BRIEF COMMUNICATION

Different responses to UV-B enhanced solar radiation in radish and carrot

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Abstract

Radish (*Raphanus sativus* L.) and carrot (*Daucus carota* L.), plants with underground storage organs grown in the field, were exposed to either ambient (UVA) or 20 % UV-B (UVE) enhanced solar radiation till their root yield stage. In radish, UVE produced a significant increase in shoot and root fresh mass (FM), increase in the contents of chlorophyll, carotenoids, flavonoids, and total proteins per unit FM, Hill reaction rate, and root yield. In contrast, carrot responded negatively to UVE showing a loss in the above parameters.

Additional key words. carotenoids; chlorophylls; *Daucus*; fresh and dry mass; Hill reaction; protein; *Raphanus*; root.

UV-B radiation affects many physiological parameters such as CO_2 uptake, photosynthetic electron transport chain, dark respiration, stomatal behaviour, pigment contents, and endogenous content of phytohormones (Tevini and Teramura 1989, Kulandaivelu *et al*. 1991, Nedunchezhian and Kulandaivelu 1991, Šprtová *et al.* 2003, Núñez-Olivera *et al*. 2004). UV-B irradiation reduces the overall photosynthesis and plant growth. Besides several anatomical changes, stunted growth and increase in contents of UV-B absorbing pigments occurs (Murali and Teramura 1986, Tevini *et al*. 1991). The photosynthetic damage is associated primarily with photosystem 2, PS2 (Tevini *et al*. 1991) as well as with disruption of the chloroplast. The information on response to UV-B radiation in crops with underground storage organs is scanty. This is why we compared the effects of UV-B enhanced solar radiation in such plant species differing in response to UV-B radiation.

Certified seeds of *Raphanus sativus* L. and *Daucus carota* L. obtained from the Agriculture Department, Madurai, India were sown in experimental plots in the University Botanical Garden. After an initial growth of up to the first leaf phase, one set of plants continued to grow under ambient solar radiation (UVA) and the other under 20 % UV-B enhanced (UVE) radiation supplemented by *Philips TL 40W/12* sun lamp (*Gloelampenfabrieken*, The Netherlands).

Pigments were extracted in 80 % acetone, and amounts of chlorophyll (Chl) and carotenoids (Car) were determined using the coefficient values of Wellburn and Lichtenthaler (1984). Flavonoids were extracted from leaves following the method of Mirecki and Teramura (1984). The absorbance at 315 nm was expressed as A-units. Estimation of proteins was done according to the method of Lowry *et al*. (1951) using bovine serum albumin as the standard.

Chloroplasts were isolated from fresh leaves by homogenising in semi-frozen isolation medium consisting of 50 mM PO_4 buffer, pH 6.8, 5 mM $MgCl_2$, 10 mM NaCl, and 400 mM sucrose. The homogenate was filtered through 4 layers of cheese cloth and centrifuged at 500×*g* for 30 s. The supernatant was carefully collected and centrifuged at 2 000×*g* for 2 min. The pellet was washed once with the isolation medium and the final pellet suspended in the same medium. All the operations were carried out at 0–2 °C. Hill reaction in the presence of *p*-benzoquinone was measured as O_2 evolution using an O_2 electrode (*Hansatech*, UK) at 25 ˚C. Saturating "white light" of 600 μmol(photon) m^{-2} s^{-1} was provided by a slide protector. The reaction mixture in a total volume of

