J Food Sci Technol (July 2016) 53(7):3035–3042
DOI 10.1007/s13197-016-2275-z

ORIGINAL ARTICLE

The effect of ultraviolet treatment on enzymatic activity and total phenolic content of minimally processed potato slices

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Revised: 22 May 2016 / Accepted: 2 June 2016 / Published online: 26 July 2016

Abstract In this work, potato slices were exposed to different doses of UV-C irradiation (i.e. 2.28, 6.84, 11.41, and 13.68 kJ m^{-2}) with or without pretreatment [i.e. ascorbic acid and calcium chloride (AACCl) dip] and stored at 4 ± 1 °C. Changes in enzymatic activities of polyphenol oxidase (PPO), peroxidase (POD) and phenylalanine ammonia lyase (PAL), as well as total phenolic content (TPC) were investigated after 0, 3, 7 and 10 days of storage. Results showed that untreated and UV-C treated potato slices at 13.68 kJ m^{-2} dosage level showed significantly higher PPO, POD and PAL activities. Conversely, untreated potato slices showed the lowest TPC during storage period. Potato slices subjected to AACCl dip plus UV-C at 6.84 kJ m^{-2} produced lower PPO, POD and PAL activities, as well as maintained a high TPC during storage.

Keywords Enzymatic browning · UV-C treatment · Polyphenol oxidase (PPO) · Peroxidase (POD) · Phenylalanine ammonialyase (PAL) · Total phenolic content (TPC)

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Introduction

Fresh- cut fruits and vegetables usually have short shelf life because they are very susceptible to shriveling, microbial growth, loss of nutrients and enzymatic browning (Gil et al. 1996; López-Rubira et al. 2005; Maghoumi et al. 2013a). Minimal processing involves mechanical operations such as washing, peeling, and cutting which alters the tissue integrity causing the cut fruits and vegetables to be more perishable than the intact surface. Mechanical injury during processing results in cellular delocalization of enzymes and their substrates, leading to biochemical deteriorations such as enzymatic browning, off- flavors and texture breakdown, as well as increasing respiration rate and ethylene biosynthesis. Oxidation of phenolic substrates by polyphenol oxidase (PPO) is the major cause of enzymatic browning which promotes the browning and blackening as secondary injury (Parkin et al. 1989; Lamikanra 2002). The act of cutting leads to an increase in enzymatic activity of phenylalanine ammonia lyase (PAL), polyphenol oxidase (PPO) and peroxidase (POD) as a response to stress undergone by tissue which shorten the shelf- life of cut produce (Saltveit 2000). This becomes major limiting factors for the postharvest life of many minimally processed fruits and vegetables (Lamikanra 2002).

Potato (*Solanum tuberosum*) is one of the world's major agricultural crops that are consumed worldwide (Onwueme and Charles 1994; Chiavaro et al. 2006; Akanbi et al. 1996). Minimally processed potatoes may represent an interesting product to increase the sale of raw pre-peeled

potatoes in catering and retail market as the consumer's demand for high- convenience food keep growing. However, potatoes are prone to browning after cutting, peeling and exposure to the air (Ozo et al. 1984; Vitti et al. 2011). Many approaches have been examined to improve the shelf-life of minimally processed vegetables such as optimization of raw material quality, processing conditions (e.g. gentle handling, strict hygienic practices, and correct packaging technology), distribution and retailing (Ohlsson 1994; Ahvenaine 1996).

In recent years, there has been an increasing concern on the effectiveness of minimal processing as a strategy for modern food preservation especially in meeting consumer demands for high-convenience food products (Walkling-Ribeiro et al. 2009). Consumption of minimally processed fruits and vegetables have becomes popular due to their convenience and health benefits (Shen et al. 2013) over fully processed products (Lasekan et al. 1996). Among the non- thermal techniques investigated, short-wave ultraviolet light (UV-C) irradiation is viewed as a promising non-thermal technique which has been used for decades in disinfestation of air and water, solid surfaces and packaging containers in food industry (Koutchma et al. 2009). The germicidal effect of UV-C has long been used to inactivate pathogen and spoilage microorganisms by disrupting their nucleic acid at an optimal wavelength at 254 nm (Koutchma 2009).

