

*Full Length Research Paper*

# Effect of ultraviolet-C (UV-C) illumination on postharvest quality and bioactive compounds in yellow bell pepper fruit (*Capsicum annuum* L.) during storage

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The effects of ultraviolet-C (UV-C) illumination on postharvest quality and bioactive compounds of yellow bell pepper during refrigerated storage were investigated. The yellow bell pepper fruit were illuminated with three different UV-C dosages, 2.2, 4.4 and 6.6 kJ m<sup>-2</sup> and then stored at 12 ± 1°C for 15 days. UV-C illumination at 6.6 kJ m<sup>-2</sup> showed the best results in maintaining firmness and reducing the increase in weight loss and electrolyte leakage (EL) throughout storage. No significant differences in both weight loss and firmness were detected in the fruit illuminated with UV-C at 2.2, 4.4 kJ m<sup>-2</sup> and the control fruit over storage. UV-C illumination had no effect on the changes in tristimulus colours (lightness, L\* value, and yellowness, b\* value), ascorbic acid (AsA) and total phenol (TP) contents of the yellow pepper fruit and these remained constant over storage. UV-C illumination at 6.6 kJ m<sup>-2</sup> enhanced total carotenoid (TC), total flavonoid (TF) contents, antioxidant capacity and the activities of antioxidant enzymes including catalase (CAT), superoxide dismutase (SOD), guaiacol peroxidase (G-POD) and ascorbate peroxidase (AsA-POD) when compared to the control fruit. In conclusion, UV-C illumination prevented the loss of firmness, weight and EL increase and enhanced biologically active compounds, especially, antioxidants, in yellow bell pepper fruit.

**Key words:** Yellow bell pepper fruit, UV-C illumination, postharvest quality, bioactive compounds.

## INTRODUCTION

Recently, the demand for fresh fruit and vegetables has been increased markedly, as the concern of human health has been promoted. It is universally recognized that fresh fruit and vegetables are the excellent sources of biologically active components that impact health benefits beyond basic nutrient (Erkan et al., 2008). As the consumption of fresh product has been continuously increased, the biologically active compounds contents are becoming an important factor of the quality of fresh fruit and vegetables. The changes in biologically active compounds during postharvest period have been recently

interested by consumers. Nowadays, the research in postharvest technology has focused on the application of physical method to replacing the use of chemical control techniques (Wisniewski et al., 2001). ultraviolet-C (UV-C) irradiation is a potential technology used as an alternative to chemical treatment for postharvest fruit and vegetables. Generally, UV-C is harmful to tissues but it can be a beneficial effect on fresh fruit and vegetables at low doses (Shama, 2007) to induce their defense metabolic response including an accumulation of phytoalexins and activate genes encoding pathogenesis-related proteins that arises as a result of the perceived abiotic stress which is known as hermosis (Calabrese et al., 1987; Obande et al., 2011). Phytoalexin accumulation is associated with the inducible defense such as cell wall degradation, defense enzymes and antioxidant activity

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(González-Aguilar et al., 2007).

Barka et al. (2000) suggested that the radiation with hormic dose lowered the lipid peroxidation markers and softening in tomato fruit which might be related to the activation of an antioxidant enzyme and the inhibition of cell wall enzyme activities. Obande et al. (2011) reported that preharvest UV-C treatment maintained firmness and induced pathogen resistance in postharvest tomatoes fruit. Moreover, the effect of UV-C treatment on enhancing antioxidant capacity and antioxidant enzymes has been reported in strawberry fruit (Erkan et al., 2008) and fresh-cut mangoes (González-Aguilar et al., 2007).

Yellow bell pepper (*Capsicum annum* L.) is one of the rich sources of bioactive compounds, especially, carotenoids and vitamin C (Howard et al., 2000; Antoniali et al., 2007; Sakaldaş and Kaynaş, 2010) and contains moderate to high level of phenolics and flavonoids contents (Hasler, 1998; Howard et al., 2000). The main factors affecting postharvest quality of bell pepper are shriveling, decay development and chilling injury (at the temperature below 7 to 10°C) (Vicente et al., 2008; Sakaldaş and Kaynaş, 2010). Previous works had reported the use of UV-C irradiation to reduce decay, chilling injury incidence, and to maintain firmness of bell pepper fruits (Vicente et al., 2008; Sakaldaş and Kaynaş, 2010). Andrade et al. (2011) had reported that UV-C treatment is a potential alternative to prevent chilling injury and weight loss in red pepper of which these might be related to increased antioxidant enzyme activities. However, little information is available on the effect of UV-C treatment on bioactive compounds in yellow bell pepper. Therefore, the aim of this work was to investigate the effect of UV-C illumination on postharvest quality attributes and the changes in bioactive compounds, including antioxidant capacity, total phenol (TP), total flavonoid (TF) and ascorbic acid (AsA) contents and the activities of antioxidant enzymes in yellow bell pepper during refrigerated storage.

## MATERIALS AND METHODS

### Plant materials

Yellow bell pepper fruit (*C. annum* L.) were obtained from a commercial grower in Sakon Nakhon province, Thailand. The fruit were harvested at the maturity of 60 days after full bloom (mature green stage) and screened for uniformity that is, being free from physical damages and diseases. The fruit were then delivered to Plant Physiology Laboratory at Faculty of Natural Resources and Agro-Industry, Kasetsart University in 1 h after being harvested. The fruits were immediately cleaned using tap water and air-dried. Two fruits were packed in a foam tray. For UV-C illumination, the bell pepper trays were placed into a box (1.32 m length, 1.85 m wide and 0.8 m deep) containing two germicidal UV lamps (TUV, 30W, Salvania, Japan) and were irradiated at distance of 70 cm for 30, 60 and 90 min to obtain dosages of 2.2, 4.4 and 6.6 kJ m<sup>-2</sup>, respectively. Each fruit was rotated manually two times to ensure uniform surface exposure to UV light. Non-illuminated yellow bell pepper fruit were considered as the control. After treatment, the fruit tray was wrapped with PVC cling film and then stored at 12 ± 1°C

for 15 days. Ten replications (20 fruits) were used to determine weight loss, texture, electrolyte leakage (EL), tristimulus color. Given the reduced weight loss, reduced EL increase and maintained firmness of the 6.6 kJ m<sup>-2</sup> UV-C illumination (as shown in result) and this condition was chosen to investigate bioactive compounds such as antioxidant capacity, TC, TP, TF, AsA contents and the activities of antioxidant enzymes, namely catalase (CAT), superoxide dismutase (SOD), guaiacol peroxidase (G-POD) and ascorbate peroxidase (AsA-POD) in the yellow bell pepper fruit compared to the untreated fruit. On each sampling day, fruit was analyzed immediately or otherwise cut, frozen and stored at -80°C until use. Five replications of samples were used in the course of the experiment.

