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Morphological and biochemical responses of broccoli florets to supplemental ultraviolet-B illumination

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ABSTRACT

The effect of different doses of supplemental ultraviolet-B (UV-B) illumination on yield, plant growth, biochemical changes and antioxidant activity of broccoli florets was evaluated. The broccoli plants were grown under three different supplemental UV-B illumination doses (2.2, 8.8 and 16.4 kJ m^{-2} d^{-1}) in the glasshouse. Plant height decreased with increasing supplementary UV-B illumination dose. However, leaf thickness increased with increasing UV-B dose. Chlorophyll content in the leaves also increased during the growing period. The lowest chlorophyll content was found at 16.4 kJ m^{-2} d^{-1} UV-B dose. Total yield decreased with supplemental illumination, especially at 16.4 kJ m^{-2} d^{-1} illuminated dose. Total dry matter, total soluble solids, carotenoids, chlorophyll *a* and *b* content in broccoli florets decreased with increasing UV-B illumination dose. Conversley, ascorbic acid, sinigrin, total phenolic, and flavonoid content and antioxidant activity increased in UV-B illuminated florets. Surprisingly, glucotropaeolin content, one of the forms of glucosinolate in broccoli, was not affected significantly by UV-B illumination or enhanced by UV-B illumination doses.

1. Introduction

Sustainable agriculture management practices may improve productivity of agricultural crops and support an economic crop production by providing enhanced ecosystem services (Cucci et al., 2016; Sönmez et al., 2016). Greenhouse production is aimed at producing fruits and vegetables under cladding materials to control environmental factors such as light, temperature and humidity. Different cladding materials can be used for protected cultivation including glass and polyethylene plastics. These cladding materials directly or indirectly affect the yield, quality and disease development of the products grown. Solar radiation is of great importance for plants not only as a source of energy for photosynthesis but also as an environmental signal that regulates growth and development (Morales Suárez, 2014).

Previously, UV-B light was accepted as one of the major abiotic stress factors that adversely affect plant development (Eichholz et al., 2012; Tsurunaga et al., 2013). However, recent studies reveal that UV-B has a pivotal role in regulation of plant growth and development (Jansen and Bornman, 2012; Schreiner et al., 2012; Schreiner et al., 2016; Csepregi et al., 2017). The studies conducted on this subject have shown that ambient UV-B levels or enhanced UV-B illumination trigger the accumulation of secondary plant metabolites (health promoting compounds), such as phenolic compounds (Du et al., 2012; Castagna et al., 2013), anthocyanin, (Sun et al., 2014) carotenoids (Schreiner et al., 2012), antioxidants (Jansen et al., 2008; Darré et al., 2017) and glucosinolates, especially in broccoli florets (Mewis et al., 2012; Topcu et al., 2015; Darré et al., 2017). In addition, molecular studies indicated that UV-B illumination increases the frequency of somatic homologous DNA rearrangements in *Arabidopsis thaliana* and *Nicotiana tabacum* (Ries et al., 2000). The advent of employing molecular genetics, identification of a specific UV resistance locus 8 (UVR8) as a UV-B photoreceptor in *Arabidopsis thaliana* might help us to gain a better understanding of plant UV-B responses (Rizzini et al., 2011; Tilbrook et al., 2013). Once plants are unavoidably exposed to excess doses of UV-B, physiological and morphological responses are mostly associated with negative consequences leading to reductions in leaf thickness (Inostroza-Blancheteau et al., 2014), photosynthetic CO_2 assimilation and photosynthetic efficiency (associated with photosystem II) (Basahi et al., 2014; Jordan et al., 2016), stomatal conductance, sub-stomatal CO_2 concentration (Martinez-Luscher et al., 2013), consequently in growth and crop productivity (Kakani et al., 2003). Whilst increasing UV-B levels decreases chlorophyll content of plant by 10–70%, it

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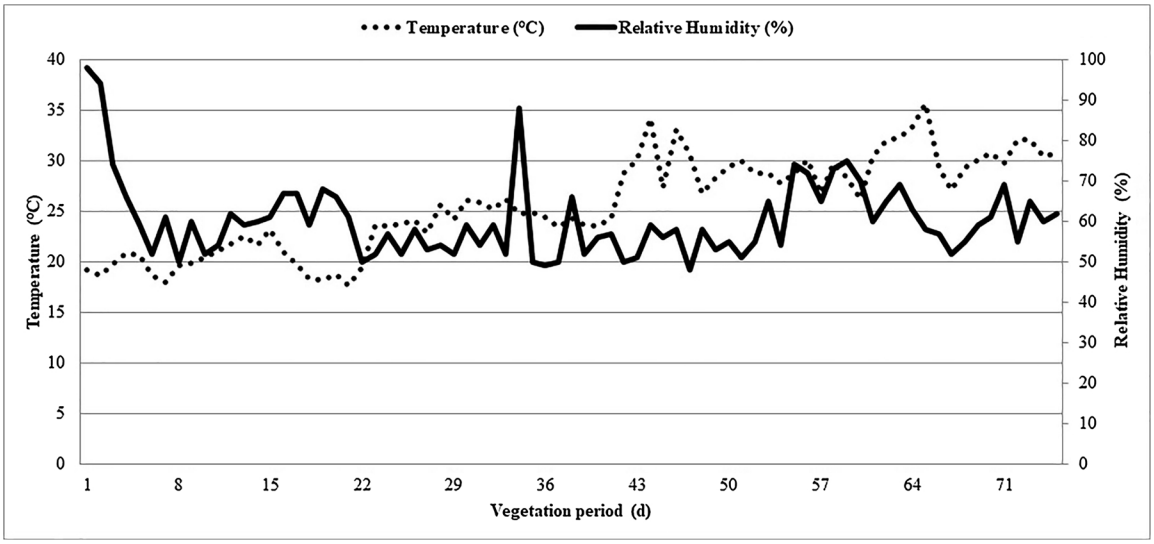