In addition, UV-C irradiation at low doses led to accumulation of antifungal compounds in tissues which reduces postharvest decay, and controls natural infection, and maintains the overall quality of several fruits and vegetables (Artés-Hernández et al. 2010; Crupi et al. 2013; Erkan et al. 2001). Alegria et al. (2012) also reported that UV-C induces antioxidant activity, reduces respiration rates, control rot development and delay senescence in many fruits and vegetables. Some studies have been conducted on the pasteurization of liquid foods such as apple cider, milk, and liquid egg using UV-C irradiation (Basaran et al. 2004; Geveke 2008; Matak et al. 2004; Oteiza et al. 2005). Exposure to UV-C light has been shown to elicit a range of chemical responses in fresh produce ranging from antifungal, enzymes inhibition to phytoalexins (Shama 2007).

Presently, there is no information available on the effect of UV-C treatment on minimally processed potato slices and their enzymatic activities. The main objective of this study was to investigate the effect of UV-C treatment and AACCl dip alone and in combination on the activities of enzymes PPO, POD, as well as PAL in minimally processed potato slices during storage (10 days, 4 ± 1 °C).

Materials and methods

Sample preparation

Potato tubers (*Solanum tuberosum* L.) of the "Holland" variety were obtained from Pasar Borong Selangor, Malaysia and stored at 4 ± 1 °C until use. Tubers with uniform maturity and free from defects were sorted. Selected tubers were washed in water and dipped in sodium hypochlorite (100 ppm free chlorine) to reduce surface contamination. Tubers were hand peeled to remove the skin and cut into a disc of 3.5 cm in diameter and 0.6 cm thickness with a circular mold. Potato discs were then immediately dipped in cold distilled water (4 °C) for 1 min to eliminate cellular fluid and paper dried (Gómez et al. 2010; Cabezas-Serrano et al. 2009).

Ultraviolet treatment

The UV-C irradiation device consisted of two banks of unfiltered germicidal emitting lamps (VL-215G, Vilber Lourmat, Marne la Vallée, France) at 254 nm with a reflector for optimum UV irradiance. The UV lamps were located at 15 cm above the produce tray and were supported by a lamp holder. The UV lamps and the treatment area were enclosed in a wooden box covered with aluminum foil. The UV lamps were allowed to stabilize by turning them on at least 15 min before irradiation. The UV-C intensities emitted from the lamps were determined by using a UVX radiometer (Ultra-Violet Products Ltd, Cambridge, UK). The applied UV-C intensity was calculated as the mean of 20 UV-C readings measured within a uniform area of the radiation field. UV-C intensity was kept constant and different applied doses were obtained by altering the exposure time at a fixed distance. The samples were placed within a uniform area of the radiation field to minimize the variations in radiation dose. Potato slices were irradiated with doses of 2.28, 6.84, 11.41, and 13.68 kJ m^{-2} respectively. Non-irradiated samples were considered as the control. After treatment, the samples were packed in closed plastic boxes permeable to air and stored in the dark at 4 ± 1 °C (Gómez et al. 2010; López-Rubira et al. 2005).

Combined pretreatment and UV-C treatment

Pretreatment was prepared by dipping the potato slices into a solution containing 1 % (w/v) ascorbic acid and 0.1 % (w/v) calcium chloride for 5 min at 4 °C. The potato slices were irradiated using the following doses: 2.28, 6.84, 11.41, and 13.68 kJ m^{-2} respectively. After UV treatment,

the samples were packed in closed plastic boxes permeable to air and stored in the dark at 4 ± 1 °C.

Extraction of PPO and POD

PPO and POD were extracted according to the method of Cabezas-Serrano et al. (2009). Potato slices (5 g) were ground with a mortar and pestle and then homogenized in 30 ml of 0.1 M phosphate buffer, pH 6.2 together with 1 g of polyvinylpyrrolidone (PVPP), and centrifuged at 3500 rpm for 15 min. The supernatant was collected for the determinations of PPO and POD activities respectively.

PPO activity

The supernatant (1.5 ml) collected after extraction was mixed with 1 ml phosphate buffer, and 0.5 ml of 100 mM 4-methylcatechol. The absorbance of the mixture was measured at 410 nm over a period of 2 min at 25 °C. The results obtained were expressed as units of enzymatic activities (Cabezas-Serrano et al. 2009). One unit of enzyme activity was defined as the amount of the enzyme, which caused a 0.01 change in absorbance in the first 15 s that were within the first linear region of each curve (Kahn 1977).

