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The influence of post-harvest UV-C and pulsed light treatments on quality and antioxidant properties of tomato fruits during storage

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ABSTRACT

In this work, immature green tomatoes were exposed to different doses of either PL or UV-C irradiation (1-8 J/cm^2) and then stored at 20 ± 2°C for up to 21 days. The effects of light treatments on the physical-chemical properties and antioxidant compounds of tomato fruits, were evaluated during storage and compared with those of untreated samples. Results indicated that, at the energy doses investigated, pH and °Brix of all samples were not affected by light treatments and storage period. The skin colour of untreated and treated fruits turned from green to red during storage and no appreciable influence of the light treatments was detected. However, the content of lycopene, total carotenoid, phenolic compounds and antioxidant activity of light treated samples increased during storage up to, respectively, 6.2, 2.5, 1.3, and 1.5-fold, when compared with the untreated samples. These results demonstrated that PL and UV-C irradiation have the potential to enhance the accumulation of health-beneficial food compounds in tomatoes without significant changes of the physical properties of the product during storage.

1. Introduction

The market sales of ready-to-use vegetables and fresh produce have grown rapidly in recent years partially due to the health benefits associated with the consumption of these foods (Ribeiro, Canada, & Alvarenga, 2012). Tomatoes are among the most widely consumed vegetables in the world and represent an important source of many traditional nutrients and a predominant source of several carotenoids (Tommonaro et al., 2008).

Carotenoids accumulate in tomatoes during ripening due to the degradation of the chlorophyll and the transformation of the chloroplasts into chromoplasts during the lag phase preceding the maturation. This results in a change of tomato colour from green to yellow, yellow to orange, orange to pink and pink to red during ripening (Inbaraj & Chen, 2008). Within the class of carotenoids, lycopene is the most abundant and represents more than 80% of the total content of carotenoids in the fully ripened fruit (Tommonaro et al., 2008). The lycopene content in tomatoes is of great importance not only because of the colour imparted to the ripe fruits, which influences the quality perception of fresh tomatoes, but also due to its remarkable antioxidant activity. Several epidemiological studies have shown that the consumption of lycopene-rich foods is inversely associated with the risk of cardiovascular diseases, atherosclerosis, prostate cancer and cognitive impairment (Giovannucci, 1999).

In addition to carotenoids, tomatoes are also a good source of other natural antioxidants such as ascorbic acid and phenolic compounds, namely flavonoids and phenolic acids (Giovanelli, Lavelli, Peri, & Nobili, 1999), which are also recognized for their beneficial health properties as anti-inflammatory, antihistaminic and antitumorals.

It is well known that the antioxidant content of climacteric fruits such as tomatoes may vary greatly depending not only on the cultivar and farming methods, but mostly on the post-harvest handling practices (Jagadeesh et al., 2009). Therefore, the development of effective methods aimed at prolonging the fresh status as well as preserving or even increasing the content and activity of antioxidant compounds of fresh produce through post-harvest handling and processing, could be of utmost importance for the valorisation of the market of fresh produce as well as for the improvement of the positive effects of the consumption of fruits and vegetables on human health. In the last decade,

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continuous-wave ultraviolet light (UV, 200–400 nm) and high intensity pulsed light (PL) technologies have attracted an increasing interest not only as non-thermal methods for the inactivation of microorganisms in liquid foods (Koutchma, Forney, & Moraru, 2009; Pataro et al., 2011) and the surface decontamination of fresh-cut produce (Gómez-López, Ragaerta, Debeverea, & Devlieghere, 2007; Schenk, Guerrero, & Alzamora, 2008), but also as post-harvest preservation treatments of fruits and vegetables (Oms-Oliu, Aguiló-Aguayo, Martín-Belloso, & Soliva-Fortuny, 2010; Ribeiro et al., 2012).

Several studies have reported that the exposure (from minutes to hours) of fresh produce to the short wavelength UV-C (200–280 nm) light irradiation at very low (hormetic) doses (<1 J/cm^2), may induce a series of biochemical events within the plant tissue, which stimulate the biosynthesis of defensive secondary metabolites with antimicrobial activity (Ribeiro et al., 2012). These compounds are highly desirable as they can contribute to prolong the life and maintain the quality of vegetable and fruits by delaying senescence and fruit ripening, and induction of natural defences against fungi and bacteria (Ribeiro et al., 2012). The positive role of UV-C treatments in the control of post-harvest ripening and diseases has been demonstrated in tomatoes, mushroom, strawberries, baby spinach, broccoli, peppers, and blueberries among others (Ribeiro et al., 2012).

