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Original article

Effects of UV-C irradiation on postharvest quality and antioxidant properties of wampee fruit (*Clausena lansium* (Lour.) Skeels) during cold storage

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Summary

Introduction – **Wampee (*Clausena lansium* (Lour.) Skeels) is a tropical fruit with high content of bioactive compounds that are beneficial to human health. However, postharvest wampee fruits exhibit a short shelf life and show browning symptoms in acceleration of fruit senescence after only 3 days of room temperature storage.** *Materials and methods* – **Wampee fruit (cv. 'Dajixin') were harvested from an orchard in the town of Yongxing (Hainan, China), the main fruit quality and antioxidant properties were assessed at 4 °C storage for 12 days, including browning index, weight loss, firmness, total soluble solid (TSS), total acid (TA), vitamin C (VC), MDA, total phenolics, flavonoids, superoxide dismutase (SOD) and polyphenol oxidase (PPO) activity.** *Results and discussion* – **In contrast with the control (CK), UV-C irradiation at 1.1 kJ m^{-2} best inhibited the increase in weight loss and browning index, retarded decreases in firmness and TA content, and maintained TSS and VC content at higher levels during storage. The 0.6 kJ m^{-2}, 1.7 kJ m^{-2} and 2.3 kJ m^{-2} UV-C irradiation treatments also maintained fruit quality, but to a lesser extent. UV-C treatment enhanced total phenolics content, total flavonoids content and the antioxidant enzyme activity of SOD, and prevented an increase in PPO when compared with the control. In particular, the 1.1 kJ m^{-2} treatment produced the best effects.** *Conclusion* – **1.1 kJ m^{-2} can be considered the optimum dosage of UV-C irradiation to maintain the quality and alleviate the browning of wampee fruit during cold storage.**

Keywords
China, *Clausena lansium*, browning, ultraviolet irradiation, antioxidants

Significance of this study

What is already known on this subject?

- Wampee is a tropical fruit with high content of bioactive compounds and short postharvest life due to browning symptoms.

What are the new findings?

- UV-C irradiation effectively maintained wampee fruit postharvest quality and antioxidant properties, among which 1.1 kJ m^{-2} dosage produced the best effects in promoting the accumulation of total phenolic content, total flavonoids content, and the antioxidant enzyme activity of superoxide dismutase (SOD), and preventing an increase in polyphenol oxidase (PPO) when compared with the control.

What is the expected impact on horticulture?

- The results of applying UV-C irradiation will prove useful to reduce the browning index, maintain postharvest quality, and extend storage life of cold stored wampee fruit.

Introduction

UV-C irradiation (200–280 nm) is known as the germicidal wavelength range, since it has a microorganism inactivation function in fruit and vegetables. UV-C can also be absorbed quickly and thus is almost undetectable in nature (Gayán *et al.*, 2014; Koutchma *et al.*, 2009). At proper dosages, UV-C treatment has been reported as a promising approach for the maintenance of fruit quality and the extension of postharvest life, with treatment effects including improving antioxidant capacity and inducing a natural defence against microorganisms (Ribeiro *et al.*, 2012). For example, 2.46 kJ m^{-2} UV-C irradiation has been reported to effectively maintain the quality and prolong the shelf life of leaf vegetables (Liao *et al.*, 2016). UV-C treatment at 6.6 kJ m^{-2} maintained yellow bell pepper fruit postharvest quality by enhancing the bioactive compound content, antioxidant capacity and antioxidant enzyme activities (Promyou and Supapvanich, 2016), while 2.15 and 4.30 kJ m^{-2} UV-C illumination produced the best decay inhibition in strawberry fruit (Erkan *et al.*, 2008). In addition, the combination of UV-C with other approaches such as blue irradiation (Ávila-Sosa *et al.*, 2017; Pérez-Ambrocio *et al.*, 2018), UV-B (Formica-Oliveira *et al.*, 2017), 1-methylcyclopropene (Xu and Liu, 2017), ascorbate and calcium chloride (Teoh *et al.*, 2016) and antagonistic yeast (Ou *et al.*, 2016) has also been reported as useful in maintaining fruit quality and extending shelf life.

Browning is a major physiological disorder affecting postharvest fruit, including litchi, longan, rambutan, banana, pear, guava and apple (Ioannou and Ghoul, 2013). A number

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of effective physical and chemical treatments have been developed to prolong fruit postharvest life and alleviate browning, such as micro-vacuum (Fan *et al.*, 2016), chitosan (Jiang *et al.*, 2018), atmosphere storage (Ali *et al.*, 2016), ascorbic acid (Terdbaramee *et al.*, 2006), organic acid (Shafique *et al.*, 2016; Shah *et al.*, 2017) and the combination of several treatments (Lo'ay and Taher, 2018). In addition, UV-C's function as a browning retardant has also been observed in various fleshy fruit, including longkong (Kaewskusaeng *et al.*, 2010), white table grapes (González-Barrio *et al.*, 2005) and banana (Ding and Ling, 2014). However, no study has yet investigated the effects of UV-C irradiation on wampee fruit.

