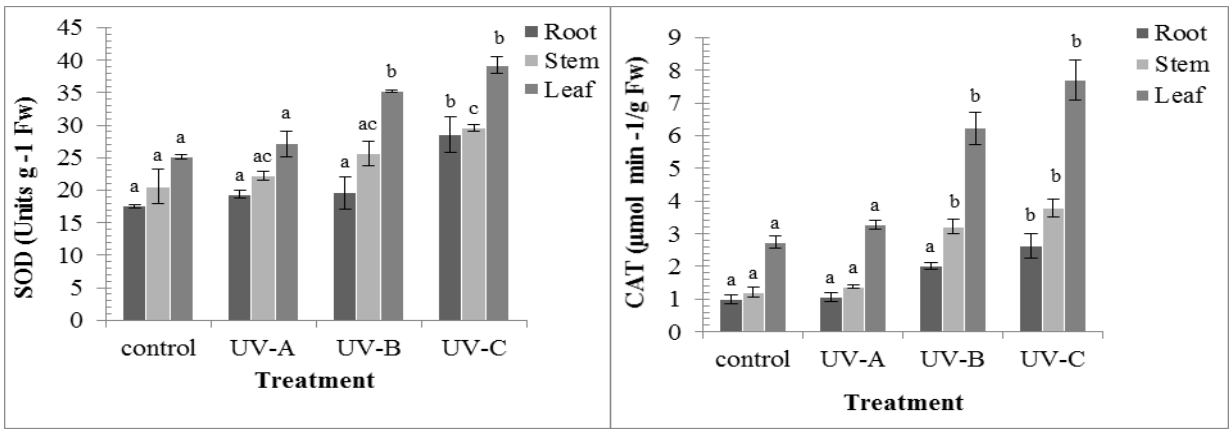


(a) (b)

Fig. 1
Effects of different UV treatments on okra leaves, stems and roots. (a) Ascorbic acid (AA) content, and (b) Lipid peroxidation (MDA) content. (Mean±SE, n = 4), P < 0.05.

Okra plants grown under the UV-A, UV-B, and UV-C treatment showed different enzymatic activities. SOD activity significantly increased in UV-B and UV-C treated leaves by 44.3 and 50.63% respectively. Also, in the stems of SOD activity significantly increased by 37.45 and 47.66%, respectively. But in leaves and stems UV-A treated plants there was no significant increase (13.87 and 7.16% respectively in comparison with the control). In the root of plants treated with UV-C the SOD activity significantly increased by 41.9%, but in the leaf, stem and root of plants treated with UV-A (13.87, 7.17, and 10.38%, respectively) and in the root of UV-B treatment (17.04%) SOD activity did not significantly increase when compared to the control plants (Figure 2.a). CAT activity increased due to UV-B in the leaves, stems, and roots when compared to control (Figure 2.b). Significant

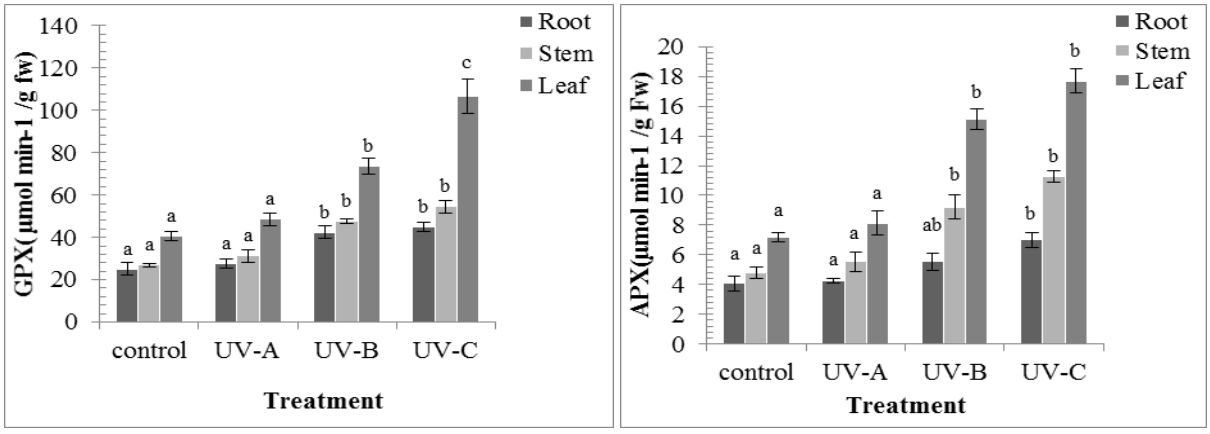
increase (55.1, 63 and 50%) in CAT activity was observed in leaves, stems and root respectively of UV-B treated plant as compared to leaves, stems and roots of control. CAT activity in leaves, stems and roots significantly increased by about 64.38, 67.5, and 62% at UV-C respectively, but no significant changes in CAT activity were observed in the leaves, stems and roots of okra exposed to UV-A treatment while the activities showed increase by about 16.11, 11.5, and 4.9% in respectively leaves, stems and roots when compared to the control plants (Figure 2.b).