POD activity

After extraction, 0.1 ml of the extract obtained was mixed with 2.7 ml of phosphate buffer, 0.1 ml of 0.46 % (v/v) H_2O_2 and 0.1 ml of 4 % (w/v) guaiacol and in a final volume of 3 ml. POD activity determined by measuring the absorbance at 470 nm for 3 min at 25 °C. One unit of enzymatic activity was defined as the amount of the enzyme that caused a change of 0.01 in absorbance per minute (Macadam et al. 1992).

Extraction and PAL activity

Extraction and measurement of PAL activity were carried out as described by Cabezas-Serrano et al. (2009). Five grams of potato slices were ground and homogenized in 20 ml of cold acetone for 1 min. The residue was washed with cold ethanol, filtered and dried at room temperature. PAL was extracted from acetone powder (200 mg) with 10 ml of 0.1 M sodium borate buffer (pH 8.8), containing 0.02 % of ascorbate. The enzyme extract was centrifuge at 3500 rpm for 15 min, and the supernatant was collected for the determination of PAL activity. The reaction mixture contained 1 ml of extract, 2 ml of water, and 1 ml of 60 µM L-phenylalanine. Enzyme samples were incubated for 1 h at 37 °C. PAL activity was measured by determining the absorbance of cinnamic acid at 290 nm. One unit of enzymatic activity was defined as the amount of the enzyme that caused a change of 0.01 in absorbance per minute.

Total phenolic content (TPC) activity

TPC was determined according to the method of Singleton and Rossi (1965). One gram of potato slices was homogenized in 80 % methanol for 1 min. The extract was filtered and then centrifuged at 3500 rpm for 15 min. Each extract (100 µl) was mixed with 1.58 ml of water, 100 µl of of Folin-Ciocalteau's reagent, and 300 µl of sodium carbonate solution (200 g/l) the mixture was then read at 760 nm. A standard curve of gallic acid was used to calculate the total phenolic content, and was expressed as mg of gallic acid equivalents per 100 g of fresh weight (mg GAE/100 g fw).

Statistical analysis

The experiments were performed in a completely randomized design. All experiments were carried out in triplicate. Data were presented as the mean ± standard deviation of three replicate determinations. Analysis of variance (ANOVA) was performed using Minitab 16 to determine significant differences between the means at the 5 % level. Multiple comparisons were performed using Tukey test.

Results and discussion

PPO activity of potato slices during storage

The effect of AACCl dip, UV-C treatment and the combinations of AACCl dip plus UV-C treatment on PPO activity of potato slices during storage at 4 ± 1 °C is shown in Table 1. Results have shown that AACCl dip, UV-C treatment and their combinations significantly ($p < 0.05$) reduced the POD activity. Undipped and dipped slices exposed to UV-C treatment at 13.68 kJ m^{-2} showed the highest PPO activity during storage. The most effective treatment was observed to be the combination of AACCl dip and UV-C exposure at 6.84 kJ m^{-2}. This was closely followed by the combination of AACCl dip plus UV-C at 11.41 kJ m^{-2}. This observation has shown that PPO activity in potato slices can best be controlled by the application of AACCl dip and a moderate UV-C treatment (i.e. 6.84 kJ m^{-2}) (Table 1). Increasing the UV-C dosage increased the PPO activity significantly ($p < 0.05$). Similar observation was noticed when potato slices were treated with only UV-C (Table 1). Very low UV-C dosage of 2.28 kJ m^{-2} was not as effective as 6.84 kJ m^{-2}. In

Table 1 The effect of AACCl dip, UV-C treatments and the combinations of AACCl dip and UV-C treatments on PPO activity of potato slices during storage at 4 ± 1 °C