The fruit of the wampee (*Clausena lansium* (Lour.) Skeels), a member of the Rutaceae family and native to southern China, contain a large number of bioactive compounds that are beneficial to human health (Rodrigues *et al.*, 2017). However, wampee fruit also exhibit browning symptoms in acceleration of fruit senescence after only 3 days of room temperature storage. A previous study conducted by the present authors indicated that 4 °C is the optimal low temperature for wampee fruit postharvest storage, maintaining fruit quality and extending postharvest life (data not shown). As studies examining the postharvest regulation of wampee fruit preservation are rare, the present work was carried out in order to investigate UV-C regulation during wampee fruit cold storage, evaluating parameters including fruit quality (the browning index), as well as the detection of browning-related bioactive compounds and enzymes.

Materials and methods

Plant materials

Wampee fruit (*Clausena lansium* (Lour.) Skeels cv. 'Dajixin') were obtained from an orchard in the town of Yongxing (Hainan, China), with fruit of uniform maturity and size transported to the laboratory on the day of harvest. Specimens without disease, cracks or mechanical wounding were then selected and randomly divided into five groups of ~500 fruit each.

Treatments

Ultraviolet irradiation treatments were conducted using an ultraviolet lamp (30 W, G30T8, China) emitting at 254 nm and placed 25 cm above the wampee fruit. The tested UV-C intensity was measured via a digital UV-C intensity meter (LS126C, Shenzhen, China), providing a corresponding intensity of 0.188 mW cm^{-2}. Four groups of wampee fruit were treated respectively with 0.6 kJ m^{-2}, 1.1 kJ m^{-2}, 1.7 kJ m^{-2}, and 2.3 kJ m^{-2}, equal to durations of 5 min, 10 min, 15 min and 20 min at 4 °C and 80–90 % RH for 12 days storage, respectively; the fifth group was stored directly at 4 °C for 12 days as the control. Fruit flesh from three replicates of the fifth fruit was sampled every two days. Flesh tissues were frozen in liquid nitrogen and stored at -80 °C for further use.

Measurement of weight loss and firmness

Wampee fruit weight loss was measured both before treatment and every 2 days during storage. The weight loss percentage during storage was calculated compared to the initial weight. Fruit firmness was determined using a firmness tester (FHM-1, Takemura Motor Manufacturing, Matsumoto, Japan); measurements were made at two 180° positions on the equator of each fruit, with three replicates of five fruits performed and the results expressed in newtons (N).

Measurement of browning index, MDA and VC content

Calculation of the browning index was carried out based on the methods of Chen *et al.* (2014). Pericarp browning was assessed by measuring 20 individual fruits according to the following five grades: (1) ¼ or less surface browning; (2) ¼–½ surface browning; (3) ½–¾ surface browning; (4) ¾ or more browning; (5) total surface browning. Browning index values were then calculated according to the following formula:

$$\text{Browning index} = \sum_{L=1}^{5} LN_L / M$$

where L represents the browning grade (1 to 5), N_L represents the number of wampee fruit with the corresponding grade and M represents the total number of wampee fruit.

MDA content was measured via the thiobarbituric acid reaction method of Heath and Packer (1968), with slight modifications. Wampee samples (2 g) were first homogenized in 6 mL of 0.05 M phosphate buffer (pH = 7.8) containing 1 g of quartz sand, with the homogenate then centrifuged at 12,000 rpm for 30 min at 4 °C and the supernatant collected. Three mL of the supernatant was mixed with 3 mL of 0.5% (w/v) thiobarbituric acid. The mixture was then heated to 100 °C for 15 min, before being cooled rapidly and centrifuged at 12,000 rpm for 10 min at 4 °C. The final supernatant was then collected and measured at 532 nm and 600 nm, using distilled water as the blank. MDA content (mmol g^{-1}) was calculated as follows:

$$\text{MDA} = [(A_{532} - A_{600}) \times 6] / 0.155.$$

Vitamin C content was subjected to titrimetric measurement based on the method of Kampfenkel *et al.* (1995). First, 2 g of wampee fruit flesh was homogenized in 5 mL of 2% oxalic acid containing a little quartz sand, and then centrifuged at 12,000 rpm for 20 min. After fixing the supernatant to a volume of 50 mL with 2% oxalic acid, 10 mL was titrated with 2,6-dichlorophenol-indophenol and the titrated volume recorded. Vitamin C content was expressed as mg 100 g^{-1}.