(a) (b)

Fig. 2
Effects of different UV treatments on okra leaves, stems and roots. (a) Superoxide dismutase (SOD) activity, and (b) catalase (CAT) activity. (Mean±SE, n = 4), P < 0.05.

Figure 3.a shows changes of APX activity in leaves, stems, and roots of okra plant under different UV treatment. APX activity significantly increased in UV-B and UV-C treated leaves by 44.7 and 62.79%, respectively. APX activity in stems significantly increased by about 43.66 and 50.25% at UV radiation of UV-B and UV-C, respectively. APX activity in roots significantly increased by about 40.8 and 44.22% at UV-B and UV-C, respectively. But no significant changes in APX activity were observed in the leaves, stems and roots of okra exposed to UV-A treatment while the activities showed increase by about 6.7, 13.19, and 9.37%, respectively. Changes in GPX activity of leaves, stems, and roots of okra plants at different UV treatments are shown in figure 3.b. GPX activity increased due to UV-B in the leaves, stems, and roots compared to the control. GPX activity of both leaves and stems of plants treated with UV-B significantly increased by 52.43 and 48%, respectively, but, in the root of plants treated with UV-B, the GPX activity increased by 26.76%, not significant compared to the control plants. UV-C treatments also increased GPX activity in the leaves, stems and roots of the treated plants. Significant increase in UV-C treated okra leaves, stems, and roots (by 76.30, 57.36, and 42.21%, respectively) was observed, but in UV-A treated plants there was no significant increase (by 11.29, 13.26, and 4.48%, respectively) in comparison with the control (Figure 3.b).

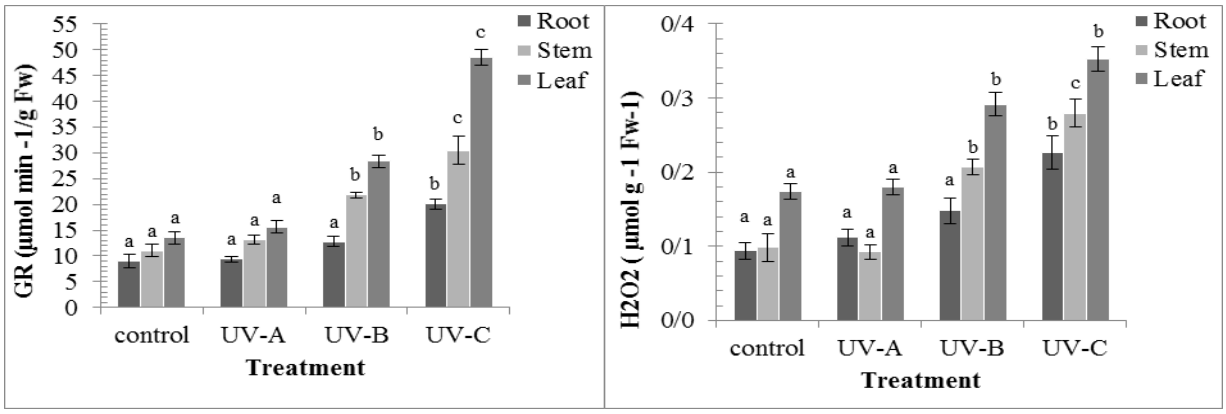


(a) (b)

Fig. 3
Effects of different UV treatments on okra leaves, stems and roots. (a) Ascorbate peroxidase (APX), and (b) guaiacol peroxidase (GPX) activity; (Mean±SE, n = 4), P < 0.05.