### Weight loss, firmness, electrolyte leakage and superficial tristimulus colour

Fresh weight loss of the yellow bell pepper fruit was measured before storage and in every 3 days until the end of storage. The percentage of weight loss during storage was calculated compared to the initial weight. Texture of the fruit was determined using Effegi fruit firmness tester. The data were expressed as newton (N). The EL measurement was modified from the method described by Ergun et al. (2005). The fruit were diced by using a cork borer (8 mm diameter). Twenty discs of the fruit were put into 30 ml of 0.4 M mannitol. The conductivity of the solution was immediately measured using a conductivity meter (sension<sup>TM</sup>5, Hatch Company, USA) and then incubated in shaking bath for 3 h at room temperature. After incubation, the sample was boiled in an autoclave for 1 h at 121°C and the conductivity was again measured. The EL was expressed as percentage of tissue EL. Superficial tristimulus colour was determined using a HunterLab MiniScan<sup>®</sup>XE Plus (Hunter Associates Laboratory Inc., USA). The tristimulus colour was present as lightness (*L*<sup>\*</sup>value) and yellowness (*b*<sup>\*</sup>value). Measurements were performed in triplicate.

### Total carotenoid content

Total carotenoid content of the yellow bell pepper fruit was determined using method as described by Hornero-Mendez and Miguez-Mosquera (2001). Ten grams of the yellow bell pepper fruit were extracted with acetone using a homogenizer. Samples were centrifuged at 12,000 × g for 10 min at 4°C. The pellet was again extracted until no colour. The supernatants were collected and brought to 100 ml with acetone. Absorbance at 472 nm was recorded. The results were expressed as OD<sub>472</sub> kg<sup>-1</sup> of fruit.

### Total flavonoid content

The TF content was determined using a method described by Jia et al. (1999). Five grams of the yellow bell pepper tissue were extracted with a 25 ml of 80% methanol and 0.5% sodium bisulfate and then centrifuged at 1200 × g for 10 min at room temperature. The reaction was begun when a 0.25 ml of the extract or catechin standard solution mixed with 1.25 ml of distilled water, 75 µl of 0.5% NaNO<sub>2</sub>. The mixture was left for 6 min and then 150 µl of 10% AlCl<sub>3</sub>·6H<sub>2</sub>O was added and allowed to stand for 5 min. After that, 0.5 mL of 1 M NaOH was added. The absorbance of the mixture was measured at 510 nm. The data were expressed as µg catechin equivalents (CE) per 100 g fresh weight of fruit (FW).

### Total phenol content

Two grams of the yellow bell pepper fruit tissue was homogenized

with 20 ml of cold distilled water and then centrifuged at  $12000 \times g$  for 10 min at room temperature. TP content was monitored using the method as described by Slinkard and Singleton (1977). 1 ml of the supernatant was added to the solution of 1 ml 50% (v/v) Folin-Ciocalteu reagent solution and 2 ml saturated  $\text{Na}_2\text{CO}_3$  solution. The mixture was left at room temperature for 30 min. The absorbance at 750 nm was recorded using a spectrophotometer. A standard curve of gallic acid (GA) solution was used to quantify the TP content. TP content of the yellow bell pepper fruit was expressed in term of  $\mu\text{g}$  GA per 100 g FW.

#### Ascorbic acid content measurement

Five grams of the yellow bell pepper fruit were homogenized with 20 ml of cold 5% metaphosphoric acid and then centrifuged at  $12000 \times g$  for 15 min at  $4^\circ\text{C}$ . The AsA content was assayed according to the method of Hashimoto and Yamafuji (2001). A 0.8 mL of supernatant was mixed with 0.4 ml of 2% di-indophenol. Then, 0.8 ml of 2% thiourea and 0.2 ml of 1% dinitrophenol hydrazine were added into the mixture and the mixtures were then incubated at  $37^\circ\text{C}$  for 3 h. After incubation, 1 ml of 85% sulfuric acid was added and the mixture was again incubated at ambient temperature for 30 min. Absorbance at 540 nm were recorded. The AsA content was expressed as mg AsA per 100 g FW.

#### Antioxidant capacity measurement

Two grams of the bell pepper was homogenized with 20 ml of cold distilled water and then centrifuged at  $4000 \times g$  for 15 min. The supernatant was collected and kept in ice bath. Ferric reducing antioxidant potential (FRAP) was assayed using the method described by Benzie and Strain (1996). FRAP reagent was a mixture of 25 ml acetate and buffer pH 3, 2.5 ml and 10 mM 2, 4, 6-trioryridyl-1, 3, 5-triazine (TPTZ) and 2.5 ml 20 mM ferric chloride hexahydrate. The reaction was started when 0.3 ml of the supernatant was added into 3 ml of FRAP solution. The mixture was incubated at room temperature for 30 min and then absorbance measured at 630 nm using a spectrophotometer. Antioxidant capacity was expressed as  $\mu\text{mole}$  Trolox equivalents (TE) per 100 g FW.

#### Activities of antioxidant enzymes measurements

CAT (EC 1.11.1.6) activities were assayed at  $25 \pm 2^\circ\text{C}$ , following the method described by Andrade et al. (2011). CAT activity was determined by monitoring the decomposition of  $\text{H}_2\text{O}_2$  at 410 nm. The reaction mixture (1 ml) contained 0.1 M phosphate buffer (pH 7.0), 0.15 mM  $\text{H}_2\text{O}_2$  and 250  $\mu\text{l}$  of the extract. Aliquots of 150  $\mu\text{l}$  of the reaction mixture were taken at 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 and 5.0 min and then added to the test tubes containing 300  $\mu\text{l}$  of 0.02 M  $\text{TiCl}_4$ , 200  $\mu\text{l}$  of conc.  $\text{H}_2\text{SO}_4$  and 1.35 of distilled water. The absorbance at 410 nm was recorded. One unit of CAT activity and enzyme activity unit (EAU), was defined as the amount of enzyme consuming of  $\text{H}_2\text{O}_2$  per min. SOD (EC 1.15.1.1) activity was measured using a modification of the method of Ukedate et al. (1997). The reaction mixture contained 50 mM sodium phosphate buffer (pH 8.0), 3 mM xanthine, 3 mM EDTA, 0.75 mM XTT (2, 3-bis(2-methoxy-4-nitro-5-sulfophenyl)-2H-tetrazolium-5-carboxanilide), and 0.14 units of xanthine oxidase. Activity was determined by monitoring the reduction rate of XTT at 470 nm, using mixtures with and without the enzyme extract. The unit of SOD was defined as the amount of enzyme that produced half-maximal inhibition.

The assay of G-POD (EC 1.11.1.7) and AsA-POD (EC 1.11.1.11) activities was modified from the method described by Andrade et al.

(2011). The reaction mixture of guaiacol-POD contained 600  $\mu\text{l}$  of 0.5% (v/v) guaiacol, 500  $\mu\text{l}$  of enzyme extract and 1.6 ml phosphate buffer (pH 7.0). The reaction started when 300  $\mu\text{l}$  of 0.059 M  $\text{H}_2\text{O}_2$  was added. Enzyme activity was determined by monitoring the increase in the absorbance at 470 nm. The unit of the enzyme activity was expressed as the  $\Delta\text{OD}$  per min per g FW.

The mixture of AsA-POD consisted of 600  $\mu\text{l}$  of 5 mM sodium ascorbate, 500  $\mu\text{l}$  of enzyme extract and 1.6 ml of phosphate buffer (pH 7.0) and the reaction began when 300  $\mu\text{l}$  of  $\text{H}_2\text{O}_2$  was added. The absorbance at 290 nm due to the oxidation of ascorbate and the enzyme activity unit was expressed as the amount of enzyme that oxidized 0.01 mmol ascorbate per minute per g FW.

