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Effects of simultaneous UV-C radiation and ultrasonic energy postharvest treatment on bioactive compounds and antioxidant activity of tomatoes during storage

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ARTICLE INFO

Chemical compounds studied in this article:
Iron (III) chloride (PubChem CID: 24380)
Sodium carbonate (PubChem CID: 10340)
Ascorbic acid (PubChem CID: 54670067)
2, 6 dichlorophenolindophenol (PubChem CID: 13726)
Acetic acid (PubChem CID: 176)
Trolox (PubChem CID: 40634)
2, 2-diphenyl-1-picrylhydrazyl (PubChem CID: 74358)
Metaphosphoric acid (PubChem CID: 3084658)
2, 4, 6-tris (2-pyridyl)-s-triazine (PubChem CID: 77258)
Hydrochloric acid (PubChem CID: 313)
Gallic acid (PubChem CID: 370)
Sodium acetate trihydrate (PubChem CID: 23665404)
Chloroform (PubChem CID: 6212)
Methanol (PubChem CID: 887)

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ABSTRACT

The effects of a novel technology utilizing a simultaneous combination of Ultraviolet-C radiation and ultrasound energy postharvest treatment on tomato bioactive compounds during 28 days' storage period was investigated by varying Ultraviolet-C radiation intensities of 639.37 or 897.16 μW/cm^2 at a constant ultrasound intensity of 13.87 W/L from a 40 kHz–1 kW transducer. A minimal treatment time of 240 s at Ultraviolet-C dosage of 2.15 kJ/m^2 was observed to provoke a considerable increase in bioactive compounds content, proportioned to treatment time. Although treatment led to temperature increase in the system reaching 39.33 °C due to heat generation by ultrasonic cavitation, the extractability and biosynthesis of phytochemicals were enhanced resulting in 90%, 30%, 60%, 20%, and 36% increases in lycopene, total phenols, vitamin C, hydrophilic and lipophilic antioxidant activities respectively. Results present the potential use of the combined non-thermal technologies as post-harvest treatment to improve bioactive compounds and antioxidant activity during storage.

1. Introduction

Recent trends in epidemiological research have associated tomato consumption with a variety of health benefits such as reduced risk of chronic cardiovascular diseases, prostrate and lung cancer, and antioxidant activity (Wang, Jacobs, Newton, & McCullough, 2016; Del Giudice et al., 2017). Antioxidant activity is the foundation of a variety of biological functions such as anti-carcinogenicity, anti-mutagenicity, anti-aging and anti-inflammatory (Zou, Xi, Hu, Nie & Zhou, 2016). These benefits are ascribed mostly to the presence of lipophilic (fatty acids, tocopherols, carotenoids) and hydrophilic (sugars, ascorbic acid, phenols, folates) compounds (Rigano et al., 2014), trace elements like

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Zn, Mn and Cu, antioxidant enzyme cofactors which gives protection against damaged cells, and the interactions occurring between them at various developmental stages. Coupled with the tendency of consumers towards health consciousness, this trend has promoted and warrants profound studies towards the evaluation, preservation and improvement of these phytochemicals during postharvest handling and processing (Liu, Cai, Lu, Han, & Ying, 2012). As Guerreiro et al. (2016) mentioned that majority of natural antioxidants are multifunctional, the need for proper consideration to the various antioxidant mechanisms of action through diverse assays for reliable evaluation is therefore important.

Conventional thermal processing and sanitizer applications typically remains the most extensively utilized approach for postharvest handling of fruits and vegetables (Chipurura & Muchuweti, 2010; Ribeiro, Canada, & Alvarenga, 2012). However, nutrient loss associated with the conventional processing (Aadil, Zeng, Han, & Sun, 2013), health concerns associated with sanitizer applications (Ribeiro et al., 2012) and increasing demands for minimally processed food products with preserved fresh-like characteristics have encouraged alternatives to be sought for, especially in the form of novel and non-thermal technologies. Alternatives such as Ultraviolet-C (UV-C) radiation and ultrasound energy can function as abiotic stress elicitors towards the accumulation and biosynthesis of bioactive components of plants, with minimal effects on taste and quality (Freitas et al., 2015; Gomes et al., 2017; Jacobo-Velazquez et al., 2017).