Fig. 1. Temperature and relative humidity in greenhouse during the vegetation period.

increases plant UV-B absorbing compounds by 10–300%, which presumably increases protection from the harmful effects of UV-B. In some cases, especially when it comes to higher UV-B doses, it reduces photosynthetic activity by 3–90%, by changing the amount of pigments in the leaf and decreasing the leaf area. Not surprisingly, decreasing leaf area and chlorophyll pigments lead to lower yield biomass in most major crops (Kakani et al., 2003).

Even though several studies have examined the effects of supplemental UV-B illumination on the phytochemicals and antioxidant compounds in broccoli florets after short-term UV-B exposures (Aiamla-or et al., 2010; Du et al., 2014; Rybarczyk-Plonska et al., 2014), no studies have been conducted on the effects of supplemental UV-B illumination on broccoli plant growth and development, quality parameters, yield, in addition to phytochemicals and antioxidant compounds. Therefore, the objective of the present study was to determine the effect of different supplemental (low, moderate, and extreme) UV-B illumination during the vegetative growth period of broccoli plants on plant morphology, yield, phenolic compounds and quality. Since broccoli contains a remarkably high diversity of vitamins, phenolic compounds, carotenoids, and glucosinolates, it is accepted as the one of the healthiest plants in the world compared with other vegetables and fruits. Therefore, in this study the broccoli was intentionally selected for this investigation.

2. Materials and methods

2.1. Plant material, UV-B illumination and experimental design

Broccoli seedlings [*Brassica oleracea* L. var. *italica* cv. Naxos] were grown in a greenhouse in soilless culture during the spring season in Antalya, Turkey (36°53′N; 30°39′E, altitude 39 m). In the study, a glasshouse (500 m^2) was used with 6.5 m in height including side and top ventilation window. Since broccoli seedlings are very sensitive to UV-B lights, the seedlings were not exposed to UV-B lights during the first week after transplanting. Subsequently, the glasshouse was divided into four equal blocks for supplemental UV-B illumination. The first, the second and the third groups of broccoli plants were exposed to 2.2 kJ m^{-2} d^{-1}, 8.8 kJ m^{-2} d^{-1} and 16.4 kJ m^{-2} d^{-1} UV-B, respectively. The fourth, block of plants did not receive any supplemental UV-B illumination during the entire growing period and this group of plants was considered as control. UV-B fluorescent lamps (Philips UV-B, TL F72T12 100W/01) were used for UV-B illumination. In order to supply homogeneous UV-B illumination, plant pots were placed parallel to the UV-B lamps, which were approximately 15 cm above the seedlings. For that purpose, a special apparatus with adjustable height was designed and used for UV-B illumination. So, during the entire growing period, the height of the lamps was always kept 15 cm above the plants.

In the study, three different UV-B illumination durations and daily doses were applied to broccoli plants. These illumination durations were equal to 2.2 kJ m^{-2} d^{-1} (27 min d^{-1}), 8.8 kJ m^{-2} d^{-1} (64 min d^{-1}) and 16.4 kJ m^{-2} d^{-1} (120 min d^{-1}) on the top of the broccoli plants.

During the growing period, broccoli plants were grown in soilless culture by using a commercial production method. Seedlings were planted in white containers (75 cm in length, 25 cm in width and 25 cm in depth) having 3 plants per container. The containers were placed on benches with a width of 0.25 m, length of 13.5 m and height above the ground of 0.75 m. A 1% slope ensured drainage. Each container was equipped with 4 drippers having a total capacity of 8 l per hour. Peat and perlite mixture (1:1) was used as the growing medium. Dosatron injection system equipped with time adjustment irrigation and fertilization properties was used and the plant nutrient solution was prepared using the formulation of Salk et al. (2008).

2.2. Environmental conditions in glasshouse

The temperature and relative humidity inside the glasshouse were recorded with a data logger (Hobo, Model UX100-003, Onset Corp., Pocasset, USA) (Fig. 1). During the entire growing period, the mean temperature and relative humidity inside the glasshouse were 25.6 °C and 60.2%, respectively. Furthermore, the total UV (Radiometer Model UVX-31, UVP Inc., USA) and illumination intensity (Lutron Light Meter, Model LX-1108, Taiwan) were measured inside the glasshouse under ambient conditions. The mean total UV was 230.67 μW cm^{-2} and intensity of illumination was 320.92 (*100) Lux during the entire growing period (Fig. 2). At ambient conditions the mean total UV was 927.42 μW cm^{-2}, and the intensity of illumination was 685.16 (*100) Lux (Fig. 3).

2.3. Plant height, stem diameter, leaf thickness, receptacle diameter and yield

Plant height, stem diameter, leaf thickness, and receptacle diameter were evaluated at 15 day intervals during the vegetation period. While plant height was measured with a height meter, stem and receptacle diameter were measured with a digital caliper. Illuminated and control plants were harvested simultaneously and weighted for total yield. Total yield was given in kg m^{-2}.