Measurement of TSS and TA content

Total soluble solids (TSS, °Brix) content was determined using an ATAGO digital refractometer (PAL-1, Tokyo, Japan), with distilled water employed as a correction solution to obtain the final TSS value. Three biological replicates were performed at each sampling point for every treatment.

Titratable acidity (TA, %) was determined based on the methods of Shafique *et al.* (2015). Wampee fruit flesh samples (2.0 g) were placed in 5 mL of distilled water and homogenized with quartz sand. After centrifugation at 12,000 rpm for 20 min, the supernatant was collected and fixed to a constant volume of 50 mL. Then, 10 mL of the mixture was titrated with 0.01 M NaOH using phenolphthalein indicator. TA was calculated via the following equation:

$$\text{TA}\ (\%) = \sum (0.32 \times V_{NaOH} \times 100) / 20.$$

Measurement of total phenolics and flavonoids

For each treatment, 1 g of wampee fruit flesh was homogenized with 5 mL of 1% HCl-methanol and then fixed to a constant volume of 20 mL. The mixture was incubated at 4 °C for 20 min and, after precipitation, the supernatant collected for total phenolics and flavonoids detection. Measurements were conducted as described by Kalinowska *et al.* (2014).

The absorbance of the supernatant was measured at 280 nm, using 1% HCl-methanol as the blank, and phenolics quantified via comparison to a standard curve of gallic acid. Total phenolics content was expressed as mg GAE g^{-1} fresh weight (FW). Total flavonoids absorbance was measured at 325 nm, using 1% HCl-methanol as the blank, with flavonoids content expressed as mg catechin equivalents (CE) per g fresh weight (FW). All measurements were performed using three biological replicates.

Measurement of SOD and PPO activities

Wampee samples (2 g) were extracted with 5 mL extraction buffer (5 mM DTT and 5% PVP), the homogenate centrifuged for 30 min at 12,000 rpm at 4 °C, and the supernatant collected for SOD activity determination (Abassi *et al.*, 1998). The assaying mixture used for the determination of SOD activity consisted of 2.9 mL reagent (50 mM phosphate buffer (pH 7.8), 130 mM MET, 750 µM NBT, 100 µM EDTA-Na_2, 20 µM riboflavin) and 0.1 mL of enzyme extract. After incubation under a 4,000 lx fluorescent lamp for 30 min, absorbance was measured at 560 nm, with the reaction mixture without lamp and crude enzyme used as the blank. SOD activity was expressed as U g^{-1} fresh weight (FW).

Polyphenol oxidase (PPO) was extracted and assayed according to the method described by Alamelumangai *et al.* (2015). First, 2 g of wampee fruit was homogenized in 5 mL extraction buffer (1 mM PEG, 4% PVPP and 1% Triton X-100) at 4 °C, the homogenate centrifuged at 12,000 rpm, 4 °C for 30 min, and the supernatant collected for determination of PPO activity. The assaying mixture used for the determination of PPO activity consisted of 2.5 mL of 50 mM phosphate buffer (pH 5.5), 0.6 mL of 50 mM pyrocatechol and 0.1 mL of enzyme extract. One unit of PPO activity (U g^{-1} FW) was defined as an increase of 0.01 in absorbance per minute at 420 nm.

Data processing and statistical analysis

Quality analysis was displayed using the Origin software (v.8). All data were analysed in terms of mean values ± standard error and correlation, with statistical analysis conducted in SPSS version 17.0 (SPSS, China, Zhejiang University). Variance analysis was carried out using one-way ANOVA. Significant differences at the 5% level were established based on Duncan's New Multiple Range Test.

Results and discussion

Effect of UV-C treatments on browning index values

Pericarp browning is one of the important postharvest physiological activities in wampee fruit. Browning index is primarily used as an indicator for evaluating the browning degree of wampee fruit. Figure 1b shows that after 12 days storage, the degree of pericarp browning in UV-C treated wampee fruit was much lower than that in control fruit. Moreover, compared with the control fruit, the increase in browning index values was suspended in UV-C treated fruit, with the greatest delay observed in the 1.1 kJ m^{-2} dosage treatment (Figure 1a), consistent with the changes displayed in Figure 1b. These results indicated that UV-C could maintain the sensory quality of wampee fruit in terms of reducing peel browning. Our results are similar to those of previous studies, in which UV-C irradiation at 5.4 kJ m^{-2} reduced pericarp browning in longkong fruit to a greater degree than dosages of 0, 3.6 and 7.2 kJ m^{-2} (Kaewsuksaeng *et al.*, 2010). Ding and Ling (2014) also reported that low doses (0.01 and 0.02 kJ m^{-2}) of UV-C resulted in the non-browning of berangan banana fruit.