Treatments	Day 0	Day 3	Day 7	Day 10
Control	15.63 ± 0.46a, B	18.23 ± 0.67a, A	18.90 ± 0.49a, A	18.64 ± 0.38ab, A
AACCl*	14.83 ± 0.72a, B	15.05 ± 0.67d, B	17.13 ± 0.40bc, A	16.80 ± 0.59cd, A
UV-C at 2.28 kJ m^{-2}	14.83 ± 0.32a, C	16.67 ± 0.32bc, B	18.61 ± 0.51ab, A	17.97 ± 0.09abc, A
UV-C at 6.84 kJ m^{-2}	14.35 ± 0.34a, B	15.01 ± 0.64d, B	16.79 ± 0.30cd, A	16.36 ± 0.32cd, A
UV-C at 11.41 kJ m^{-2}	14.21 ± 0.38a, B	15.81 ± 0.26cd, AB	16.80 ± 0.91cd, A	16.66 ± 0.96cd, A
UV-C at 13.68 kJ m^{-2}	14.58 ± 0.69a, C	17.62 ± 0.56ab, B	19.76 ± 0.69a, A	19.56 ± 0.37a, A
AACCl + UV-C at 2.28 kJ m^{-2}	14.71 ± 0.54a, B	15.77 ± 0.65cd, AB	17.16 ± 0.68bc, A	16.65 ± 0.99cd, A
AACCl + UV-C at 6.84 kJ m^{-2}	14.41 ± 0.70a, A	14.86 ± 0.26d, A	15.17 ± 0.36e, A	15.12 ± 0.28d, A
AACCl + UV-C at 11.41 kJ m^{-2}	14.83 ± 0.73a, A	15.37 ± 0.26cd, A	15.48 ± 0.14de, A	15.40 ± 0.28d, A
AACCl + UV-C at 13.68 kJ m^{-2}	14.99 ± 0.91a, B	15.89 ± 0.06cd, AB	17.07 ± 0.56bc, A	17.13 ± 0.77bc, A

Values represent the mean ± standard error. At the same storage day, means followed by same lowercase letter were not significantly different at $p < 0.05$. For each treatment, means followed by same uppercase letter were not significantly different throughout storage time at $p < 0.05$

* AACCl (1 % ascorbic acid + 0.1 % calcium chloride)

addition, results have shown that AACCl dip and UV-C treatment alone, and in combination at low or high doses cannot completely control PPO activity during storage. Similar observations have been reported in "Jonagored" apple slices (Rocha and Morais 2002; Kang and Saltveit 2003).

Enzymatic browning in fresh- cut fruit and vegetable products is often linked to the action of polyphenol oxidase (PPO) and peroxidase (POD) on polyphenols which form quinones, and then polymerizes. This reaction leads to color changes. The level of PPO activity is used as an index to predict browning susceptibility in cut fruit and vegetable products (Tomás-Barberán and Espin 2001). PPO is the primary enzyme responsible for browning reaction, which catalyzes the hydroxylation of monophenols to *o*-diphenols and the oxidation of *o*-diphenols to their corresponding *o*-quinones (Richard-Forget and Gauillard 1997). Mechanical operations performed on vegetables such as peeling and cutting often cause the compartmentalization of the cells to disappear; this enable PPO to act on phenol substrate, leading to browning reactions (Olivas et al. 2007). In potatoes, PPO activity has been linked with the production of brown color pigmentation (Severini et al. 2003). High doses of UV-C have been reported to trigger PPO activity in banana fruit peel earlier than low dose UV-C (Ding and Yap 2014). Therefore, it accelerates substrate-enzyme contact and leads to earlier occurrence of browning.

POD activity of potato slices during storage

Table 2 shows the effect of AACCl dip, UV-C treatment and their combinations on POD activity of potato slices during storage at 4 °C. All treated slices had lower POD activity than untreated slices throughout the storage days. Similar to PPO activity, the combination of AACCl dip plus UV-C at 6.84 kJ m^{-2} was observed to be the most effective treatment in maintaining low POD activity. Although the combinations of AACCl dip plus moderate UV-C treatment (i.e. 6.84 kJ m^{-2}) gave better results than either UV-C treatment or AACCl dip. However, the combinations of AACCl dip plus UV-C at either high or low dosages produced significantly ($p < 0.05$) higher POD activity than only UV-C treatment at moderate dosages.

The POD activity of all the treated and untreated potato slices was increased up to day 7, and then reduced by day 10. The initial increase in POD activity may be due to progressive tissue damage during storage (Maghoumi et al. 2013b). PPO and POD showed similar behavior throughout the experiment, this agreed with Richard-Forget and Gauillard (1997) that the role of POD in enzymatic browning in apples is highly correlated to PPO activity. Ascorbic acid as a reducing agent was able to decrease the pH or sequestrated metal ions in the product and thus was able to prevent enzymatic browning for some period of time (Jang and Moon 2011; Lamikanra et al. 2005; Wang et al. 2007).

