



Contents lists available at ScienceDirect

Plant Physiology and Biochemistry

journal homepage: www.elsevier.com/locate/plaphy

The effects of UV radiation during the vegetative period on antioxidant compounds and postharvest quality of broccoli (*Brassica oleracea* L.)

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ARTICLE INFO

Article history:

Received 30 September 2014

Accepted 23 February 2015

Available online xxx

Keywords:

Broccoli

Brassica oleracea

UV radiation

MAP

Storage

Quality

ABSTRACT

In this study, the effects of supplementary UV radiation during the vegetative period on antioxidant compounds, antioxidant activity and postharvest quality of broccoli heads during long term storage was studied. The broccolis were grown under three different doses of supplementary UV radiation (2.2, 8.8 and 16.4 kJ/m²/day) in a soilless system in a glasshouse. Harvested broccoli heads were stored at 0 °C in modified atmosphere packaging for 60 days. The supplementary UV radiation (280–315 nm) during the vegetative period significantly decreased total carotenoid, the chlorophyll a and chlorophyll b content but increased the ascorbic acid, total phenolic and flavonoid contents of broccolis. All supplementary UV treatments slightly reduced the antioxidant activity of the broccolis, however, no remarkable change was observed between 2.2 and 8.8 kJ/m² radiation levels. The sinigrin and glucotropaeolin contents of the broccolis were substantially increased by UV treatments. The prolonged storage period resulted in decreased ascorbic acid, total phenolic and flavonoid contents, as well as antioxidant activity. Discoloration of the heads, due to decreased chlorophyll and carotenoid contents, was also observed with prolonged storage duration. Glucosinolates levels showed an increasing tendency till the 45th day of storage, and then their levels started to decline. The weight loss of broccoli heads during storage progressively increased with storage time in all treatments. Total soluble solids, solids content and titratable acidity decreased continuously during storage. Titratable acidity was not affected by UV radiation doses during the storage time whereas soluble solids and solids content (dry matter) were significantly affected by UV doses. Supplementary UV radiation increased the lightness (*L*^{*}) and chroma (*C*^{*}) values of the broccoli heads. Pre-harvest UV radiation during vegetative period seems to be a promising tool for increasing the beneficial health components of broccolis.

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1. Introduction

During the last few decades, there has been considerable concern over the depletion of the stratospheric ozone layer. The depletion of the ozone layer is closely related to an increase in UV-B radiation on the earth's surface. Although UV-B radiation is only a minor component of total solar radiation, due to its high energy, its potential for causing biological damage is exceptionally high and even small increases could lead to significant biological damage in

living plant cells (Zlatev et al., 2012). Plants are vulnerable to increased UV-B radiation because many cellular components, such as nucleic acids, proteins, lipids and quinones can absorb UV-B radiation directly (Jordan, 1996). Thus, the effects of increased UV-B radiation on growth and physiology of different agricultural crops, grown in greenhouse or open-field conditions, have become an important area of study.

The UV wavelength band ranges from 100 to 400 nm and UV radiation is generally divided into three sub-bands UV-A (320–400 nm), UV-B (280–320 nm) and UV-C (200–280 nm) wavelength ranges (Gondor et al., 2014).

Plants are affected by numerous stress factors, and exposure and impact are location, species or even variety specific. UV radiation

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can be regarded as both a stress factor and a regulatory factor. UV can significantly affect plant growth and nutritional quality. Thus, UV-B is an important abiotic environmental factor that can cause many direct and indirect effects on plants (Tsurunaga et al., 2013). For example, UV radiation impacts on the pathways involved in the biosynthesis of the three principal groups of secondary metabolites. These metabolites are phenolics, terpenes, and nitrogen-containing compounds (Cisneros-Zevallos, 2003).

A number of studies have demonstrated that supplemental UV-B radiation can have adverse effects, not only on plant physiological processes (Rathore et al., 2003), but also on photosynthetic CO₂ assimilation, and photosynthetic efficiency (Xiaoqin et al., 2008). UV-B can influence plant processes either through direct damage or alternatively via various regulatory mechanisms, including via the UV8 photoreceptor response (Potters et al., 2009).

Different plant responses to supplemental UV-B radiation have been established, some are injurious, but there are many recent studies which report that the use of UV-B radiation can be beneficial, especially by increasing levels of health beneficial substances in different plant products (Avena-Bustillos et al., 2012; Du et al., 2014).

Plants may produce secondary products to protect themselves against UV radiation damage. However, these metabolites also play an important role in crop quality and impact on human health. For example, phenolics, flavonoids and anthocyanins are responsible for antioxidant activity in fruits and vegetables (Tsormpatsidis et al., 2008). UV-B can induce a range of specific plant responses, some of which are particularly desirable from a horticultural perspective (Jansen et al., 2008). Park et al. (2007) reported that UV-B can increase the development of color in salad leaves, and control plant disease-tolerance and morphology. For some fruit crops, UV-B exposure has been reported to increase the synthesis of UV-B absorbing compounds of flavonoids and other phenolics (Interdonato et al., 2011). There are even some studies which indicate that postharvest UV-B radiation increases total soluble phenolics and flavonoids content and antioxidants in fruit and vegetables (Du et al., 2014). The UV-B induced increase in antioxidative defenses is further demonstrated by increases in both the reduction state and pool-size for antioxidants such as ascorbate, glutathione, xanthophylls, and tocopherol (Jansen et al., 2008).