Effect of UV-C treatments on weight loss and firmness

Weight loss and fruit softening are important physiological activities during the storage and transportation of many fruits. Fruit weight and firmness were here considered the other most important quality attributes affecting wampee texture. Although Figure 2a reveals that wampee fruit weight loss increased gradually after treatment, UV-C irradiation effectively retarded this effect. In particular, the 1.1 kJ m^{-2} dosage had the greatest impact, with weight loss of fruit in this treatment recorded at 2.11% on day 12, compared with 3.66% in control fruit. In contrast, firmness decreased during postharvest storage and exhibited a negative correlation (r = -0.982) with weight loss (Figure 2b; Table 1). Nevertheless, UV-C treatment effectively maintained fruit firmness, with a dosage of 1.1 kJ m^{-2} again having the most significant effect; fruit firmness in this treatment was recorded at 7.89 N on day 0 and decreased to 7.19 N at 12 days, much higher than the 6.27 N observed for control fruit at 12 days (Figure 2b).

Similar results have also been reported in strawberries (Erkan *et al.*, 2008; Pombo *et al.*, 2009), tomatoes (Pinheiro

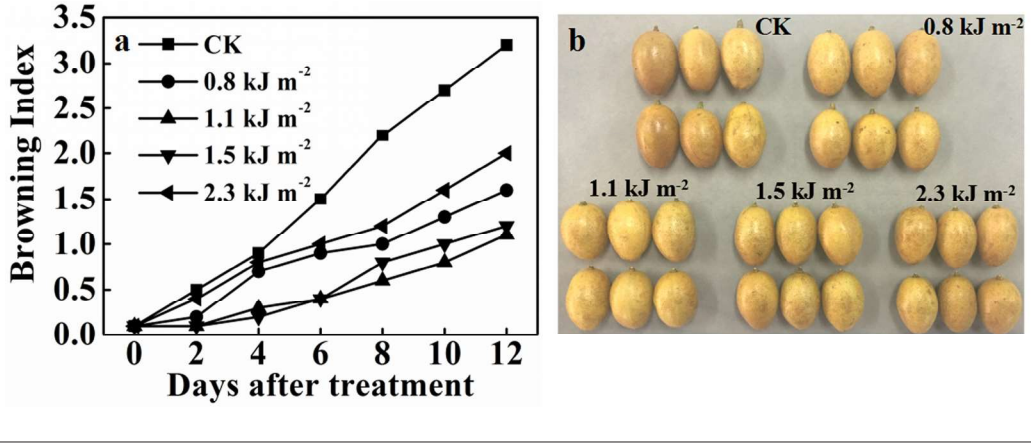

Figure 1. Effects of UV-C treatment on browning index (a) and appearance (b) of wampee fruit during storage at 4 °C. Error bars indicate standard errors of three replicates.

Table 1. Correlation among wampee fruit parameters for 1.1 kJ m^{-2} UV-C treatment during 0 to 12 days storage at 4 °C.

	BI	Weight loss	Firmness	TSS	TA	VC	MDA	Total phenol	Flavonoid	SOD	PPO
BI	-										
Weight loss	0.927**	-									
Firmness	-0.904**	-0.982**	-								
TSS	0.150	0.337	-0.427	-							
TA	-0.802*	-0.939**	0.941**	-0.625	-						
VC	-0.620	-0.419	0.305	0.646	0.122	-					
MDA	0.912**	0.987**	-0.992**	0.437	-0.956**	-0.327	-				
Total phenol	0.835*	0.953**	-0.967**	0.588	-0.990**	-0.146	0.971**	-			
Flavonoid	0.899**	0.988**	-0.994**	0.428	-0.951**	-0.310	0.989**	0.964**	-		
SOD	-0.399	-0.156	0.080	0.832*	-0.181	0.909**	-0.063	0.119	-0.064	-	
PPO	0.830*	0.964**	-0.978**	0.409	-0.928**	-0.242	0.961**	0.957**	0.975**	-0.041	-

* or ** are significantly different at $P \leq 0.05$, 0.01, respectively.

et al., 2016), kiwi fruit (Bal and Kok, 2010) and mangoes (Promyou and Supapvanich, 2016), with UV-C irradiation effectively reducing fruit weight loss and firmness decline. This ability of UV-C treatment to maintain fruit firmness might be caused by a reduction in the activity of cell wall degrading enzymes, gene suppression (Bu *et al.*, 2013; Pombo *et al.*, 2009), or ethylene response factor activation (Severo *et al.*, 2015). In addition, correlation analysis here showed that weight loss and firmness respectively exhibited a positive ($r = 0.927$) and negative ($r = -0.904$) correlation with fruit browning (Table 1). These results suggest that weight loss and firmness strongly affect wampee pericarp browning, and thus the use of UV-C irradiation may both reduce weight loss and increase firmness.