The most common peroxidase enzymes found in animal, plant and microorganism tissues are guaiacol peroxidase and ascorbate peroxidase, catalyzing oxide- reduction between hydrogen peroxide (H_2O_2) and various reducing compounds (Hiraga et al. 2001). Oxidation of many types of phenols by POD enzyme in the presence of peroxidase contributed to enzymatic browning of harvested fruit such as pineapple (Selvarajah et al. 1998; peach (Stutte 1989) and litchi (Zhang et al. 2005). In addition, POD is also

Table 2 The effect of AACCl dip, UV-C treatment and the combinations of AACCl dip and UV-C treatment on POD activity of potato slices during storage at 4 ± 1 °C

Treatments	Day 0	Day 3	Day 7	Day 10
Control	1.76 ± 0.06a, C	2.61 ± 0.05a, A	2.68 ± 0.07a, A	2.41 ± 0.09a, B
AACCl*	1.71 ± 0.10a, C	2.41 ± 0.03ab, A	2.47 ± 0.05ab, A	2.19 ± 0.08bc, B
UV-C at 2.28 kJ m^{-2}	1.73 ± 0.06a, C	2.52 ± 0.07ab, A	2.57 ± 0.12ab, A	2.27 ± 0.10ab, B
UV-C at 6.84 kJ m^{-2}	1.69 ± 0.05a, C	2.23 ± 0.15b, AB	2.37 ± 0.05ab, A	2.03 ± 0.04c, B
UV-C at 11.41 kJ m^{-2}	1.71 ± 0.04a, B	2.29 ± 0.21b, A	2.40 ± 0.15ab, A	2.13 ± 0.04bc, A
UV-C at 13.68 kJ m^{-2}	1.75 ± 0.07a, C	2.47 ± 0.06ab, AB	2.53 ± 0.19ab, A	2.24 ± 0.05ab, B
AACCl + UV-C at 2.28 kJ m^{-2}	1.72 ± 0.05a, C	2.30 ± 0.10ab, AB	2.44 ± 0.11ab, A	2.12 ± 0.02bc, B
AACCl + UV-C at 6.84 kJ m^{-2}	1.69 ± 0.07a, A	1.81 ± 0.09c, A	1.85 ± 0.03c, A	1.75 ± 0.04d, A
AACCl + UV-C at 11.41 kJ m^{-2}	1.71 ± 0.03a, B	1.81 ± 0.06c, AB	1.88 ± 0.05c, A	1.80 ± 0.04d, AB
AACCl + UV-C at 13.68 kJ m^{-2}	1.75 ± 0.08a, C	2.39 ± 0.07ab, AB	2.48 ± 0.08ab, A	2.20 ± 0.08bc, B

Values represent the mean ± standard error. At the same storage day, means followed by same lowercase letter were not significantly different at $p < 0.05$. For each treatment, means followed by same uppercase letter were not significantly different throughout storage time at $p < 0.05$

* AACCl (1 % ascorbic acid + 0.1 % calcium chloride)

involved in several deteriorative changes affecting flavor, texture, color and nutrition in processed fruits and vegetables. There is a relationship between residual POD activity and the development of off- flavors and off- odors (Bett-Garber et al. 2005).

PAL activity of potato slices during storage

The browning inhibition has been correlated with the repressing induction of PAL activity (Murata et al. 2004; Saltveit 2000). PAL is the first key enzyme in the metabolic route of phenols in vegetables and is induced by wounding during minimal processing (Ojeda et al. 2014). It catalyzes deamination reaction which converts L- phenylalanine into *trans*-cinnamic acids and free ammonia ions. This reaction is the first step in the reactions that involve biosynthesizes of the phenylpropanoids (Jones 1984). *O*-Diphenols such as dicaffeoyltartaric acid (diCTA) and 5-caffeoylquinic acid (5-CQA) formed along the phenylpropanoid pathway are oxidized by PPO to form a brown pigment (Murata et al. 2004). The effect of AACCl dip, UV-C treatment and the combinations of AACCl dip plus UV-C treatment on PAL activity of potato slices during storage at 5 °C is shown in Table 3. Potato slices treated with the combinations of AACCl dip plus UV-C at 6.84 kJ m^{-2} were observed to have the lowest PAL activity during storage. At day 7 and day 10, there was no significant difference ($p > 0.05$) in PAL activities among treated and untreated slices.