GR activity increased during UV radiation treatment in the leaves, stems, and roots of okra plants (Figure 4.a). In the leaves and stems of plants treated with UV-B, the GR activity significantly increased by 52.44 and 49.2%, respectively, but in the roots of plants treated with UV-B, GR activity increased by 29.74%, not significantly compared to the control plants. In the leaves, stems and roots of the plants treated with UV-C, GR activity significantly increased by 72.84, 63, and 55% compared to the control plants (Figure 1.a). But in the leaves, stems, and roots of plants treated with UV-A, GR activity increased by 35.35, 15.81, and 3.64%, respectively, not significant compared to the control plants (Figure 4.a).

Figure 4.b shows that the exposure to UV radiation increased the H2O2 content in the leaves, stems and roots compared to the control plants. H2O2 content significantly increased by 40.52, 51, and 36.05% in respectively leaves, stems, and roots of the UV-B treated plants, and significantly increased by 50.85, 41 and 59.1% of okra leaves, stems, and roots respectively, compared to the control plants. However in the leaves, stems and roots of plants treated with UV-A, H2O2 content increased by 3.88%, 6.2%, and 16.07%, respectively not significant compared to the control plants (Figure 4.b).

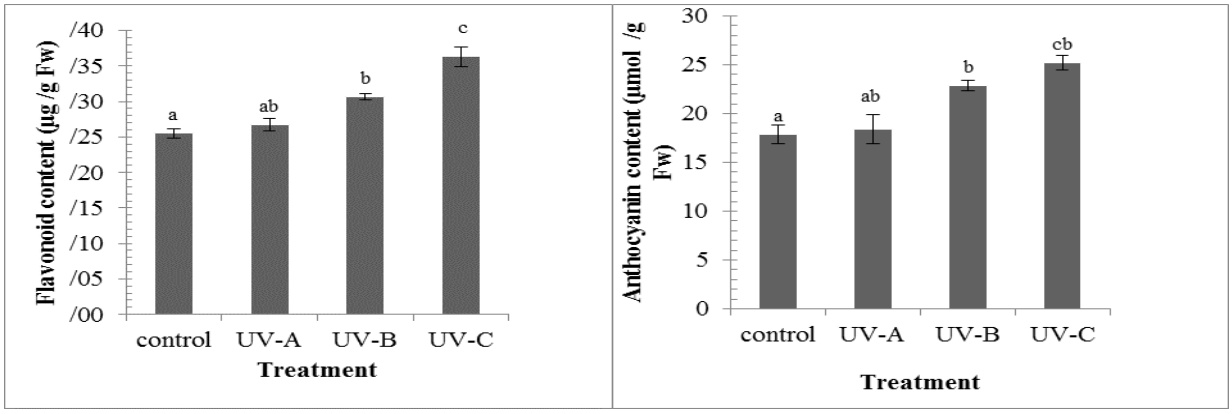


(a) (b)

Fig. 4
Effects of different UV treatments on okra leaves, stems and roots (a) glutathione reductase (GR) activity, and (b) hydrogen peroxide (H2O2) content; (Mean±SE, n = 4), P < 0.05.

Significant changes in total flavonoid contents were observed in the leaves under different UV treatments when compared to the controls. In the leaves of plants treated with UV-B and UV-C, total flavonoid content significantly increased by 16.66 and 30.55%, respectively. However in the leaves of plants treated with UV-A total flavonoid content increased by 3.83%, not significant in comparison with the controls (Figure 5.a).

Results of anthocyanin content are given in figure 5.b. In the leaves of the plants treated with UV-B, the anthocyanin content significantly increased by 21.78% and with UV-C treatment significantly increased by 29.16% compared to the control plants, but in the leaves of the plants treated with UV-A, anthocyanin content increased by 2.82%, not significant when compared to the control plants (Figure 5.b).



(a) (b)

Fig. 5
Effects of different UV treatments on okra leaves, stems and roots (a) flavonoid content (b) anthocyanin content. (Mean±SE, n = 4), P < 0.05.