Effect of UV-C treatments on TSS, TA, VC and MDA contents

TSS and TA, VC are important chemical components of wampee fruit, and they are main nutrients and flavor substance for wampee fruit. TSS in both the control and UV-C treated wampee fruit increased over the first 4 days and decreased gradually during subsequent low-temperature storage. However, UV-C treatment significantly maintained TSS levels, with the 1.1 kJ m^{-2} dosage producing the greatest effect ($P < 0.05$) (Figure 3a). Although TA in both control and UV-C treated fruit decreased gradually during storage, significant differences were observed between treatments, with the 1.1 kJ m^{-2} dosage again providing the best results (Figure 3b).

VC content increased in all treatments in the first 2 (CK and 2.3 kJ m^{-2}) or 4 (0.8, 1.1, 1.5 kJ m^{-2}) days, before decreasing during subsequent cold storage. As before, significantly higher VC content was recorded in 1.1 kJ m^{-2} UV-C treated fruit throughout the entire storage period ($P < 0.05$) (Figure 3c). The positive effect of UV-C treatment on VC content was probably due to the antioxidant activity of VC, which are stimulated in the presence of enzymes, *e.g.*, ascorbate oxidase and superoxide dismutase.

MDA is a major product of plant membrane fatty acid oxidation, it has been acted as a membrane integrity indicator. Although MDA content increased during the postharvest cold storage of wampee fruit, UV-C treatment retarded this increase, with 1.1 kJ m^{-2} UV-C treated fruit exhibiting significantly lower values ($P < 0.05$) (Figure 3d). Moreover, MDA content was also highly related to the browning index, with a coefficient of 0.912 (Table 1) indicative of the close relationship between membrane integrity and fruit browning. These results showed that UV-C could be a good treatment to maintain membrane integrity and delay wampee fruit browning and senescence.

Physical treatments such as nitric oxide (Zheng *et al.*, 2017), pulsed electric field (González-Casado *et al.*, 2018) and heat (Moreno *et al.*, 2018) are seen as promising methods for the stabilisation of fruit quality attributes. Similarly, UV-C treatment is known to maintain fruit quality in mango

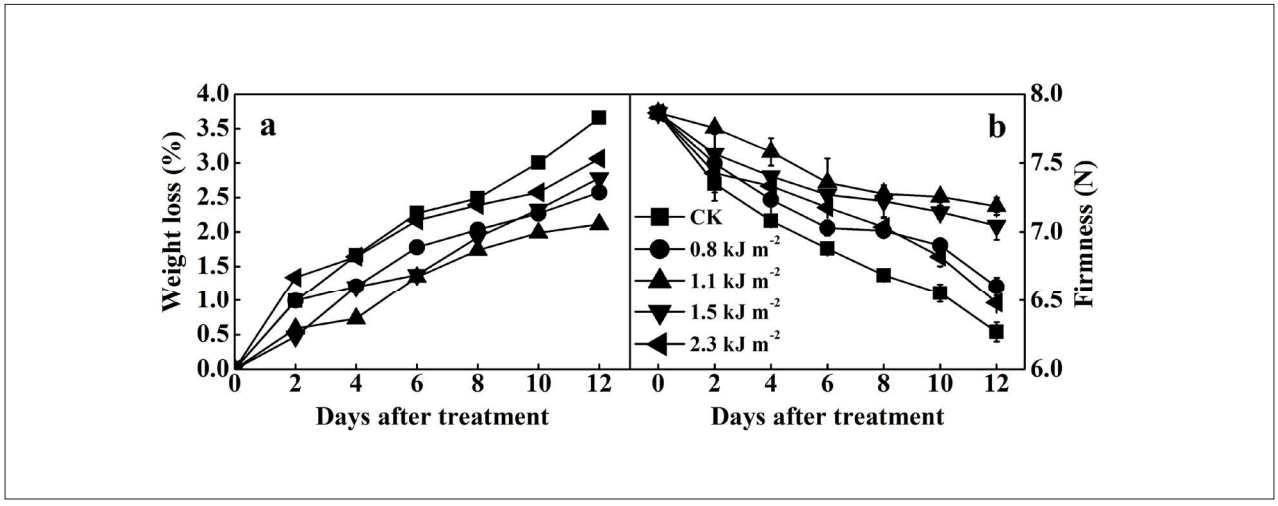

Figure 2. Effects of UV-C treatment on weight loss (a) and firmness (b) of wampee fruit during storage at 4 °C. Error bars indicate standard errors of three replicates.