#### Statistical analysis

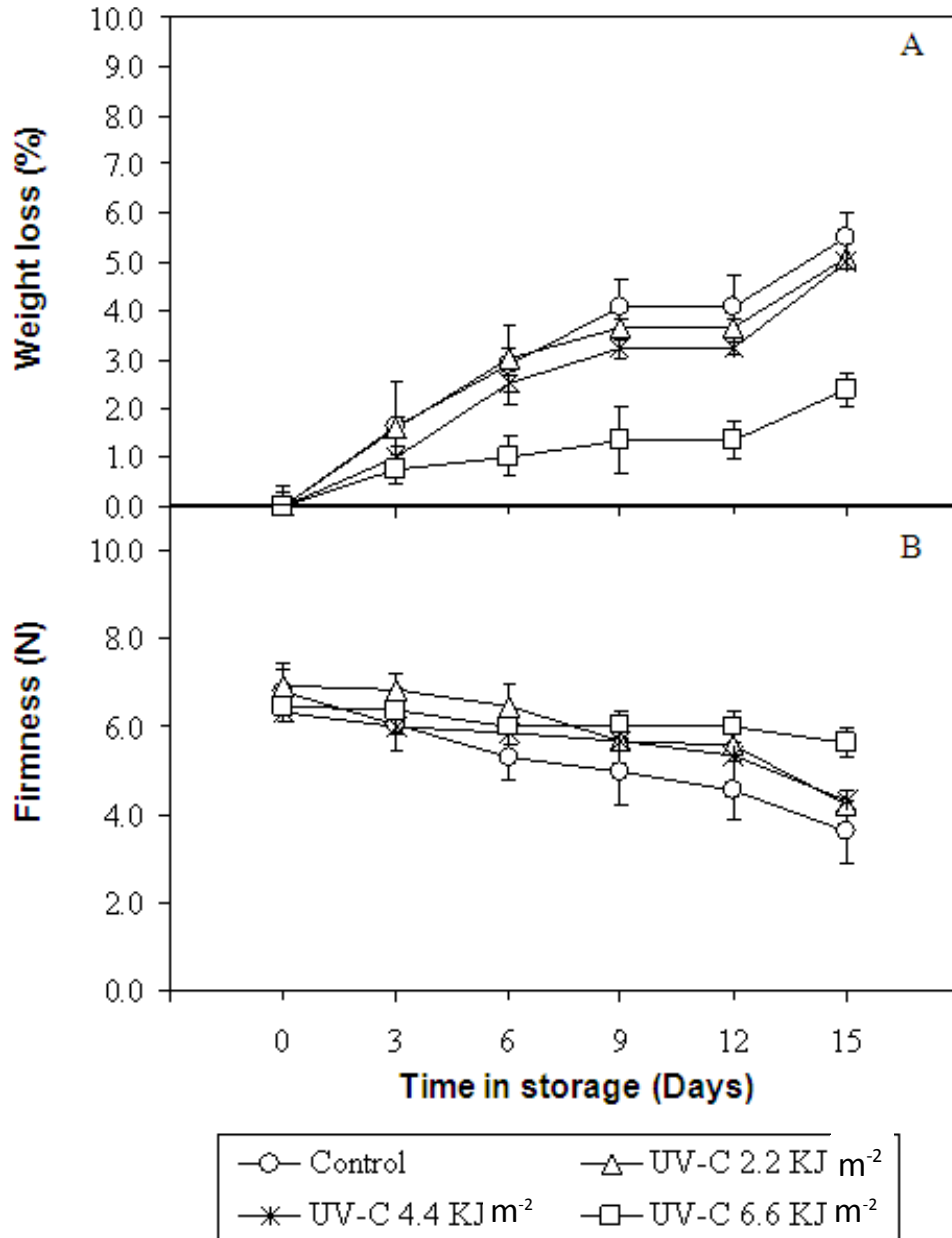
The Complete Randomized Design (CRD) was used in the experiment. Five replicates of 2 fruits were evaluated. Statistical analysis was carried out using the analysis of variances (ANOVA) performed in SAS software program. The treatment means were separated using the least significant difference (LSD) method at a significance level of  $p \leq 0.05$ . Data are shown as mean  $\pm$  standard error (S.E.).

## RESULTS AND DISCUSSIONS

#### Weight loss and firmness

Fresh weight and firmness were recognized as the main factors affecting quality attributes of fresh commodities. The results in Figure 1A showed that the weight loss of the yellow bell pepper fruit increased continuously throughout storage in all treatments. UV-C illumination reduced the increase in loss when compared to the control fruit. The yellow bell pepper fruit illuminated with 2.2 and 4.4  $\text{KJ m}^{-2}$  UV-C showed weight loss slightly lower than the control fruit. The weight loss of the fruit illuminated with an UV-C dose of 6.6  $\text{KJ m}^{-2}$  was significantly lower than that of other treatments ( $p < 0.05$ ). In the same context, UV-C illumination inhibited the loss of firmness, as shown in Figure 1B. A marked loss of firmness was shown in the control fruit. The yellow bell pepper fruit illuminated with 2.2 and 4.4  $\text{KJ m}^{-2}$  UV-C showed a slight decrease in firmness over storage whilst the firmness of 6.6  $\text{KJ m}^{-2}$  UV-C treated fruit remained constant over storage at  $12 \pm 1^\circ\text{C}$  for 15 days and the data were significantly higher than that of the control fruit ( $p < 0.05$ ).

It is widely accepted that the increase in weight loss is related to the reduction of tissue turgor pressure which could lead to the loss of firmness. Wills et al. (2007) suggested that 4 to 6% weight loss in fresh commodities led to shriveled fruit and commercial value loss. The results showed that the weight loss of the control fruit at day 15 reached to 5.5% and the firmness markedly decreased when compared to the UV-C illuminated fruit. These suggest that UV-C illumination effectively reduced the losses of fresh weight and firmness of the yellow bell pepper fruit during storage. Similar results have also been reported in tomato fruit (Barka et al., 2000; Liu et