Discussion

Production of ROSs can be induced by interaction between UV-B radiation, oxygen, and certain organic compounds, such as dissolved organic matter or humic substances (19). SOD converts O2- to H_2O_2 that is then scavenged in coloroplast by a series of oxidation/ reduction reactions known as the halliwell asada pathway, using AA, GSH, and NADPH as electron donors (20). In the present study, the treatment with UV-B and UV-C increased the H2O2 amount in okra plants significantly. Similar increase in concentration of H2O2 was also observed by Agrwal (2007) in Cassia seedlings and by Katerova, (2009) in Pea and Ke–Tang et al. (2010) in peanut seedling, probably as a result of induced superoxide dismutase activity during the treatment (4, 21, 22, 23). The available report indicate that H2O2 could be important as a secondary messenger that induces different defense processes in plants and could play a role in lignin synthesis (24; 25). We can consider that one of the causes of the increase in antioxidant defense system in okra plant is the increase of H2O2 in UV-B and UV-C treated plants. Also, H2O2 might act as a signal molecule to induce different defense systems. Significantly increased concentrations of MDA as an index of lipid oxidation in biological system in the okra plants treated by UV-B and UV-C was in agreement with earlier observations of Agrawal (2007) in Cassia seedlings, Dai et al. (1997) in rice (*Oryza sativa*) leaves, Hernan et al. (2002) in sunflower cotyledons, and Ke–Tang et al. (2010) in peanut seedlings (4, 21, 26, 27). MDA is the product of peroxidation polyunsaturated fatty acid, in particular linolenic acid and is used as indicator of degree of membrane injury and indicates lipid peroxidation level (28). Our results suggest that increase in ROSs in the UV treatment increases MDA content in okra. In this study, the SOD, CAT, APX, GPC and GR activity significantly increased in UV-B and UV-C treated okra plants after a 12 day treatment. Increased SOD activity have also been reported in other plant species in response to UV radiation (4, 21, 22, 29, 30). Also in this study, the total SOD activity in okra treated with different UV illuminations. Moreover, previous studies suggested that increased activity of plant enzymes, such as SOD after the UV radiation was assessed as adaptive response of the plant towards oxidative stress caused by harmful factors (31). Induction of CAT activity after treatment of the plants with different UV radiation has previously been reported (4, 5, 21). Decreased CAT activity in the vtc1 mutants of *A. thaliana* during UV-B treatment has been observed and it might be due to destruction of the peroxisome via increase in lipid peroxidation (32). The APX is one of the important peroxidases in H_2O_2 detoxification, which operate both in cytosol and chloroplasts. In the first step of the ascorbate-glutathione cycle, APX consumed two AA as electron donor to reduce H_2O_2 to H_2O. GR is the key enzyme of the ascorbat-glutation cycle for the removal of H_2O_2 in different cellular compartments and a member of flavoenzyme family which catalyzes the regenerates GSH from GSSG, with NADPH as a source of reducing power (33). This reaction maintains a proper GSH/GSSG concentration ratio in cells (34). Induction of APX enzymes activity after treatment of plants with UV radiation has previously been reported (4, 5). In the present study, UV stress caused an increase in activity of GPX. This enzyme is an important member from peroxidase and is used as a substrate for the measurement of POX activity (35), which is one of the most widely distributed antioxidant enzymes in the plant cells (36). In agreement with our results, have reported that UV-B stress caused an increase in activity of GPX and CAT which have an important role in the control of endogenous H2O2 content. Increased POX activity has also been reported in other plant species in response to UV radiation (27). In this study, the AA and UV absorb compounds (anthocyanin and flavonoid) content significantly increased in UV-B and UV-C treated okra plants after 12 days of treatment. Nasibi et al. (2005) found that DHAS and AA contents of Brassica napus increased after exposure to UV-B and UV-C (37). Observed that the AA deficient A. thaliana sozl mutants were sensitive to oxidative damage caused by exposure to UV-B and sulphur dioxide (38). AA is a substrate for APX enzyme in detoxification of H_2O_2 and has the capacity to directly eliminate several different ROSs including singlet oxygen, superoxide, and hydroxyl radicals. Also AA has a major role in photo protection as a cofactor utilized in xanthophyll cycle (39). As a result, the increase in AA content observed in UV-B and UV-C treated plants might act as an antioxidant compound to reduce oxidative damage in different parts of okra plants. Some plants are more tolerant to UV-B than others because they produce a variety of secondary metabolites that effectively absorb UV radiation and prevent it from penetrating into the leaf mesophyll cells (3). Flavonoids are the most common group of polyphenolic compounds and useful for screening out damaging UV-B radiation (40). For conclusion increase in UV absorbing compounds prevents from penetration of UV radiation to sensitive tissues. UV-B radiation can stimulate key transcripts of PAL in the phenylpropanoid pathway (41, 42). Increase in PAL activity stimulates the synthesis of flavonoid and anthocyanin. The increase in PAL activity in *Phyllanthus amarus* L. and increased synthesis of flavonoid, and anthocyanin have been shown in UV-B treated *A. thaliana* L. seedlings (43), and treated with UV was observed by Indrajith et al. (3). Reported that the flavonoids and anthocyanin had an important role in the solar screens by absorbing UV and preventing penetration of this radiation into sensitive mesophyll tissue (44).