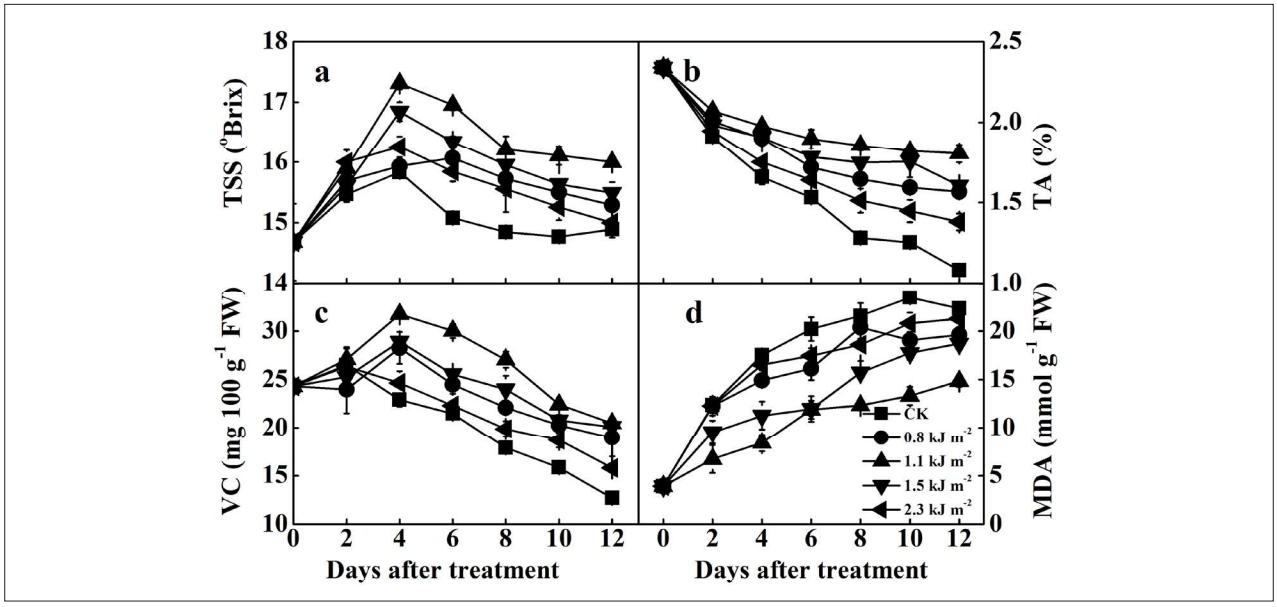

Figure 3. Effects of UV-C treatment on TSS (a), TA (b), VC (c) and MDA (d) content of wampee fruit during storage at 4 °C. Error bars indicate standard errors of three replicates.

(Promyou and Supapvanich, 2016) and pineapple (Sari *et al.*, 2016) during storage. Xu and Liu (2017) reported that UV-C treatment effectively delayed TA and TSS losses, and also retarded MDA accumulation in blueberry fruit during cold storage at 4 °C. Thus, UV-C treatment might offer an alternative method of controlling fruit quality and membrane integrity in postharvest wampee fruit.

Effect of UV-C treatments on total phenolics and total flavonoids contents

Phenolic compounds in fruits possess antioxidant properties and are protecting cells against oxidative injury (Scalzo *et al.*, 2005). As shown in Figure 4a, untreated wampee fruit increased in total phenolics content from 4.80 mg GAE g^{-1} FW to 10.03 mg GAE g^{-1} FW during the initial 6 days of storage, before slightly decreasing over the following 6 days, a pattern similar to that observed in 2.3 kJ m^{-2} dosage fruit (Figure 4a). The total phenolics content of 1.1 kJ m^{-2} dosage fruit increased gradually after treatment and was significantly different ($P < 0.05$) compared to both the control and all other treatments (Figure 4a). These results suggested that the accumulation of total phenolics content is a protective response of wampee fruit to oxidative stress induced by UV-C radiation. These results are in agreement with a previous study on strawberry fruit, in which the total phenolics content of both the control and the 4.30 kJ m^{-2} UV-C treatment peaked on day 10 of storage at 10 °C, while dosages of 0.43 and 2.15 kJ m^{-2} produced a gradual increase in total phenolics content (Erkan *et al.*, 2008). A positive effect of UV-C (at 4 and 8 kJ m^{-2}) on total phenolics content has also been reported in tomato and pineapple fruits (Liu *et al.*, 2012; Ou *et al.*, 2016).