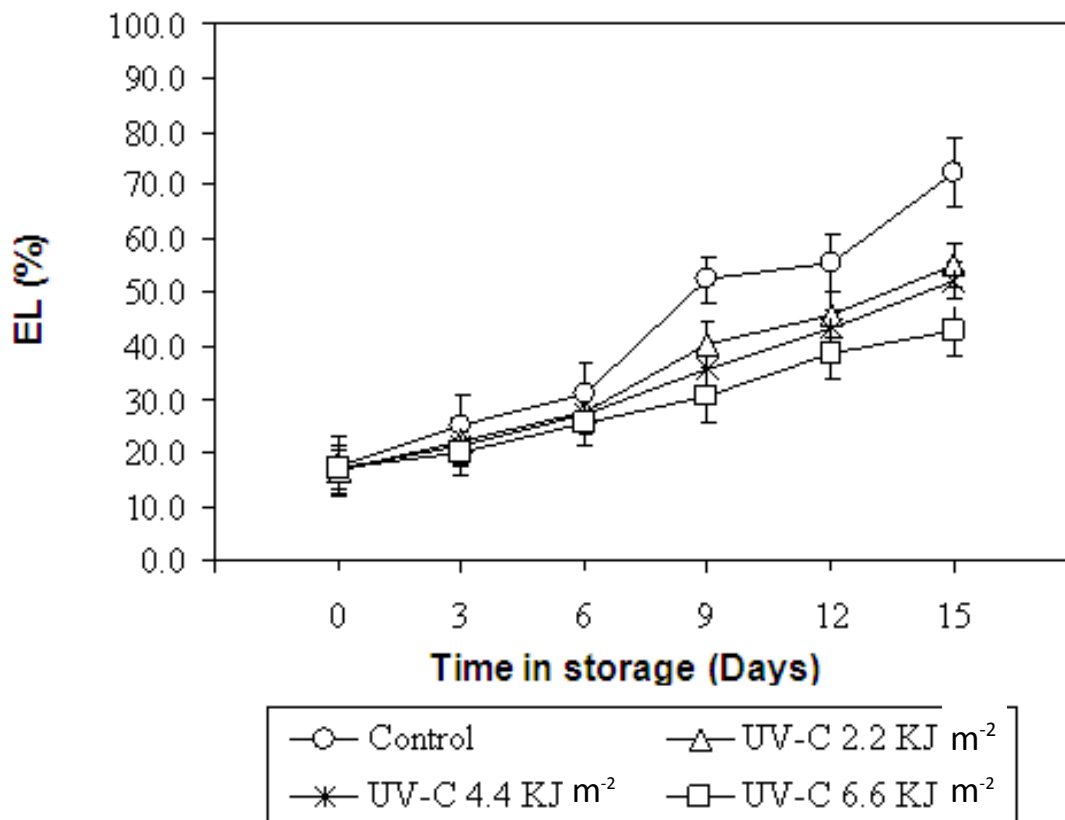
**Figure 1.** Weight loss (A) and firmness (B) of untreated and UV-C treated yellow bell pepper fruit stored at  $12 \pm 1^\circ\text{C}$  for 15 days. Data are the mean of five replications and vertical bars represent standard error.

al., 2009; Obande et al., 2011), red pepper fruit (cv. Zafiro) (Vincente et al., 2005), kiwifruit (Bal and Kok, 2009) and strawberry fruit (Erkan et al., 2008). Andrade et al. (2011) had also reported that UV-C treatment inhibited the increase in weight loss of red pepper fruit during storage. The higher values of firmness detected in the UV-C illuminated fruit were associated with the effect of UV-C on the reduction of cell wall degrading enzymes activity as described by Barka et al. (2000) and Steven et al. (2004). Lower weight loss and higher firmness of the fruit treated with  $6.6 \text{ KJ m}^{-2}$  UV-C might be related with the prevention of cell membrane dysfunctions as the

lower electrolyte leakage was detected when compared to the untreated fruit (Figure 2). Supapvanich and Tucher (2012) suggested that the loss of fresh weight and firmness in melon fruit were positively associated with the increase in electrolyte leakage of tissue.

#### Electrolyte leakage

The increases in EL were observed in both control and UV-C illuminated fruit throughout storage (Figure 2). The UV-C illuminated fruits showed lower EL than the control



**Figure 2.** Electrolyte leakage (EL) of untreated and UV-C treated yellow bell pepper fruit stored at  $12 \pm 1^\circ\text{C}$  for 15 days. Data are the mean of five replications and vertical bars represent standard error.

fruit over storage. The least EL was found in the fruit illuminated with an UV-C dose of  $6.6 \text{ KJ m}^{-2}$ . The results also showed that the increase in EL was concomitant with the reduction of firmness and the increase in weight loss as shown in Figure 1. UV-C illumination was able to reduce the increase in EL of yellow bell pepper fruit which a similar result had been reported in red pepper treated with UV-C (Vincente et al., 2005). This could be explained that UV-C light induces biological stress and defense mechanism (Mercier, 1997) and prevents membrane damages by inducing polyamines accumulation in plant tissue (González-Aguilar et al., 2004).