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Abbreviations: BQ – *p*-benzoquinone; Car – carotenoids; Chl – chlorophyll; DM – dry mass; FM – fresh mass; PS2 – photosystem 2; UV-B – ultraviolet-B (280-320 nm) radiation.
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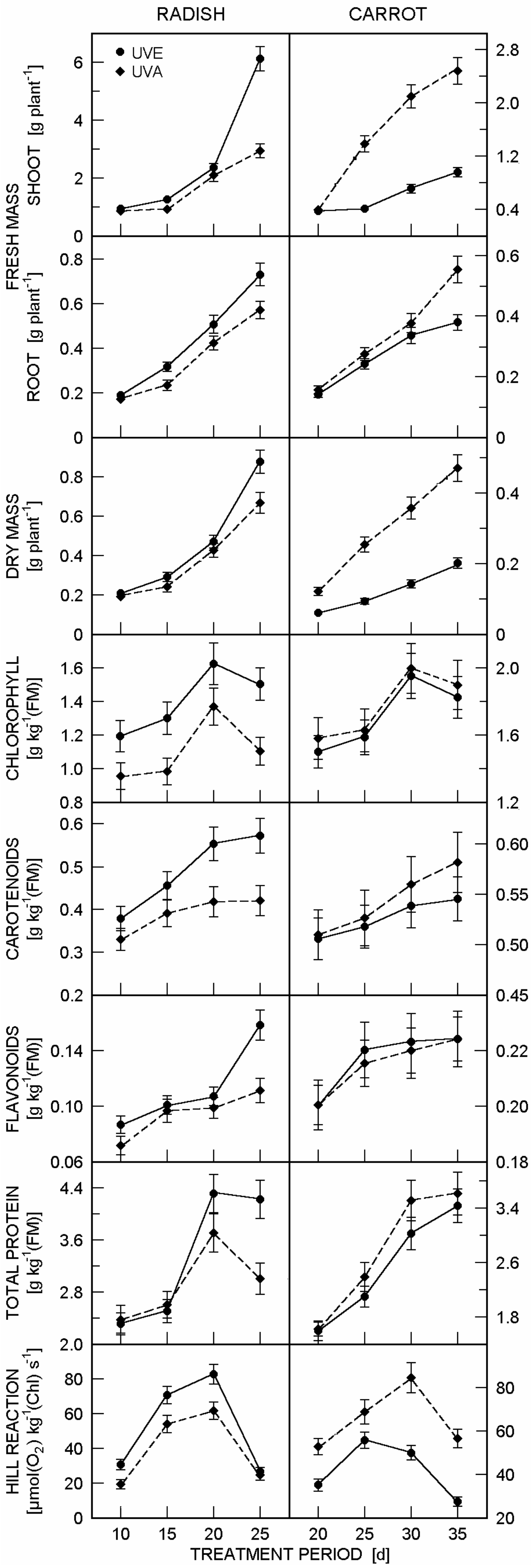

Fig. 1. Changes in the shoot and root fresh and dry masses, contents of chlorophylls, carotenoids, flavonoids, and proteins, and in the rate of Hill reaction of chloroplasts of radish and carrot plants grown under the ambient (UVA) and UV-B enhanced (UVE) solar radiation. Means of 20 plants (FM and DM), 3 (pigments, Hill reaction) or 5 (protein) independent measurements.

1.0 cm^3 contained 5 mM Na/K PO_4 buffer, pH 7.5, 5 mM $MgCl_2$, 10 mM NaCl, 100 mM sucrose, and chloroplasts equivalent to 20 µg Chl.

Changes in all checked parameters are shown in Fig. 1. Under UVE, the fresh mass (FM) of radish shoots increased slowly during the first 10 d of treatment (similar to UVA plants) and subsequently increased rapidly. A 2-fold maximum occurred on the 25th day. In contrast, a more or less linear increase was observed in carrot FM under UVA, while UVE reduced it. More than 65 % reduction was observed when the seedlings were fully developed. Changes in shoot dry mass (DM) followed a similar trend except that the fully developed radish plants showed small difference between UVA and UVE and carrot maintained a large difference. Similar positive increase in the root FM was also observed in radish; a maximum 25 % increase was observed under UVE on the 20th day. In carrot, the reduction in root biomass was marginal during the initial treatment period and a maximum reduction of 30 % was found on the 35th day.

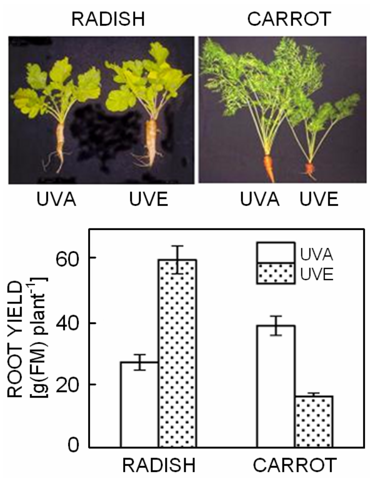

Fig. 2. Typical morphological changes in radish and carrot plants grown under the ambient and UV-B enhanced radiation at their fully developed stage (*top*) and changes in the yield of radish and carrot roots (*bottom*) of plants grown under the ambient (UVA) and UV-B enhanced (UVE) radiation. Means of 20 samples.

The Chl (*a*+*b*) content in radish remained higher in plants grown under UVE than under UVA. The extent of increase was maintained similar at all phases of plant growth. The decrease in Chl content was observed at the entry of plants into senescence. The differences found in carrot were not significant. Similar differences were found in content of Car in the leaves of radish. A 65 % increase was observed in plants grown under UVE at their fully developed phase. In carrot, lower amounts of Car were found in UVE plants than in the UVA ones. The content of flavonoids was higher in UVE grown radish plants than in UVA plants only at early senescence. In carrot, the differences in flavonoids were not significant.