Flavonoids are important bioactive compounds that act in plants as antioxidants, antimicrobials, photoreceptors, phytoalexins, and feeding repellents (Iwashina, 2003). As shown in Figure 4b, changes in total flavonoids contents were similar to those of total phenolics, increasing from 1.31 mg CE g^{-1} FW to 1.86 mg CE g^{-1} FW in the control after 6 days, followed by a decrease during the remainder of the storage period. UV-C exposure promoted the accumulation of total flavonoids, to 2.90 mg CE g^{-1} FW after 12 days in the 1.1 kJ m^{-2} dosage treatment (Figure 4b). This is unsurprising, as it is well known that UV-C induces higher levels of flavonoids due

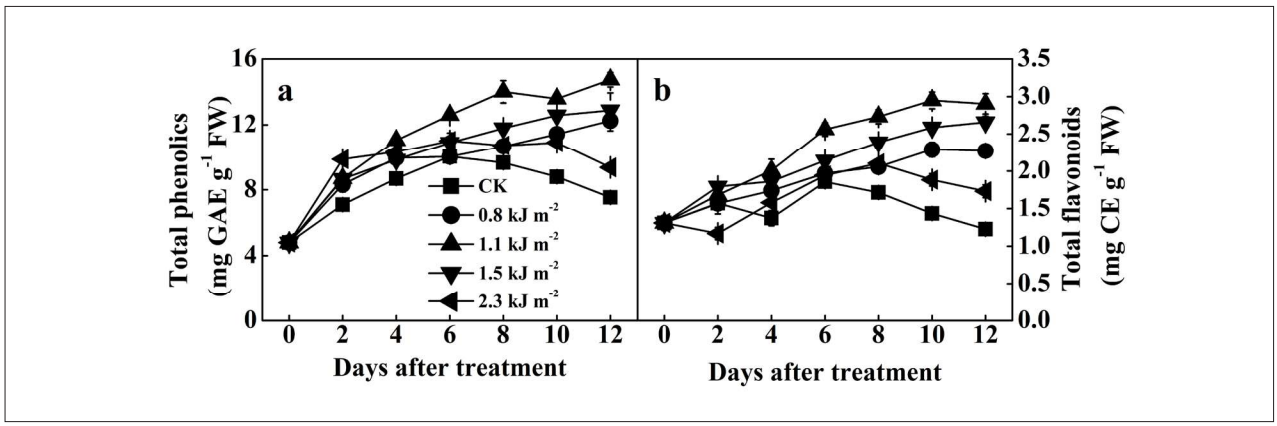

Figure 4. Effects of UV-C treatment on total phenolics (a) and total flavonoids (b) content of wampee fruit during storage at 4 °C. Error bars indicate standard errors of three replicates.

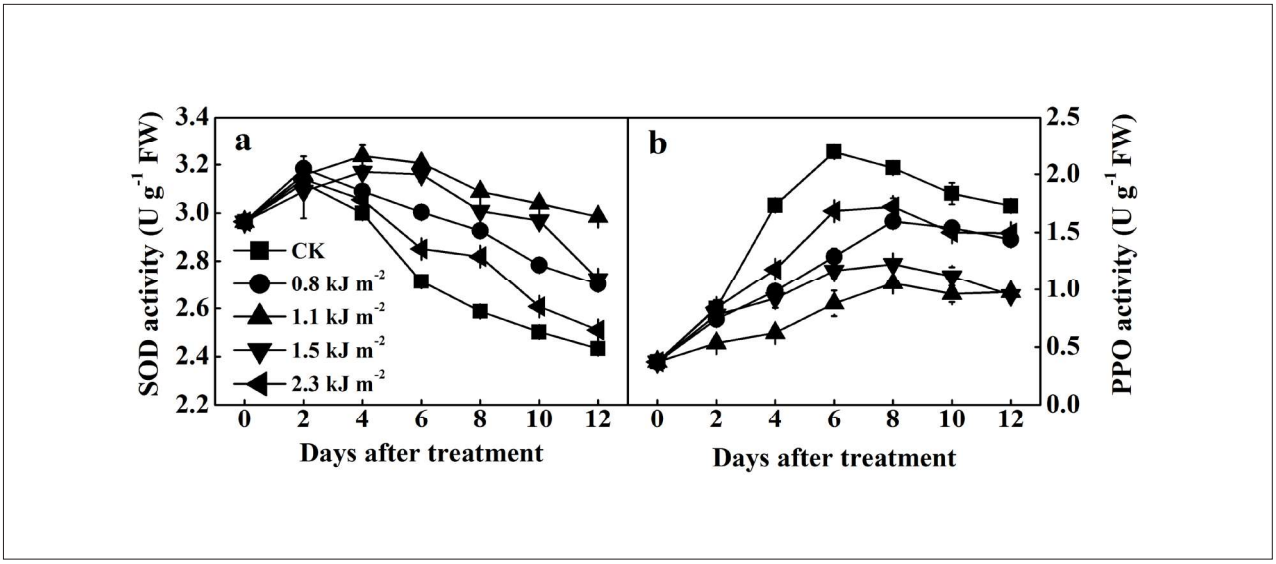

Figure 5. Effects of UV-C treatment on SOD (a) and PPO (b) activities of wampee fruit during storage at 4 °C. Error bars indicate standard errors of three replicates.