The PAL activity in potato slices was high initially and then decreased towards the end of storage. The high initial PAL activity was due to wounding after cut. This is a typical response of PAL to stress and the preexisting latent levels of this enzyme in the tissues (Cantos et al. 2001a; Saltveit 1996). However, the lower initial PAL activities of potato slices treated with the combination of AACCl dip and UV-C may be attributed to the presence of ascorbic acids which caused a decrease in pH as this enzyme requires a pH close to pH 8 for its optimal activity (Ojeda et al. 2014). High level of PAL activity is always associated with an increase in the concentration of total phenolic content, which act as substrates for oxidative enzymes of PPO and POD. Therefore, the level of browning substrate may be regulated by a dynamic equilibrium of PPO, POD and PAL activities (Sun et al. 2009). The decline in PAL activity in all treated and untreated slices was probably related to the auto-regulation of metabolic activity (Vitti et al. 2011).

TPC of potato slices during storage

Phenolic compounds are known to contribute to the taste, color, and nutritional value of potatoes (Cheynier 2005). The effect of AACCl dip, UV-C treatment, and their combination on TPC of potato slices is shown in Table 4. The TPC of potato slices treated with the combinations of AACCl dip plus UV-C were higher than those treated with AACCl alone. This was followed by samples treated with only UV-C and lastly control. UV-C treatment increased TPC of potato slices. The untreated slices showed the lowest TPC throughout the storage. Potato slices treated with the combination of AACCl dip and UV-C at 6.84 kJ m^{-2} was able to maintain TPC throughout the storage period.

Phenols are secondary metabolic compounds which exhibits different chemical structures and different

Table 3 The effect of AACCl dip, UV-C treatment and the combinations of AACCL dip and UV-C treatment on PAL activity of potato slices during storage at 4 ± 1 °C

Treatments	Day 0	Day 3	Day 7	Day 10
Control	0.16 ± 0.08a, A	0.14 ± 0.00a, B	0.13 ± 0.01a, B	0.11 ± 0.00a, C
AACCl*	0.14 ± 0.01cd, A	0.13 ± 0.00ab, A	0.12 ± 0.00a, B	0.10 ± 0.01a, B
UV-C at 2.28 kJ m^{-2}	0.15 ± 0.00abc, A	0.13 ± 0.01ab, AB	0.12 ± 0.00a, B	0.10 ± 0.00a, C
UV-C at 6.84 kJ m^{-2}	0.14 ± 0.00abc, A	0.13 ± 0.01ab, AB	0.12 ± 0.00a, BC	0.10 ± 0.01a, C
UV-C at 11.41 kJ m^{-2}	0.15 ± 0.00abc, A	0.14 ± 0.00a, A	0.12 ± 0.00a, B	0.10 ± 0.00a, C
UV-C at 13.68 kJ m^{-2}	0.16 ± 0.01ab, A	0.14 ± 0.01a, A	0.12 ± 0.00a, B	0.11 ± 0.00a, B
AACCl + UV-C at 2.28 kJ m^{-2}	0.14 ± 0.00c, A	0.13 ± 0.01ab, AB	0.12 ± 0.01a, B	0.10 ± 0.00a, C
AACCl + Uv at 6.84 kJ m^{-2}	0.12 ± 0.01d, A	0.11 ± 0.00b, AB	0.11 ± 0.01a, AB	0.09 ± 0.00a, B
AACCl + UV-C at 11.41 kJ m^{-2}	0.13 ± 0.00cd, A	0.12 ± 0.01ab, AB	0.11 ± 0.02a, B	0.10 ± 0.01a, C
AACCl + UV-C at 13.68 kJ m^{-2}	0.14 ± 0.00bc, A	0.13 ± 0.01ab, A	0.12 ± 0.01a, AB	0.11 ± 0.01a, B

Values represent the mean ± standard error. At the same storage day, means followed by same lowercase letter were not significantly different at $p < 0.05$. For each treatment, means followed by same uppercase letter were not significantly different throughout storage time at $p < 0.05$