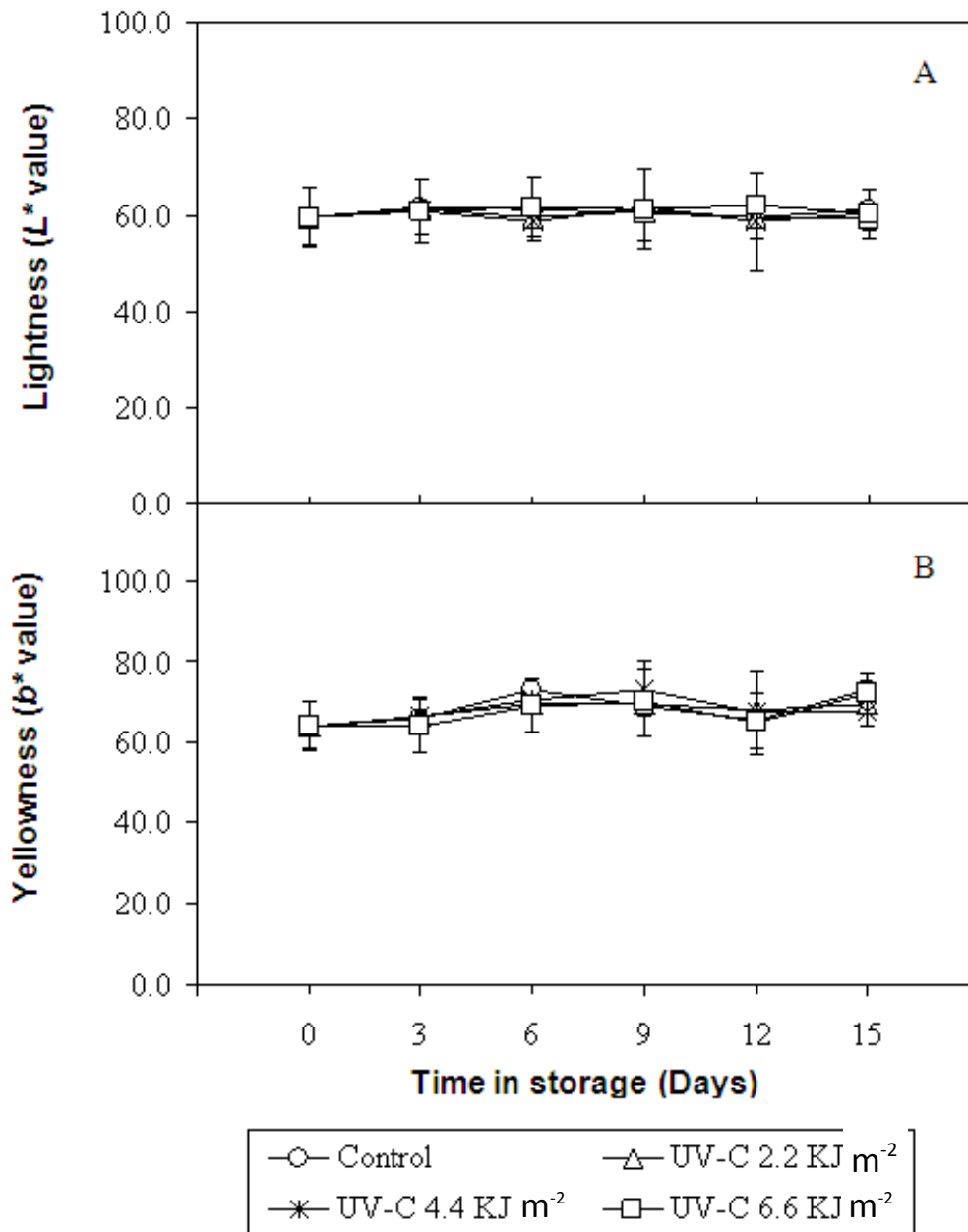
### Superficial tristimulus colour

No differences in both  $L^*$  and  $b^*$  values were found between the control and UV-C illuminated fruits (Figure 3).  $L^*$  value remained constant whilst a slight increase in  $b^*$  value was detected in all treatments during storage for 15 days. UV-C illumination had no effect on change in tristimulus colour of the yellow bell pepper fruit throughout storage. A similar result has been reported in red pepper cv. Zafiro (Vincente et al., 2005) and tomatoes cv. Red Ruby (Liu et al., 2009) UV-C illumination

illumination shows no effect on colour changes during storage. Artés-Hernández et al. (2010) had also reported that the interaction among UV-C doses and storage time was not significant for  $L^*$  value of fresh-cut watermelon fruit. The results showed that the  $6.6 \text{ KJ m}^{-2}$  UV-C illuminated fruit had lower weight loss and EL and higher firmness when compared to other treatments; the bioactive compounds in the yellow bell pepper fruit were also investigated.

### Total carotenoid content

The TC content of the yellow bell fruit increased continuously with storage time (Figure 4). UV-C illumination enhanced TC content in the yellow bell pepper fruit. Just after UV-C irradiation, there was no difference in the TC content compared to the control fruit. After 9 days, TC content of the UV-C illuminated fruit showed significantly higher than that of the control fruit until the end of storage (15 days) ( $p < 0.05$ ). It is widely recognized that the increase in TC content was concomitant with the increase in  $b^*$  value (Figure 3B) and nutritional values as it is the sources of vitamin A and has a role in antioxidant defense. Interestingly, the yellowness of the bell pepper



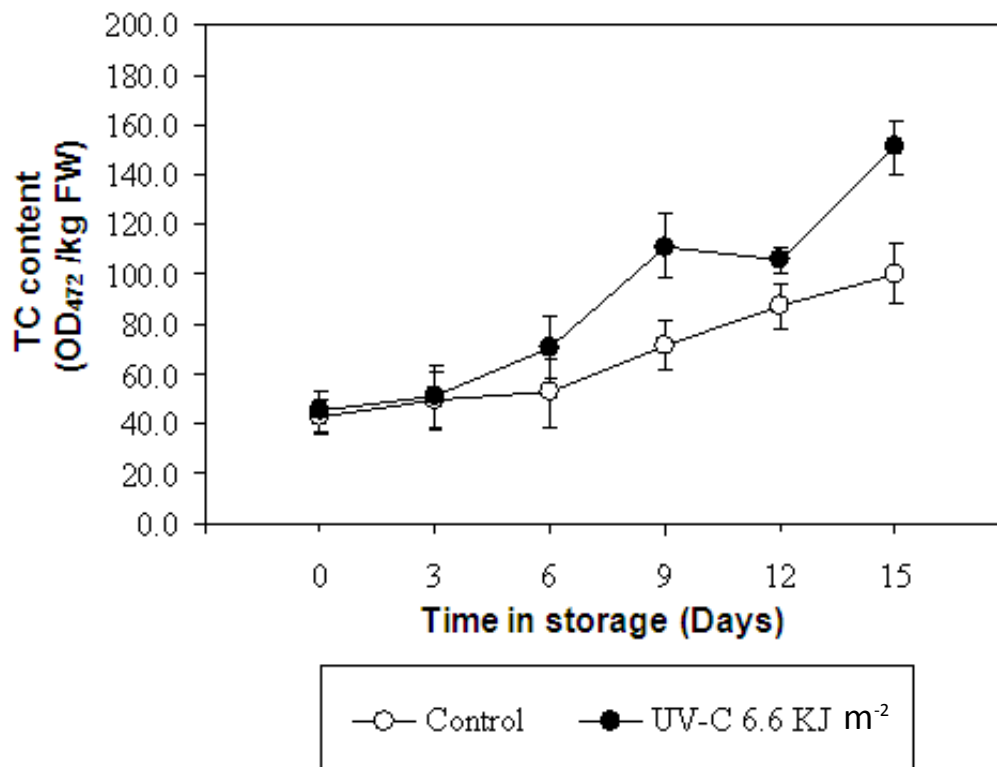
**Figure 3.** Changes in lightness ( $L^*$  value) (A) and yellowness ( $b^*$  value) (B) of untreated and UV-C treated yellow bell pepper fruit stored at  $12 \pm 1^\circ\text{C}$  for 15 days. Data are the mean of five replications and vertical bars represent standard error.

slightly increased and there was no significant differences between UV-C illuminated fruit and the control fruit, whereas, TC content of the UV-C treated fruit was higher than that of the control fruit. The result showed the contrast compared to the previous works. Vincente et al. (2005) had reported that UV-C illumination lowered TC content in red pepper fruit when compared to the untreated fruit. Liu et al. (2009) also reported that lycopene content, known as a carotenoid compounds, in "Red ruby" tomato fruit was enhanced by UV-C light whilst  $\beta$ -carotene was not affected. However, this result

shows that UV-C illumination induced the accumulation of TC content in yellow pepper fruit.

#### Ascorbic acid, total flavonoid and total phenols contents

As shown in Figure 5A and 5C, AsA and TP contents from the yellow bell pepper fruit illuminated with  $6.6 \text{ kJ m}^{-2}$  UV-C and the control fruits seemed constant during 15 days storage period. However, the UV-C illuminated fruit



**Figure 4.** Total carotenoid (TC) content of untreated and UV-C treated yellow bell pepper fruit stored at  $12 \pm 1^\circ\text{C}$  for 15 days. Data are the mean of five replications and vertical bars represent standard error.