to their chromophore and light-absorption properties (Sisa *et al.*, 2010). In agreement with our results, studies examining fruits such as blueberry and tomato have reported similar increases in total flavonoids content after UV-C treatment (Liu *et al.*, 2012; Wang *et al.*, 2009).

Both total phenolics and total flavonoid contents were strongly correlated with wampee fruit browning, with coefficients of 0.835 and 0.899, respectively (Table 1). Furthermore, all dosages of UV-C (0.8, 1.1, 1.5 and 2.3 kJ m^{-2}) clearly resulted in an increase in total phenolics and total flavonoids content in treated wampee fruit compared to the control (Figure 4). There is general agreement that the promoting of phenolic compounds content are considered to be a browning retardant owing to its ability to scavenge free radicals and defense mechanisms against UV-C irradiation. Thus, UV-C treatment may achieve browning alleviation by promoting the accumulation of total phenolics and flavonoids.

Effect of UV-C treatments on SOD and PPO enzyme activity

All UV-C treated wampee fruit exhibited higher SOD activities than control fruit after 2 days storage. SOD activity was highest in fruit treated with a dosage of 1.1 kJ m^{-2}, followed by the 1.5 kJ m^{-2} treatment, as shown in Figure 5a. SOD activity exhibited a slight increase during the initial 2 (0, 0.8, 2.3 kJ m^{-2} doses) or 4 (1.1 and 1.5 kJ m^{-2} doses) days, before decreasing over the remaining period of storage at 10 °C (Figure 5a). Although no correlation was observed between SOD activity and fruit browning ($r = -0.399$) (Table 1), UV-C treated fruits exhibited increased SOD activity. SOD has been reported to be an antioxidative enzyme that is produced to scavenge redundant reactive oxygen species against free radicals (Scandalios, 1993). Ou *et al.* (2016) found that UV-C induced higher SOD activity in pineapple fruit, and also maintained fruit quality post-harvest. Similarly, Erkan *et al.* (2008) revealed that higher SOD activities in strawberry fruit were related to both increased antioxidant levels and the extension of postharvest life.

PPO enzyme activity in control fruit increased rapidly, reaching a peak on the 6th day, before decreasing during the remainder of the experimental period (Figure 5b). UV-C treatment at all dosage levels significantly ($P < 0.05$) retarded the increase in PPO activity, with maxima recorded on day 8. PPO activity was lowest in fruit treated with a dosage of 1.1 kJ m^{-2}, followed by the 1.5 kJ m^{-2} UV-C treatment (Figure 5b). A positive correlation coefficient of 0.830 was found between PPO activity and browning index values (Table 1). This result is unsurprising, as PPO enzymes oxidise phenolics to quinones, resulting in the brown appearance of fruit tissues (Mayer and Harel, 1979). The PPO activity changes in wampee fruit treated with UV-C observed here and their positive correlation with browning index values are in agreement with data previously reported for banana fruit (Ding and Ling, 2014) and eggplant (Mishra *et al.*, 2013). Thus, UV-C treatment may achieve browning alleviation by inhibiting the PPO activity and the accumulation of subsequent browning substance quinones. All results show that UV-C irradiation treatment could maintain the quality of wampee fruit, which can be attributed to the enhancement in antioxidants contents, such as phenolics, flavonoids and VC, and can be attributed to the increase in SOD activity and the reduce in PPO activity.

Conclusions

The results of the present study indicate that UV-C irradiation treatment is able to effectively maintain wampee fruit postharvest quality and prolong storage life by alleviating external browning, maintaining TSS, TA and vitamin C content, inhibiting both the increase in MDA content and PPO activity and the decrease in SOD activity, as well as promote the accumulation of total phenolics and total flavonoids. A dosage level of 1.1 kJ m^{-2} UV-C was found to have the greatest effect on each of these parameters. Moreover, correlation analysis revealed that weight loss, MDA content, total phenolics content, total flavonoids content and PPO activity showed a positive relationship with wampee fruit browning. In summary, the postharvest application of 1.1 kJ m^{-2} UV-C irradiation could be a promising method with which to maintain the quality and alleviate the browning of wampee fruit during cold storage.

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