* AACCl (1 % ascorbic acid + 0.1 % calcium chloride)

Table 4 The effect of AACCl dip, UV-C treatment and the combinations of AACCl dip and UV-C treatment on TPC potato slices during storage at 4 ± 1 °C

Treatments	Day 0	Day 3	Day 7	Day 10
Control	42.19 ± 1.15e, B	45.03 ± 0.50d, A	40.60 ± 0.83f, B	37.96 ± 0.83f, C
AACCl*	48.05 ± 1.28bc, AB	51.17 ± 1.37abc, A	48.34 ± 1.31bc, AB	45.39 ± 1.20bc, B
UV-C at 2.28 kJ m^{-2}	44.71 ± 1.47cde, AB	48.22 ± 0.53cd, A	42.56 ± 2.37ef, BC	39.69 ± 1.17ef, C
UV-C at 6.84 kJ m^{-2}	46.38 ± 1.31cd, AB	48.57 ± 0.50bcd, A	44.30 ± 0.89de, BC	42.13 ± 1.39cde, C
UV-C at 11.41 kJ m^{-2}	45.34 ± 2.26cde, AB	48.74 ± 1.57bcd, A	43.94 ± 1.08def, B	41.55 ± 1.14de, B
UV-C at 13.68 kJ m^{-2}	43.30 ± 0.71de, B	48.42 ± 0.87cd, A	42.92 ± 1.11ef, B	39.84 ± 1.45ef, C
AACCl + UV-C at 2.28 kJ m^{-2}	51.35 ± 1.05ab, AB	53.03 ± 4.87abc, A	45.58 ± 0.55cde, BC	42.33 ± 1.29cde, C
AACCl + UV-C at 6.84 kJ m^{-2}	52.58 ± 1.60a, A	54.59 ± 0.90a, A	52.35 ± 0.85a,	51.00 ± 1.00a, B
AACCl + UV-C at 11.41 kJ m^{-2}	52.25 ± 1.00a, A	51.42 ± 0.70abc, AB	49.69 ± 0.37ab, BC	48.15 ± 1.43ab, C
AACCl + UV-C at 13.68 kJ m^{-2}	53.84 ± 1.02a, A	53.74 ± 1.21cd, A	46.43 ± 1.36bcd, B	44.22 ± 1.11cd, B

Values represent the mean ± standard error. At the same storage day, means followed by same lowercase letter were not significantly different at $p < 0.05$. For each treatment, means followed by same uppercase letter were not significantly different throughout storage time at $p < 0.05$

* AACCl (1 % ascorbic acid + 0.1 % calcium chloride)

biological properties in vegetables. They are capable of affecting the appearance, flavor, texture and safety of processed products (Robinson 1991). TPC in the UV-C treated samples was observed to be higher than the untreated samples. The reason for this might be due to induction of phenolic biosynthesis which occurred under stress conditions such as excessive UV light, wounding or pathogen infection (Wang et al. 2015). Similar findings had been reported in UV-C treated table grapes (Cantos et al. 2001b) and lemons (Ben-Yehoshua et al. 1992). Total phenol content is always linked with enzymatic browning as it is a consequence of the reaction between oxidative enzymes, such as polyphenol oxidase and phenols which occurs after the breakdown of cell compartmentalization (Degl'Innocenti et al. 2005; Marangoni et al. 1996). Browning changes have been correlated with a reduction in total phenolics and an increased in PPO, (Toivonen 1992). Cantos et al. (2002) reported that relatively high phenol content in potato does not limit the browning rate; but rather, it explained partially the browning susceptibility of the potato with the extend of PAL activity.

Conclusion

After 10 days storage at 4 ± 1 °C, potato slices treated with the combination of AACCl dip and UV-C at 6.84 kJ m^{-2} produced the lowest PPO, POD, and PAL

activities, as well as the highest phenolic content. In addition, this treatment was able to maintain lower enzymatic activities throughout the storage period.

Acknowledgments The authors are grateful for the extensive financial support of the Fundamental Research Scheme (No. 5524558) at the University Putra Malaysia.

Author contributions Li Shing Teoh was involved with planning, collecting, interpreting and drafting of the manuscript. Lasekan, Noranizan and Norhashila conceived the idea and edited the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interest.

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