In recent years, the production of cabbages and other brassicas has increased, due to their beneficial health effects. Generally, consumption of *Brassica* ssp. vegetables, especially broccoli, have been claimed to exert protective effects against cancer due to their rich contents of glucosinolates (including glucobrassicin and glucoraphanin), flavonoids (quercetin, kaempferol etc.), vitamins (C and E) and other mineral nutrients (Jeffery and Araya, 2009). Similarly, epidemiological processes indicate that a frequent intake of cruciferous vegetables, such as broccoli, can highly diminish the risk of bladder cancer (Liu and Lv, 2013).

Since broccoli is a highly perishable vegetable, the preservation of its nutrient content and antioxidant activity during the postharvest period is extremely important (Serrano et al., 2006). Broccoli is susceptible to yellowing after harvest, which negatively affects its nutritional and commercial value as well. Generally, the "head quality" of broccoli markedly decreases when flowering heads are kept at room temperature for 3–5 days after harvest. So, it is essential that this fast postharvest yellowing is avoided during handling and storage to protect the nutritional quality, and to prolong the postharvest life of this perishable crop. To maintain the postharvest quality of broccolis, it is crucial to store heads at low temperatures as soon as possible after harvesting. Low temperature (0–4 °C) and high relative humidity (90–95%) are required to maintain the postharvest quality of broccoli heads. Modified atmosphere packaging (MAP), in combination with low temperature,

is simple, beneficial, and economical and also the most effective method to delay postharvest yellowing and deterioration and to maintain the visual and postharvest quality of broccolis (Serrano et al., 2006).

There are several studies on the effects of UV-B radiation on the postharvest quality, and phytochemicals and antioxidant compound content in harvested broccoli (Aiamla-or et al., 2010; Rybarczyk-Plonska et al., 2014). However, there are only a few experiments which have involved analyzing the effects of supplemental UV-B radiation, during the broccoli vegetative growth and development period, on the postharvest quality parameters.

The objective of this present study is to investigate the effect of different supplementary UV radiation doses, given during the vegetative period of glasshouse grown broccoli, on postharvest characteristics, physiological and biochemical parameters, and antioxidant compounds. The long term aim is to provide information that leads to a longer storage life and improved phytochemical properties for this short-lived nutritious vegetable.

2. Materials and methods

2.1. Plant material and experiment site

Broccoli seedlings (*Brassica oleracea* L. italica var. Naxos F1) were grown in a soilless culture in a growing mixture with a peat/perlite (1:1 v/v) in a glasshouse in the experimental unit of Akdeniz University in Antalya, Turkey (36°53' N; 30°39' E, altitude 39 m). The annual number of sunny days at the experimental site is approximately 300 days. Inside the glasshouse, PAR radiation intensity was about 34% of the outdoors levels around solar noon, when the UV treatments were applied. No UV-B absorbing film was used in the experimental glasshouse so a small amount of UV-C light, emitted by the UV-tubes, would have reached plants in the glasshouse.

2.2. UV-B radiation exposures

Broccoli seedlings having 3 true leaves (13.9 cm height) were obtained from a commercial seedling company and they were planted in the glasshouse on January 7th 2014. After planting, the glasshouse was separated into four groups for different UV radiation treatments. The first group of plants was radiated with 2.2 kJ/m²/day, the second and third group of broccoli plants were radiated with 8.8 and 16.4 kJ/m²/day, respectively. The fourth and last group of plants was the control group and these broccoli plants received no supplemental UV radiation during the entire vegetation period. Since broccoli seedlings are rather sensitive to UV radiation, the first radiation exposure was applied 15 days after planting. Philips narrow band (TL F72T12 100W/01 UV-B) UV lamps were used for the radiation exposures (280–315 nm). The different UV radiation doses were obtained by altering the duration of the exposure at the fixed distance of 15 cm above the upper parts of plants. Prior to use, the UV lamps were allowed to stabilize by turning them on at least 15 min beforehand. From fifteen days after planting till harvesting, UV exposures were applied to the broccoli on a daily basis. These radiation durations were 27 min (for 2.2 kJ/m²), 64 min (8.8 kJ/m²) and 120 min (16.4 kJ/m²).

2.3. Storage of broccoli heads

Broccoli grown in a soilless culture in a glasshouse was harvested 91 days after planting, at the commercial maturity stage (average head weight 450–500 g; total soluble solids (TSS) 7.76%; total titratable acidity (TTA) 0.17%) on May 8th 2014. The harvested broccoli heads were immediately transported to the postharvest laboratory and cold storage unit of the Department of Horticulture,

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