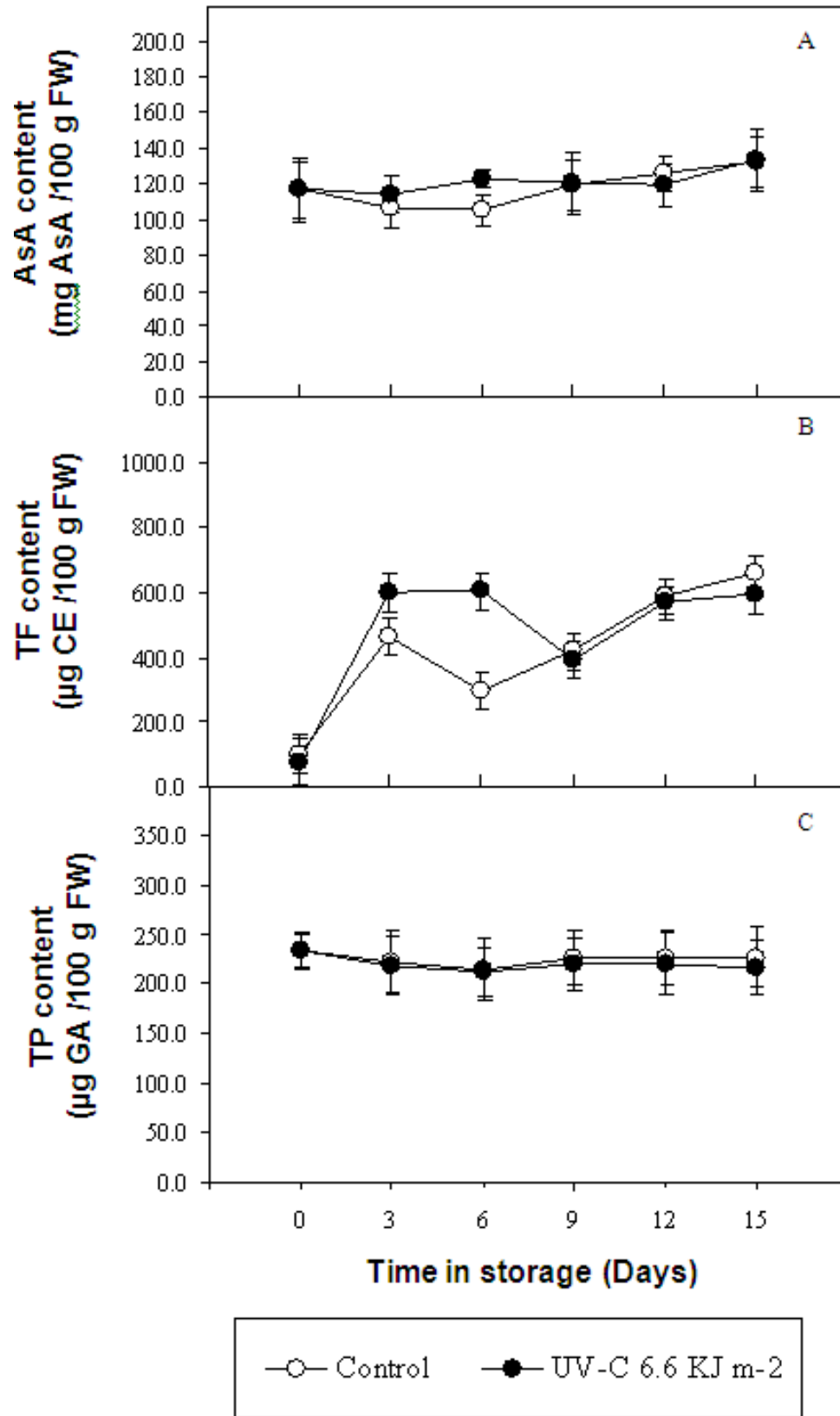
showed slightly higher in both AsA and TP contents than the control fruit. An increase in TF content was found in both the UV-C illuminated and the control fruits on day 3 (Figure 5B). A decrease in the compound of the control was detected on day 6 and then continuously increased over storage whilst that of the UV-C illuminated fruit was found on day 9 and again increased over storage. At day 3 and 6 of storage, TF content of the UV-C illuminated fruit was significantly higher than that of the control ( $p < 0.05$ ). After that, no significant difference was found until the end of storage period.

Flavonoids, phenols compounds and AsA are important nutrients found in fruit and vegetables. These compounds act in plants as antioxidants and antimicrobials (Iwashina, 2003) and also produce the beneficial effects by scavenging free radicals in human beings (Chun et al., 2003). Previous works reported that UV-C application increased the accumulation of AsA content (Nasibi and M-Kalantari, 2005; Martínez et al., 2005; Andrade et al., 2011), TF, and TP compounds (Nigro et al., 2000; González-Aguilar et al., 2007). Although, no different levels of both AsA and TP contents in both the UV-C illuminated and the control fruits were found in this study, both compounds of UV-C illuminated fruit showed slightly higher than those of the control fruit. Nigro et al. (2000) addressed that the increase in phenols of strawberry fruit treated with UV-C was related to the increment of

phenylalanine ammonia-lyase activity (PAL), a key enzyme in the phenol biosynthesis, Artés-Hernández et al. (2010) suggested that UV-C did not significantly affect the vitamin C content in fresh-cut watermelon. Burana and Srilaong (2009) reported that UV-C irradiation reduced the loss of AsA content in Chinese kale during storage. In contrast, a negative effect on the maintenance of AsA by UV-C illumination was found in fresh-cut mango fruit which due to the oxidation of AsA (González-Aguilar et al., 2007). The induction of TF content in yellow bell pepper fruit by UV-C illumination is shown in this work. In agreement with this result, in vegetables such as broccoli florets and bean leaves and fresh-cut mango fruit, TF content was enhanced after UV-C illumination (Costa et al., 2006; González-Aguilar et al., 2007). Kucera et al. (2003) had explained that the induction of TF is supported by the hypothesis of the existence of different UV-signaling pathways in plant tissues.

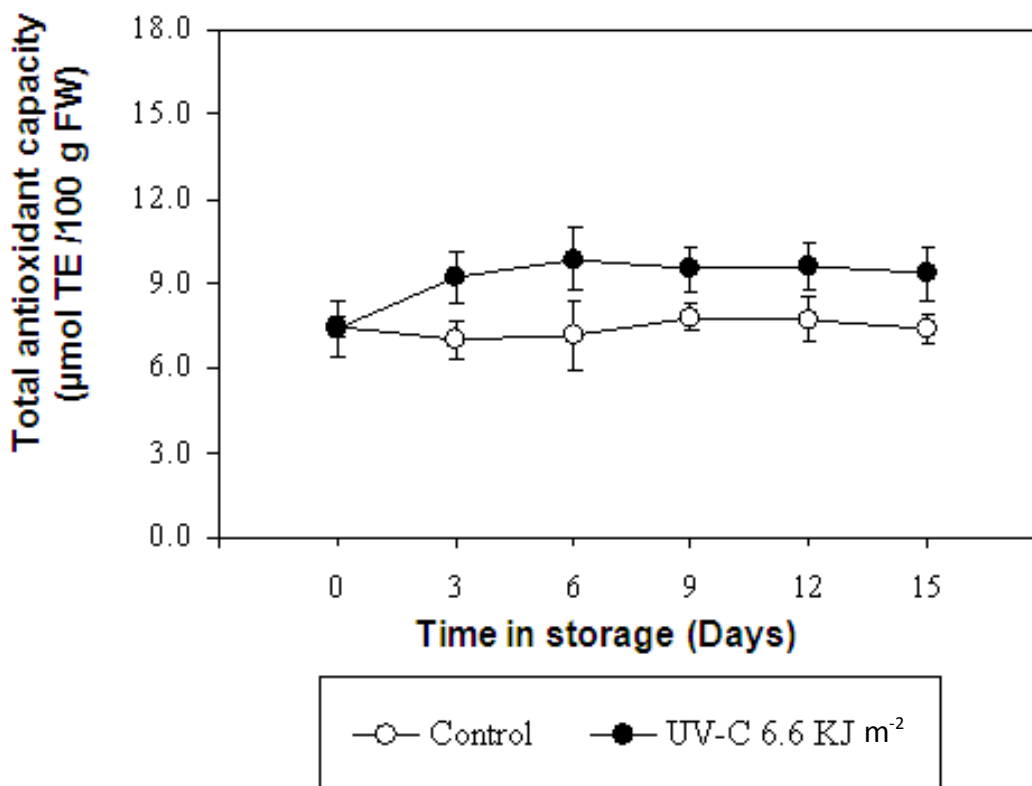
#### Antioxidant capacity

As shown in Figure 6, antioxidant capacity was expressed as TE values in yellow bell pepper fruit. Just after UV-C illumination, the amount of antioxidant capacity of the UV-C treated fruit was similar to the control fruit. The antioxidant capacity of the control fruit remained



**Figure 5.** Ascorbic acid (AsA) (A), total flavonoid (TF) (B) and total phenol (TP) (C) contents of untreated and UV-C treated yellow bell pepper fruit stored at  $12 \pm 1^\circ\text{C}$  for 15 days. Data are the mean of five replications and vertical bars represent standard error.