Moreover, the activation of plant defence mechanisms might also stimulate the formation of bioactive compounds, which exhibit antioxidant potential, increasing the nutritional value of UV-treated products (Ribeiro et al., 2012). However, literature data on the use of UV light to enhance the nutraceutical properties of fresh produce are relatively recent and in progress, thus, final conclusions cannot yet be drawn. Nevertheless, it has been reported that exposure to UV at hormetic doses resulted in the enhancement of total phenols and polyamine compounds in mangoes (González-Aguilar, Villegas-Ochoa, Martínez-Téllez, Gardea, & Ayala-Zavala, 2007; González-Aguilar, Wang, Buta, & Krizek, 2001), polyamine compounds in peaches (González-Aguilar, Wang, & Buta, 2004), anthocyanin, phenolic content, and antioxidant capacity in strawberries (Baka, Mercier, Corcuff, Castaigne, & Arul, 1999; Erkan, Wang, & Wang, 2008), flavonoids in blueberries (Wang, Chen, & Wang, 2009), phenolic stilbenes in red table grape (Cantos, Garcia Viguera, De Pascual-Teresa, & Tomas Berberan, 2000) and in wine grapes (Guerrero, Puertas, Jiménez, Cacho, & Cantos-Villar, 2010), and vitamin D_2 content in mushrooms (Koyyalamudi, Jeong, Song, Cho, & Pang, 2009; Teichmann, Dutta, Staffas, & Jagerstad, 2007). Recently, the ability of UV-C treatments, at both hormetic or slightly higher energy doses (0.1–8 J/cm^2), to enhance the content of lycopene, ascorbic acid, phenolic compounds and antioxidant activity during storage has been also demonstrated in tomatoes (Bravo et al., 2012; Jagadeesh et al., 2009; Liu, Cai, Lu, Han, & Ying, 2012; Liu, Zabaras, Bennett, Aguas, & Woonton, 2009; Ribeiro et al., 2012). However, further research is needed since, in some cases, investigations have resulted in different conclusions regarding the appropriate energy doses, the optimal ripening stage of tomatoes, and the storage conditions.

PL can be considered as the modern evolution of UV technology. PL treatments consist of exposing foodstuff to intense short pulses (1 μs–0.1 s) of polychromatic light from UV to near infrared (100–1100 nm) emitted by an inert gas (e.g. xenon) lamp (Oms-Oliu, Martín-Belloso, & Soliva-Fortuny, 2010). PL has an emission power higher than that of continuous wave UV light, which, under stress conditions, might stimulate higher production of bioactive compounds in plant tissues to minimize the damages caused by high power radiations (Rodov, Vinokur, & Horev, 2012). In addition, the very short exposure times (seconds for PL treatments, min-hours for UV treatments) required to achieve the desired effects could significantly promote the utilization of PL technology on the industrial scale (Rodov et al., 2012).

This notwithstanding, the potential use of PL technology for food decontamination has been extensively investigated (Gómez-López et al., 2007), whilst very few studies have been carried out to investigate the potential applications of PL in post-harvesting processing of vegetables to improve their nutritional quality. Recent studies have reported that PL treatment (0.2–10 J/cm^2) provides a highly effective way for increasing Vitamin D_2 content in mushrooms (Koyyalamudi, Jeong, Pang, Teal, & Biggs, 2011) and total anthocyanin and phenolic compounds content in figs (Rodov et al., 2012). However, to the best of our knowledge, there are no publications dealing with the evaluation of the effects of PL on tomato fruit. In addition, there are no published papers in which the comparison of the effects of PL and UV-C treatments on the quality of vegetables during storage as well as on the evolution of their content of bioactive compounds has been reported.

In this study, the effects of PL and UV-C treatments with different energy doses on the quality (colour, pH, and total soluble refractive solids) and functional properties (lycopene content, total carotenoids, total phenolics, and antioxidant activity) of tomato fruit during storage have been investigated and the effectiveness of the two treatments has been compared.

2. Materials and methods

2.1. Tomato samples

Tomatoes (*Solanum lycopersicum*) of the "San Marzano" variety were field-grown in the province of Salerno (Southern Italy) in spring 2012. The fruits were harvested at green stage, transported to the laboratory and, in the same day, treated with PL and UV-C light.

2.2. PL and UV-C light apparatus

PL treatments were carried out in a bench-top RS-3000C SteriPulse-XL system (Xenon Corp., Wilmington, Mass., USA) which included a power/control module, a treatment chamber and lamp housing with a linear 16″ xenon flash lamp. A quartz window, placed at 5.8 cm from the lamp source, was used to separate the lamp housing from the treatment chamber. The system generates 3 pulse/s (360 μs width) of a polychromatic light in the wavelength range between 200 and 1100 nm. An adjustable 15.75 × 40.64 cm stainless steel tray in the treatment chamber allowed changing the vertical distance from the quartz window surface from 1.93 to 16.46 cm. Consequently, the intensity of the flashes of light that reach the target can be changed, respectively, from 1.21 to 0.22 J/cm^2/pulse, for an input voltage of 3800 V, as per manufacture specification. A factory supplied photoelectric detector module (LiteMark-XL) mounted on the lamp housing, was used to check that the optical emissions from the source were consistent throughout the duration of the experiments. A forced air system with filter was used to remove ozone and heat from both the housing lamp and treatment zone.

UV-C light treatments were carried out in a laboratory scale cabinet CYTOSAFE-N 2000 (SARIN sas di Leo Temin & C., Florence, Italy) (1190 mm wide, 580 mm deep, and 660 mm high), containing a 20 W germicidal UV-C lamp (G20T10 Sankyo Denki, Nagano, Japan) with a peak emission at the wavelength of 254 nm.

2.3. PL and UV-C light treatments and storage

Before treatment, samples of tomatoes of uniform (almost cylindrical) shape and size (about 4 cm in diameter, 7 cm in length) were selected (fruits damaged and of poor quality were discarded), and separated into seven lots. As reported in Fig. 1, one lot of non-irradiated tomatoes was used as control. Four lots, namely PL1, PL2, PL4, and PL8, were exposed to PL treatments with different energy doses. In order to ensure treatment uniformity and reduce heating effects, the samples were placed in the centre of the tray and aligned with their main axis parallel to the lamp tube at the maximum vertical distance (12.46 cm) allowable between the upper surface of the fruit and the lamp source. At this distance the average energy dose per pulse (F_p) emitted by the lamp was 0.35 J/cm^2. During the treatments, the tomatoes of each lot