Difference in total protein content in radish was evident at the age of 25 d when the UVE grown plants had much larger content of proteins per FM than the UVA plants. Carrot plants grown under UVE maintained a lower protein content than the UVA grown plants.

The activity of Hill reaction in chloroplasts of radish plants increased up to full maturation of the leaves and then declined rapidly at the senescing stage. This trend was noticed in plants grown under both UVA and UVE, though the overall rate was higher in UVE plants. In carrot the rate was always higher in chloroplasts from UVA plants than in the UVE ones.

The changes in vegetative mass and photosynthetic activities were also reflected in the root biomass (Fig. 2). In radish, UVE increased the root biomass yield by 2-fold as compared to the UVA plants, while in carrot a >60 % decrease was found in UVE plants.

UV-B effects on plant growth and yield are more or less due to the direct cellular damage caused by UV-B photons, which can cause apparent photoproducts in the macromolecules such as DNA (Britt 1999) and proteins (Gerghand *et al.* 1999). In radish, UVE significantly increased the shoot, root, and leaf biomass, when compared to plants under UVA. Similar changes were reported for 16 rice cultivars from seven geographical regions (Teramura *et al.* 1991) and for the seedlings of six temperate deciduous tree species (DeLucia *et al.* 1994). According to Searless *et al.* (1995) the total plant biomass of some tropical dicotyledonous species was generally unaffected by UV-B radiation. Similarly, the leaf biomass of spruce and pine (Baumbusch *et al.* 1998) and sugar maize (Barsig and Malz 2000) was unaffected by the UV-B enhanced radiation. In our experiments carrot showed a decrease in FM and DM when grown under UVE. This is in agreement with the report of Nedunchezhian and Kulandaivelu (1997) where a reduction in biomass accumulation in the sensitive species under UVE was shown. UV-B alters the metabolic processes in leaves that ultimately change the contents of many foliar constituents such as saccharides, photosynthetic pigments, and UV-B absorbing components (Mazza *et al.* 2000).

Carrot is highly sensitive to UV-B that may induce its stunted growth. This could be due to photodegradation of auxin which absorbs in the UV-B range. The hormone related changes in plant growth might also be due to an increase in the oxidative enzyme peroxidase, the content of which increases after UV-B treatment (Pangopoulas *et al.* 1990). The UV-B treated radish plants had an increased flavonoid content compared to those under UVA. Tevini *et al.* (1983) reported a high content of flavonoids in seedlings of plants which are relatively resistant (barley and radish) to UV-B radiation. They have also shown that high UV-B absorbing compounds may not offer continued protection at increasingly higher UV-B radiation. In carrot the decrease in Chl content could be due to photooxidation by UV-B. In UVA plants the amount of Chl was high compared to the UVE treated plants. The decrease in Chl content is probably not related to Chl biosynthesis pathway but to a down regulation of the expression of genes necessary for the Chl binding protein (Strid and Porra 1992).

The Hill reaction activity showed parallel changes in both the UVA and UVE plants. Chloroplasts of plants grown under UVE maintained higher Hill rates in radish and lower rates in carrot than when grown at UVA, which could be attributed to their overall growth performance. UV-B radiation induces structural damage to the chloroplasts and to the D_1 and D_2 proteins of the PS2 core complex; this is linked to the decrease in photosynthetic capacity and growth rate (Teramura and Murali 1986). The damage to the PS2 activity may also be associated with the UV-B induced disruption of structural integrity of the lamellar membrane systems of the chloroplast, probably due to the reduction in the unsaturated/saturated fatty acid ratio of polar lipids. A similar conclusion was drawn by Brandle *et al.* (1977). The PS2 reaction is UV-B sensitive, whereas PS1 appears to be unaffected. Inhibition of the photosynthetic CO_2 assimilation and specifically on the activity, synthesis, and degradation of ribulose-1,5-bisphosphate carboxylase/oxygenase was reported in many studies (Jordan *et al.* 1992, Huang *et al.* 1993, Nagues and Baker 1995, Rao *et al.* 1995, Kulandaivelu and Nedunchezhian 1996, Allen *et al.* 1997, Bassmann *et al.* 2002, Takeuchi *et al.* 2002, Krause *et al.* 2003).

Reduction in the root biomass yield under UVE has been reported for more than half of the crop species, *e.g.* in soybean (Worrest and Grant 1989). Somatic mutations and potential heritable changes may also result (Bakken 1989, Caldwell *et al.* 1989, Kramer *et al.* 1992). Generally, UV-B mediated alterations in plant growth and fruit yield usually depend on the species sensitivity (Teramura *et al.* 1990).

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