Researchers have linked individual postharvest applications of UV-C radiation or ultrasound energy with induced secondary metabolites synthesis and accumulation of tomato phytochemicals. For UV-C radiation, Bravo and co-workers (2012, 2013) reported an increased lycopene, z-lycopene, *cis*-isomers, total phenolic content and antioxidant activity in vine-ripe and breaker tomatoes exposed to 3.0 kJ/m^2 UV-C radiation. Similar results were also reported by Liu et al. (2012) and Maharaj, Arul, and Nadeau (2014) in matured green tomatoes fruits exposed to 4 kJ/m^2 and 3.7 kJ/m^2 UV-C radiation respectively during 28 days' storage although Maharaj et al. (2014) also observed a reduction in ascorbic acid, alpha-tocopherol and glutathione content during the period. Pinheiro, Alegria, Abreu, Goncalves, and Silva (2015a) reported that UV-C treated and untreated tomato fruits reached similar values at the end of storage period when exposed to 0.32 kJ/m^2. For ultrasound treatment, Pinheiro, Alegria, Abreu, Goncalves, and Silva (2015b) reported higher contents of phenolic compounds with ultrasound treatment at 40–100% power level for 4 min during 15 days storage period. Ding et al. (2015) reported that ultrasound alone at 240 W for 10 min and in combination with slightly acidified electrolytic water (SAEW) had no significant effect on vitamin C content of tomato. As the UV-C radiation is limited by low penetration capability especially into solid materials (Tremarin, Brandao, & Silva, 2017) while the ultrasonic energy consumes high energy coupled with long treatment time, synergistic effect of UV-C radiation or ultrasound energy with other thermal and non-thermal approaches have been recognised in recent times as promising for the postharvest handling and processing of fruits and vegetables and their products (Evelyn, Kim, & Silva, 2016; Gomes et al., 2017). However, there is no information available on the effect of an integrated technology utilizing both UV-C radiation and ultrasound energy in combination and used simultaneously. An integrated technology that combines UV-C radiation and ultrasonic energy is potential towards ensuring overall safety and wholesomeness of fruits and vegetables. The influence of the application of the posited novel integrated technology on bioactive compounds content becomes a significant feature for the process appraisal, since the submission of a novel sanitizing technique to delay microbial growth on fresh produce will be of no good if it impacts negatively on functional and nutraceutical properties.

Based on these submissions, this study seeks to evaluate the influence of the simultaneous combination of UV-C radiation and ultrasound energy on the bioactive compounds and antioxidant activity of tomatoes by harnessing the advantages and minimizing the limitations associated with individual application of both technologies.

2. Material and methods

2.1. Sampling and sampling preparation

Tomato fruits (*Solanum lycopersicum* cv. Baby TM1536) of uniform sizes and shapes at the turning stage, *i.e.* between 10 and 30% of surface aggregate exhibiting a definite change in colour from green to tannish–yellow, pink, red or a combination of both were selected from heaps that were manually harvested in a commercial farm, Twin Diamond Plantation in the Cameron Highland District of Malaysia. A total of 675 fruits with weight ranging from 97.361 to 140. 019 g were used for the study. Fruits were placed in cold storage of 12 ± 2 °C at relative humidity of 76 ± 2% until treatment.

2.2. Chemicals and reagents

All chemicals and reagents used were handled with minimal exposure to light. Standards of Iron (III) chloride ($FeCl_3{\cdot}6H_2O$), 99% purity sodium carbonate (Na_2CO_3), L-ascorbic acid, 2, 6 Dichlorophenolindophenol (DCIP) sodium salt ($C_{12}H_6Cl_2NNaO_2{\cdot}2H_2O$), Folin and Ciocalteu's phenol reagent and acetic acid (CH_3COOH) were obtained from R and M Chemicals, Essex, UK. Sigma-Aldrich Chemie, Steinheim, Germany supplied trolox ($C_{14}H_{18}O_4$), 95% purity grade 2, 2-diphenyl-1-picrylhydrazyl, (DPPH), metaphosphoric acid (HPO_3) and 2, 4, 6-Tris (2-pyridyl)-s-triazine (TPTZ). Analytical grade (37%) hydrochloric acid (HCl) was purchased from Quality Reagent Chemical Product (QREC), Selangor, Malaysia. Gallic acid was procured from Acros Organics, New Jersey, USA, while SYSTERM chemicals provided sodium acetate trihydrate ($C_2H_3NaO_2{\cdot}3H_2O$), 100% reagent grade chloroform and methanol.

2.3. Combined UV-C radiation and ultrasonic energy equipment set-up

The combined UV-C radiation and ultrasonic energy equipment is a bath system utilizing the indirect ultrasonic agitation method integrated with low pressure mercury UV-C lamps having principal emission at 253.7 nm. The stainless steel tank of capacity 67.12 L measures 406 mm (L) × 406 mm (W) × 610 mm (H), with a tank cover to protect UV-C radiation exposure and a fill and drain inlet/outlet, each located at the bottom and by the side of the tank for ease of filling and draining. The equipment simultaneously emits ultrasonic cavitation from an immersible integral mounting flange type piezoelectric transducer (1 kW, 40 kHz, Branson Ultrasonic, Shanghai, China) enclosure bonded at the bottom of the tank and UV-C radiation from four single-ended pins high power series lamps (ZW18D15W-Z356, CnLight Co. Ltd, Guangdong, China), uprightly held in place on each of the interior of the four-walled tank just directly above the transducer surface.

The lamps irradiate towards the centre of the tank and are specially treated on electrode and quartz tubes for longer lifetime and improved output. The lamps, 15 mm diameter, rated 18 W and intensity of 48–54 $\mu W/cm^2$ (1 m distance) are encased in quartz glass sleeves for protection in water. A perforated stainless steel produce basket held in place by a mechanical system, positioned equidistant from the walls of the tank, and within the lamp base face length so as to ensure full surface exposure of the produce to UV-C radiation holds produce for contamination in place.

2.4. Treatment and experimental design

The power dissipated by ultrasonic cavitation was estimated from Eq. (1) (Kek, Chin, & Yusof, 2013) where temperature was logged as a function of time during heat production as a result of both ultrasonic cavitation and UV-C radiation. The effective acoustic energy density