Conclusion

The results show an increase in enzymatic and non-enzymatic antioxidant when plants are exposed to UV-B or UV-C radiation while antioxidant enzymes activities and antioxidant compounds do not significantly increase under the UV-A radiation treatments compared to the control plants. Exposure of the okra plants to UV radiation led to the accumulation of H2O2 in different tissues, which increased antioxidant enzymes activity (SOD, APX, CAT, GR, and GPX) and AA. Flavonoids and anthocyanins might be involved as part of the defenses against UV stress. Therefore, increased level of lipid peroxidation products and anyioxidant system activity may be considered as biomarkers of intensity of UV radiation stress in this species and family.

Les changements induits par les radiations UV différents dans le système de défense antioxydant de gombo

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Résumé

Dans ce document, le gombo plantes ont été traitées par différentes rayonnement UV, UV -A, UV -B et UV- C, pendant 12 jours et les effets des rayons UV sur les différentes activités des enzymes anti-oxydantes, y compris la superoxyde dismutase (EC. 1.15.1.1, SOD), l'ascorbate peroxydase (EC 1.11.1.11, APX), gaïacol peroxydase (EC 1.11.1.7, GPX), la catalase (EC 1.11.1.6, CAT), et la glutathion réductase (EC 1.6.4.2, GR) dans les feuilles, les tiges et les racines, ainsi que des composés antioxydants comprenant l'acide ascorbique (AA), l'anthocyanine, et des flavonoïdes ont été examinées dans des conditions contrôlées. Les résultats montrent une augmentation de l' enzymatiques et non enzymatiques, des anti-oxydants, lorsque les plantes sont exposées à des rayons UV- B ou UV-C tandis que les activités des enzymes anti-oxydantes et les composés antioxydants n'ont pas augmenté de manière significative sous les UV -A des traitements de radiothérapie par rapport aux plantes témoins. Nos résultats suggèrent que l'augmentation du niveau des produits de peroxydation lipidique et l'activité du système anti-oxydant dans les UV-B et UV -C, les traitements peuvent être considérés comme des biomarqueurs d' intensité de contrainte de rayonnement UV. Cependant, plus de recherches sont nécessaires pour élucider le rôle précis que le système antioxydant joue sous le stress de rayonnement UV.

Mots-clés

Antioxydantes des composés antioxydants - enzymes - gombo - oxydatif rayonnement ultraviolet stress

Diferentes UV cambios inducidos por la radiación en el sistema de defensa antioxidante en okra

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Resumen

En este okra papel plantas fueron tratados por diferentes radiación UV, la radiación UV- A, UV - B y UV - C, durante 12 días y los efectos de la radiación UV en diferentes actividades de las enzimas antioxidantes incluyendo la superóxido dismutasa (EC. 1.15.1.1, SOD), ascorbato peroxidasa (1.11.1.11 CE, APX), guayacol peroxidasa (EC 1.11.1.7, GPX), catalasa (EC 1.11.1.6, CAT), y glutatión reductasa (CE 1.6.4.2, GR) en hojas, tallos, y raíces, así como compuestos antioxidantes incluyendo el ácido ascórbico (AA), antocianina, y flavonoide se examinaron bajo condiciones controladas. Los resultados muestran un aumento en enzimáticos y no enzimáticos antioxidantes cuando las plantas están expuestas a los rayos UV - B o la radiación UV - C, mientras que las actividades de las enzimas antioxidantes y compuestos antioxidantes no aumentaron significativamente en virtud de los UV-A tratamientos de radiación en comparación con las plantas de control. Nuestros resultados sugieren que el aumento de nivel de productos de peroxidación de lípidos y la actividad del sistema antioxidante en las UV-B y UV-C tratamientos pueden considerarse como biomarcadores de la intensidad del estrés radiación UV. Sin embargo, se necesita más investigación para dilucidar el papel exacto que el sistema antioxidante juega bajo presión de radiación UV.

Palabras clave

Los compuestos antioxidantes – enzimas antioxidantes – Okra – Estrés oxidativo – La radiación ultravioleta

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