**Figure 6.** Total antioxidant capacity of untreated and UV-C treated yellow bell pepper fruit stored at  $12 \pm 1^\circ\text{C}$  for 15 days. Data are the mean of five replications and vertical bars represent standard error.

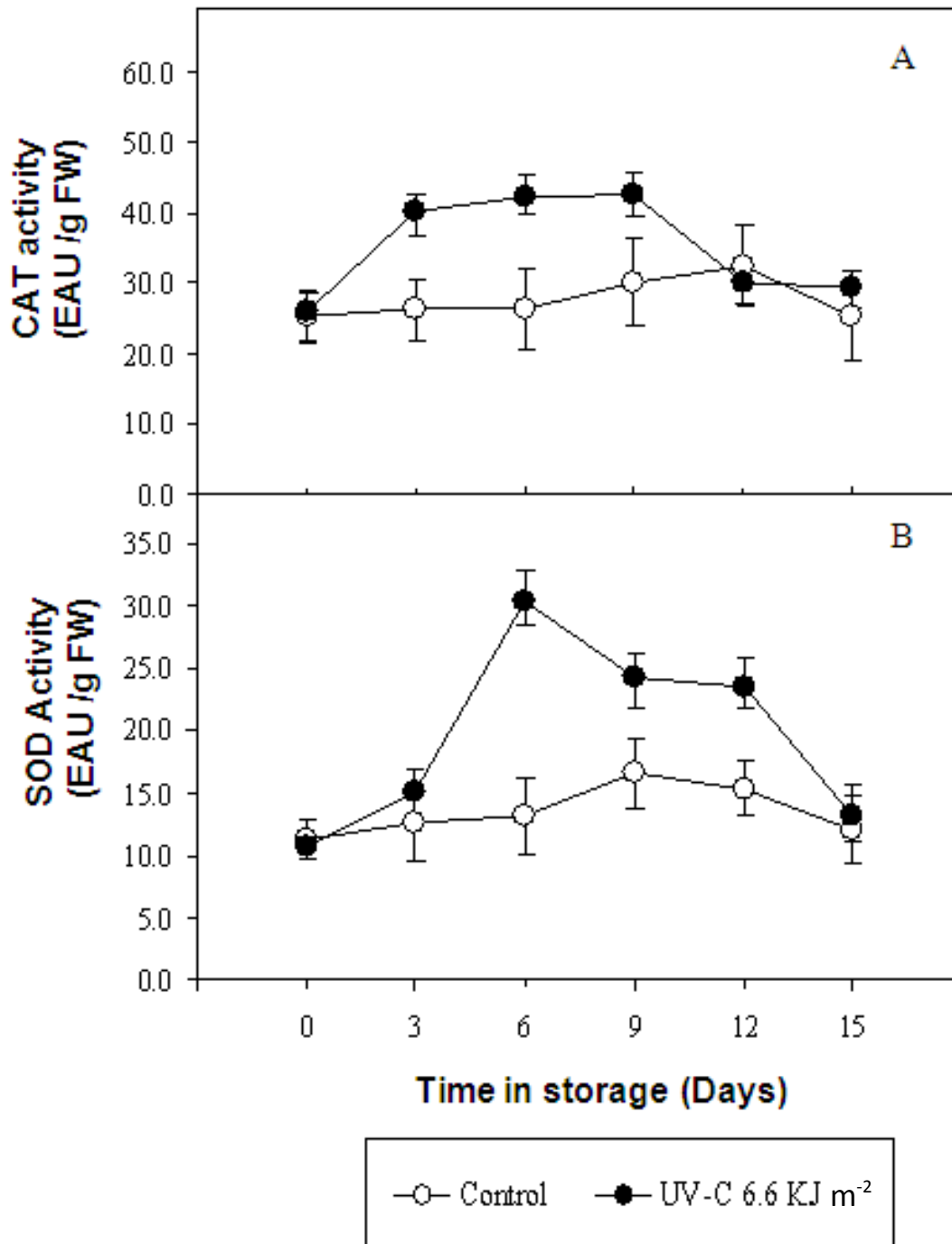
constant over 15 days of storage whilst that of UV-C illuminated fruit increased until day 6 and then remained constant. UV-C illuminated fruit was significantly higher in antioxidant capacity than the control fruit throughout storage ( $p < 0.05$ ).

Recently, antioxidant has been becoming an increasingly important parameter for the evaluation fresh commodity quality. Mercier (1997) addressed that UV light induces biological stress and defense mechanism including antioxidant activity in plants. In this study, we found that UV-C application enhanced antioxidant capacity in yellow bell pepper fruit when compared to the control fruit. In a similar vein, enhanced antioxidant capacity by UV light had been reported in red pepper fruit (Andrade et al., 2011), "Zafiro" pepper fruit (Vincent et al., 2005), tomato fruit (Barka et al., 2000), strawberry fruit (Erkan et al., 2008), broccoli florets (Costa et al., 2006) and fresh-cut mango fruit (González-Aguilar et al., 2007). Artés-Hernández et al. (2010) suggested that the increase in total antioxidant capacity in UV-C treated fruit was due to the combined effect of the stress induced by UV-C illumination and storage.

#### Activities of antioxidant enzymes

The activities of CAT and SOD are shown in Figure 7 and

both peroxidases activities, G-POD and AsA-POD, are shown in Figure 8. Just after UV-C illumination, all antioxidant enzyme activities were similar to the control fruit. Both CAT and SOD activities of the control fruit remained constant throughout storage (Figure 7A and B). The CAT activity of the yellow bell pepper fruit illuminated with UV-C was increased and significantly higher than the control fruit during storage for 9 days ( $p < 0.05$ ). After day 9 of storage, the activity was then decreased reaching to the same level of the control fruit. The SOD activity of the UV-C illuminated fruit was markedly increased over 6 days of storage and then decreased reaching to the same level of the control at the end of storage; however, the level of SOD activity in the UV-C treated fruit was significantly higher than that of the control fruit ( $p < 0.05$ ). As the results show in Figure 8A, a marked increase in G-POD activity of the UV-C illuminated fruit was found at day 3 after storage whilst that of the control fruit was found at day 6 of storage. The G-POD activity of the UV-C illuminated fruit was slightly increased until day 12 of storage. Later, G-POD activity of the UV-C illuminated fruit markedly decreased. After 6 days of storage, G-POD activity of the control fruit was continuously increased over storage. However, G-POD activity of the UV-C illuminated fruit was higher than that of the control fruit for 9 days after the treatment. As the result show in Figure 8B, AsA-POD activity of both the UV-C illuminated and

