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Impact of pulsed light on colour, carotenoid, polyacetylene and sugar content of carrot slices

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ABSTRACT

Carrot slices were subjected to pulsed light (PL) treatments on both sides (total PL fluences of 2.26, 4.52, 5.41, 9.38 and 13.15 J/cm^2) with the objective to evaluate their effect on the colour, β-carotene, polyacetylene and soluble sugar content. Higher concentrations of β-carotene were found after processing of carrot slices to the fluences of 2.26 and 4.52 J/cm^2 as compared with untreated carrots. This behaviour was partly related to the strongly colour observed in the cortex tissue of samples when similar PL treatment conditions were applied. Moreover, carrot slices treated with PL doses of 2.26 J/cm^2 also showed the highest falcarindiol (127.1%), falcarinol (94.8%) and falcarindiol-3-acetate (84.7%) retention levels. The same PL dose also led to an increment in the β-glucose in carrot slices after the treatment.

Industrial relevance: The pre-treatment of carrot slices with pulsed light would enhance the level of polyacetylene and carotenoid content as a stress response without affecting negatively the colour characteristics of the fresh material. Pulsed light technology could be useful for the food industry in production of high value phytochemical vegetable products.

1. Introduction

The market sales of minimally processed vegetables have grown rapidly in recent years partly due to the health benefits associated with the consumption of these foods (Ribeiro, Canada, & Alvarenga, 2012). The development of effective methods that could extend both the shelf life and retain or even increase the content and activity of health-beneficial food compounds is of utmost importance for the valorisation of the market of fresh and fresh-cut products (Pataro, Sinik, Capitoli, Donsì, & Ferrari, 2015). In these sense, pulsed light (PL) is a promising nonthermal technology currently under study with great potential in extending shelf life of fresh-cut products without compromising their nutritionally and sensory qualities (Aguiló-Aguayo, Charles, Renard, Page, & Carlin, 2013; Aguiló-Aguayo, Hossain, et al., 2014; Charles, Vidal, Olive, Filgueiras, & Sallanon, 2013; Oms-Oliu, Aguiló-Aguayo, Martín-Belloso, & Soliva-Fortuny, 2010). PL involves the use of intense pulses of short duration (1 μs–0.1 s) and a broad spectrum to induce microbial inactivation on the surface of both foods and packaging materials (Elmnasser et al., 2007).

The capability of PL to stimulate the production of bioactive compounds in plant tissues is still under investigation. Several researchers indicated that the stress caused in PL-treated tissue might trigger the biosynthesis of defensive secondary metabolites (Pataro et al., 2015; Rodov, Vinokur, & Horev, 2012). In tomato fruits, PL fluences of 0.6 J/cm^2 have shown an increase of over 130% in antioxidant activity (Pataro et al., 2015), whilst other studies revealed that high dose of 30 J/cm^2 promoted an increase in total lycopene, α-carotene and β-carotene contents (Aguiló-Aguayo et al., 2013). Other 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). In mango pulp, PL has shown to improve the levels of phytochemicals such as mangiferin, vitamin C and carotenoids at fluences of 0.6 J/cm^2 (Lopes et al., 2016). However, higher PL fluence of 8 J/cm^2 maintained polyphenol and total ascorbic acid content of fresh-cut mango similar to the levels in untreated samples (Charles et al., 2013).

Carrots (*Daucus carota* L., Apiaceae) are well known for their high content of carotenoids, which work as precursors to vitamin A (Surles, Weng, Simon, & Tanumihardjo, 2004). However, carrots also contain a mixture of aliphatic C17 polyacetylenes including falcarinol ((Z)-heptadeca-1,9-diene-4,6-diyn-3-ol; FaOH), falcarindiol ((Z)-heptadeca-1,9-

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diene-4,6-diyne-3,9-diol; FaDOH) and falcarindiol-3-acetate ((Z)-3-acetoxyheptadeca-1,9-diene-4,6-diyne-8-ol; FaDOAc) (Lund, 1992). These polyacetylenes have been associated to potential beneficial effects on humans including perturbation of cell proliferation, anti-inflammatory and anti-platelet aggregatory effects (Alanko, Kurahashi, Yoshimoto, Yamamoto, & Baba, 1994; Appendino, Tagliapietra, Nano, & Picci, 1993; Minto & Blacklock, 2008; Teng et al., 1989).

In common with many other secondary metabolites, the levels of polyacetylenes in carrots have been shown to be affected by a number of factors such as genotype, cultivation practices, tissue type, storage and processing conditions (Kidmose et al., 2004; Pferschy-Wenzig et al., 2009; Rawson et al., 2013; Søltoft et al., 2010). However, there is lack of knowledge on the behaviour of this type of compounds in ready-to-eat carrot products treated with PL technology.

A study on the inactivation of microorganisms in PL-treated carrot have concluded the positive effect of PL in reducing the load of yeast cells (*Saccharomyces cerevisiae*) after applying two pulses of 0.7 J/cm^2 (Kaack & Lyager, 2007). In addition, fluences of 12 J/cm^2 were effective in reducing microorganisms in slices carrots (Izquier & Gómez-López, 2011). However, there are no reports on the effect of PL on the colour and bioactive compounds from fresh-cut carrots. Therefore, the primary aim of this study was to investigate the effects of PL with different fluences on the colour, carotenoid content and levels of FaOH, FaDOH and FaDOAc in fresh-cut carrots. In addition, to determine the possible influence of PL on the association between the leaching of soluble sugars and the levels of polyacetylenes using ^{1}H NMR spectroscopy.