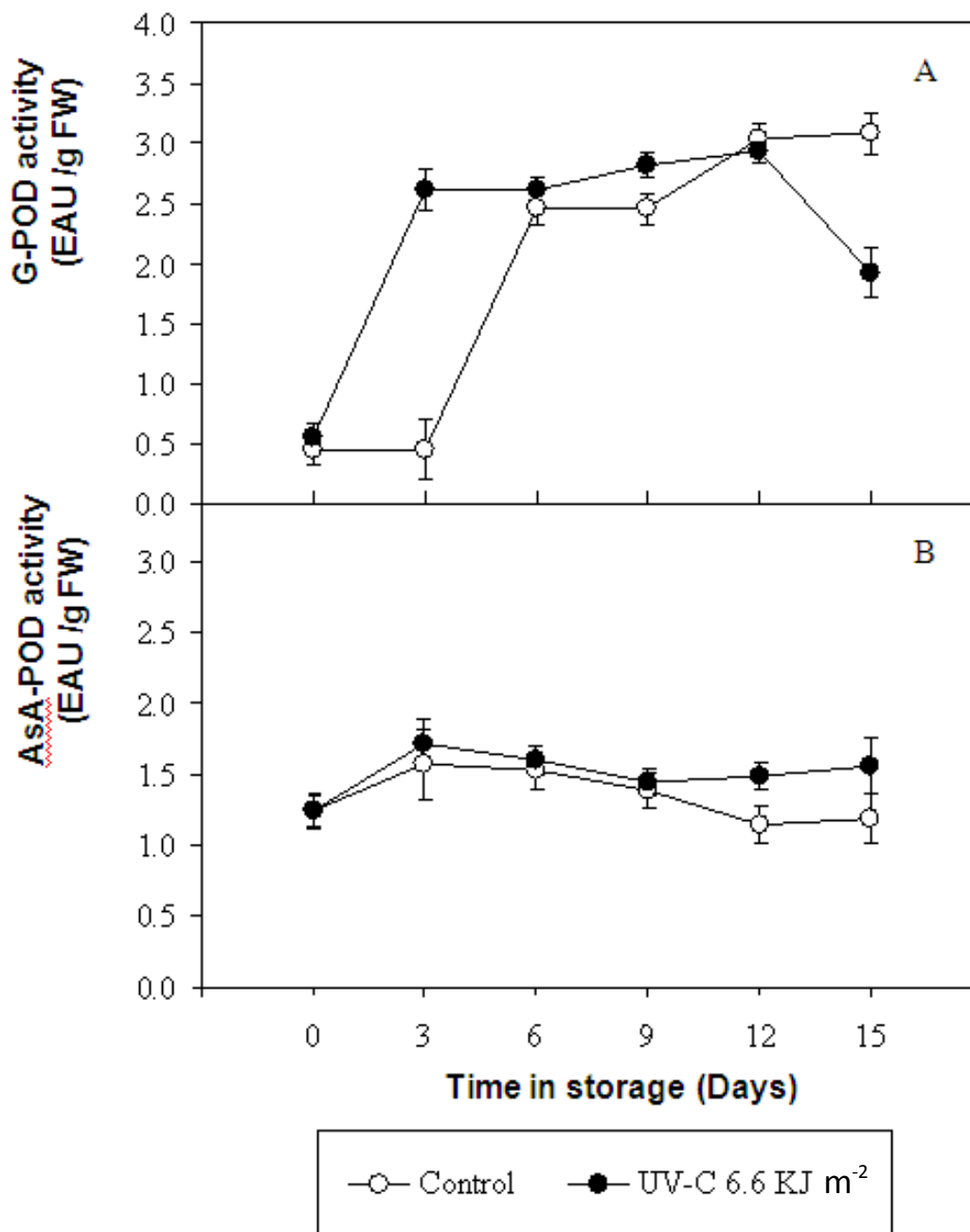


**Figure 7.** Catalase (CAT) (A) and superoxide dismutase (SOD) (B) activities of untreated and UV-C treated yellow bell pepper fruit stored at  $12 \pm 1^\circ\text{C}$  for 15 days. Data are the mean of five replications and vertical bars represent standard error.

the control fruits was increased at day 3 of storage and then slightly decreased. The UV-C treatment had higher AsA-POD activity than the control throughout storage.

Reactive oxygen species are generated as a part of normal metabolism in fresh-commodities during storage or under stress condition. In order to cope with reactive

oxygen species, plants have a series of bioactive compounds including antioxidant compounds and enzymes such as CAT, SOD and PODs (Apel and Hirt, 2004). It is widely recognized that CAT, G-POD and AsA-POD are for removal of  $\text{H}_2\text{O}_2$  whilst SOD removes  $\text{O}_2^-$  and prevents the formation of hydroxyl radicals in plant cells



**Figure 8.** Guaiacol peroxidase (G-POD) (A) and ascorbic acid peroxidase (AsA-POD) (B) activities of untreated and UV-C treated yellow bell pepper fruit stored at  $12 \pm 1^\circ\text{C}$  for 15 days. Data are the mean of five replications and vertical bars represent standard error.

as described in Glutathione-ascorbate cycle (Fridovich, 1986; Scandalios, 1993). In this study, we have found that UV-C illumination enhanced the activities of antioxidant enzymes including CAT, SOD, G-POD and AsA-POD activities in yellow bell pepper during storage. Mittler (2002) reported that UV-C light can induce the proliferation of peroxisomes, where CAT is present in plant cells. Andrade et al. (2011) also reported that UV-C illumination maintained CAT activity and stimulated SOD

and AsA-POD activities in red pepper rather than the control fruit during storage at chilling temperature. In a similar vein, in strawberry fruit, UV-C treatment can moderate the activities of SOD, G-POD and AsA-POD compared to the control fruit (Erkan et al., 2008; Pombo et al., 2011). In Chinese kale, UV-C irradiation also activated antioxidant enzymes activities including CAT, SOD and POD. Thus, increased activities of these antioxidant enzymes may be associated with the increased

antioxidant capacity as shown in Figure 6.

## Conclusion

The results showed that UV-C illumination maintained physical quality attributes of yellow bell pepper fruit by keeping firmer and lower weight loss when compared to the untreated fruit and had no effect on the changes in visual tristimulus color. A dose of UV-C light at 6.6 kJ m<sup>-2</sup> showed the best result compared to other treatments. The yellow bell pepper fruit illuminated with 6.6 kJ m<sup>-2</sup> UV-C showed higher TC, TF, antioxidant capacity and the activities of antioxidant enzymes including CAT, SOD, G-POD and AsA-POD than the control fruit. Whereas, TP and AsA contents of UV-C treated illuminated fruit remained constant and was slightly higher than those of the control fruit over storage. These showed that UV-C is an effective non-chemical treatment to maintain physical quality and enhance nutritional quality, especially, bioactive compounds, of yellow bell pepper fruit during storage.

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