2. Material and methods

2.1. Chemicals

Deuterium oxide (D_2O 99%), 3-(trimethylsilyl)propoinic acid-d_4 sodium salt (TSP), sodium sulphate (Na_2SO4), β-carotene, fructose, sucrose, β-glucose, α-glucose, acetonitrile, methanol, ethyl acetate and HPLC grade water were obtained from Sigma-Aldrich (Arklow, Ireland). Diatomaceous earth and silica gel (SiO_2) were purchased from ThermoFisher Scientific (Dublin, Ireland).

2.2. Preparation of carrot slices

Carrots (*Daucus carota* cv. Nerac) were purchased in a local retailer (Tesco, Dublin, Ireland) in May of 2013. Unpeeled carrots were washed with tap water and cut into slices of 1 cm thickness, retaining the peel. Only slices of around 3.6 ± 0.2 cm diameter were used for processing under PL conditions; slices with smaller diameter were discarded. Carrot slices selected for the experiment consisted of a central stele (mostly vascular tissue) and a peripheral cortex layer.

2.3. Pulsed light treatments

The PL treatments were carried out using a RS-3000C SteriPulse System (Xenon Corp., Woburn, Mass., USA). The equipment contains a controller unit and a treatment chamber with a Xenon flash lamp suspended from the ceiling that could deliver high intensity white light in short pulses to treated food surfaces. For each tested condition, carrot samples were centered on a stainless-steel shelf at incremental distances from the quartz face of the lamp up to 12.36 cm with a variable number of pulses at a frequency of three pulses per second and a pulse width of 360 μs. Eq. (1) was followed for fluence calculations by using the model developed by Hsu and Moraru (2011) for describing the fluence dimensional distribution ($F_{x,y,z}$) in the chamber of this PL equipment. The equation describes the three-dimensional decay fluence and the fluence vs. distance.

$$F_{x,y,z} = 2.32e^{-\left[0.14z+0.5\left(,\frac{x+1.04}{21.48}\right)^2+0.5\left(,\frac{y-0.87}{2.11}\right)^2\right]} \quad (1)$$

where F is the fluence delivered per pulse (J/cm^2) and x (x-direction along the direction of the lamp in cm), y (y-axis across the direction perpendicular to the lamp in cm) and z (z-direction vertically away from the lamp in cm) represents distances from the origin (0,0,0). Both faces of each carrot slice were treated. Total PL fluences of 2.26, 4.52, 5.41, 9.38 and 13.15 J/cm^2 were applied. Five (n = 5) carrot slices were exposed to each PL fluence and three replicates were processed per treatment. Untreated and PL-treated slices were then frozen at − 80 °C followed by lyophilisation for 18 h in a freeze-drier (D80 Leanne freeze drier, Cuddon, New Zealand) with a temperature of 30 °C and a pressure of 0.02 mbar.

2.4. Determination of colour changes

A colourimeter (Minolta Chroma Meter Model CR-400, Minolta Sensing Inc., Osaka, Japan) was used to measure the colour changes of fresh raw untreated and PL-treated carrot slices. Illuminant D65 and a 10°observer angle were set up in the equipment. At least 5 samples from each triplicate treatment were evaluated for colour at room temperature. CIE-Lab values of L* (lightness), a* (redness) and b* (yellowness) were determined. The browning index was calculated using L*, a*, b* according to Mohammadi, Shahin, Zahra, and Alirez (2008):

$$\text{Browning index (BI)} = [100(x - 0.31)]/0.17 \quad (2)$$

where

$$x = (a^* + 1.75\,L^*)/(5.646\,L^* + a^* - 3.012b^*) \quad (3)$$

2.5. Total carotenoid content determination

Total carotenoids were evaluated according to the method described by Koca, Burdurlu, and Karadeniz (2007) with slight modifications. Firstly, total carotenoid extraction were performed using 25 mL of hexane:acetone (7:3) and 0.5 g of freeze dried sample. Samples were then homogenized for 1 min at 24,000 rpm using an Ultra-Turrax T-25 homogenizer (Janke & Kunkel, IKA®-Labortechnik, Staufen, Germany), vortexed with a V400 Multitude Vortexer (Alpha laboratories, North York, Canada) for 20 min at 1050 rpm and centrifuged for 15 min at 3500 rpm (MSE Mistral 3000i, Sanyo Gallenkamp, Leicestershire, UK). The residue was re-extracted with fresh hexane:acetone (7:3 v/v) solvent until it became colourless. The resulted filtrates were combined in a separating funnel and washed with 50 mL of distilled water. The water phase was discarded and Na_2SO_4 (10 g) was added as desiccant. The hexane phase was transferred to a 50 mL volumetric flash and brought to volume with hexane. The absorbance of this solution was then determined at 450 nm using a UV–Vis spectrophotometer (Shimadzu UV-1700, Shimadzu Corporation, Kyoto, Japan). External calibration with authenticated β-carotene standards solutions (0.5 μg/mL–10 μg/mL) in hexane:acetone (7:3) was used to quantify carotenoids in the solutions. Carotenoid content was expressed as β-carotene equivalents (βCE) in mg/g dry weight of sample and results were expressed as relative β-carotene content (Eq. (2))

$$\text{Relative β-carotene content} = \frac{C_t}{C_0} \quad (3)$$

where C_t and C_0 are the concentration of carotenoids of PL-treated and untreated (i.e. unprocessed carrot slice) sample, respectively.

2.6. Extraction of polyacetylenes

Extraction of polyacetylenes was performed using pressurized liquid extraction with an ASE 200 automated system (Dionex, Surrey, UK) at the following previously optimized conditions: 100% ethyl acetate at a