Journal of Food Science and Agricultural Technology

International peer-reviewed scientific online journal

Published online: http://jfat.mfu.ac.th

Original Research Article

Effects of UV-C irradiation on ripening quality and antioxidant capacity of mango fruit cv. Nam Dok Mai Si Thong

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ARTICLE INFO

Article history:
Received 30 September 2014
Received in revised form 27 January 2015
Accepted 16 February 2015

Keywords:
Antioxidant capacity
Mango
Ripening
UV-C Irradiation

ABSTRACT

It is known that UV-C can delay senescence and also influence the accumulation of certain bioactive compounds in fruit. Despite the effects of UV-C in some fruits having been clearly found, there are still shortcomings within the treatment, which should be addressed. The effects of UV-C irradiation on ripening quality and antioxidant capacity of Nam Dok Mai Si Thong mangoes were investigated. Mango fruit at commercial stage was treated with UV-C (4.93 kJ/m^2) then stored at 14 ^{o}C and 90% relative humidity for 20 days. A significant ($P<0.05$) color by L*, a*, and hue values difference existed between untreated and treated mango. The UV-C treated fruit had higher a* value but lower L* and hue appeared as blackened lenticel and skin browning on its peel. However, the application of UV-C did not significantly affect respiration rate, texture, total soluble solids, and titratable acidity. Antioxidant capacity measured as total phenolic compounds, DPPH, and FRAP were decreased after UV-C treatment compared to control. This study suggested that at the investigated dose, UV-C was not suitable to be applied in conserving Nam Dok Mai Si Thong and did not increase antioxidant capacity, thus further evaluation on the efficacy of UV-C in mango, both in flesh and peel is required. In addition, the combination of UV-C irradiation with other physical or chemical treatment, which probably could give better ripening quality in mango especially to reduce its browning effect, should be further investigated.

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Published by School of Agro-Industry, Mae Fah Luang University

ISSN: 2408-1736

INTRODUCTION

Mango (*Mangifera indica*) belongs to the family Anacardiaceae, which comprises more than 70 genera (Ribeiro and Schieber, 2010). Mangoes are produced worldwide (approximately 39 million tons, FAOSTAT, 2013) and it is the second largest tropical fruit production, after banana (Yahia, 2011; FAOSTAT, 2013). Thailand was the top three-exporter country of mango worldwide (FAOSTAT, 2013). Nam Dok Mai cultivar is Thailand's number one variety for domestic and export markets (Watanawan *et al.*, 2013). The popularity of mango is due to its bright color, characteristic taste, and nutritional properties (Kim *et al.*, 2007).

Mango is a seasonal fruit, processing is an alternative procedure to reduce postharvest losses and add the value of finished products (Liu *et al.*, 2013). Several important changes are known to occur in mango during ripening. Prompt cooling and low temperature storage is effective in reducing the rate of these changes, delaying the ripening and control of postharvest decay while high humidity conditions protect the produce from water loss (Yahia, 2011).

Hormesis is the application of potentially harmful agents at low doses to living organisms in order to induce stress responses (Shama and Alderson, 2005). UV has been shown to produce both positive and detrimental effects. It also played a role as ripening and disease control. UV also induced some beneficial compounds in fruit. As ripening control, UV delayed chlorophyll degradation (Costa *et al.*, 2006; Pongprasert *et al.*, 2011), suppressed ethylene production (Bu *et al.*, 2013; Stevens *et al.*, 1998), lowered respiration rate (Maharaj *et al.*, 1999; Costa *et al.*, 2006), reduced weight loss (Srilaong *et al.*, 2011; Syamaladevi *et al.*, 2014), and maintained fruit firmness (Pombo *et al.*, 2009; Bu *et al.*, 2013).

Although UV treatment was found to have positive effects, it also could cause some undesirable effects upon its application. In higher dose, UV reduced organic acid (Gonzalez-Aguilar *et al.*, 2001). In some cases, even small UV dose reduced β-carotene level (Gonzalez-Aguilar *et al.*, 2007a), delayed color development (Liu *et al.*, 2012), and caused skin scald (Cia *et al.*, 2007). The present work helps to gain some physiological understanding for the changes observed in mangoes following UV irradiation treatment. It also provides information on whether UV-C is affordable and applicable technology for prolonging the shelf life and improving bioactive compounds in mangoes or not.

MATERIALS AND METHODS

Plant material

Nam Dok Mai Si Thong mangoes (*Mangifera indica L.*, cv Nam Dok Mai Si Thong) were obtained on May 2014 from an orchard in Chiang Mai, Thailand at commercial stage (100-105 days after flowering). All the fruits were washed with 200 ppm of chlorine and rinsed with tap water, and then left until dry well. Fruits were then selected for uniformity in size and shape, and free from defects. They were randomly divided into two groups of 80 fruits each; one of the groups was used as the control.

UV-C irradiation treatment

The UV-C radiation chamber with two side of radiation source (Sylvania Ultraviolet G8W) of the rack (Figure 1) was used as described by Allende *et al.* (2006). Mangoes were placed under the lamps at a distance of 25 cm and illuminated from both upper and lower side. Ultraviolet irradiation was evaluated using a digital UV-C meter (LUTRON UVC-254SD) to determine the intensity. The average intensity was 2.2 mW/cm^2. Following to Gonzalez-Aguilar *et al.* (2007b), which used 'Haden' variety that has similar peel color (yellow reddish) with 'Nam Dok Mai Si Thong' mango (yellow) and has positive correlation with higher levels of certain bioactive compounds, 4.93 kJ/m^2 was the dosage used in this investigation. At 112 sec intervals (half of the tested exposure time), each fruit was rotated 180° vertically so that their ends had equal chance to face the lamp to ensure uniform irradiation. All samples were then stored in a refrigerator at 14°C and 90% RH for 20 days in darkness. For ripening quality assessment, analyses were carried out at 0, 5, 10, 15, and 20 days of storage. The samples were then frozen and stored for antioxidant analysis.

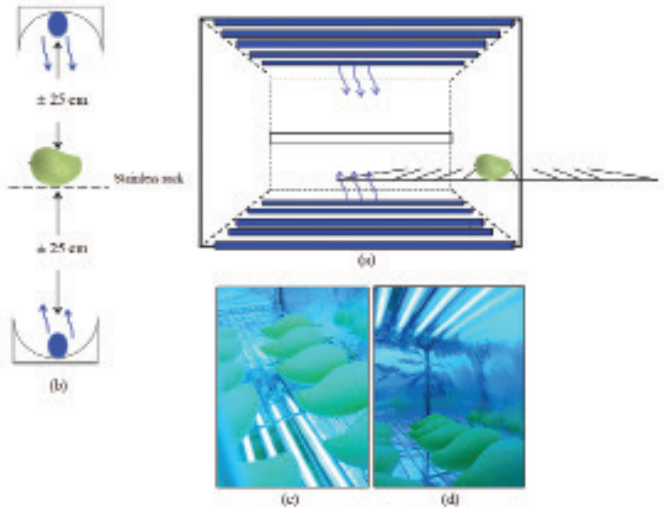

Figure 1 UV-C irradiation device; (a) Schematic of UV equipment using 10 UV-C lamps; (b) Schematic distance between lamp and fruit surface; (c) and (d) Irradiated fruits arranged on adjustable rack of UV-C equipment

Ripening quality assessment

Changes in peel color were expressed by lightness (L*), redness (a*), and hue angle (^{0}hue) with chroma meter (Mini Scan EZ 45/0 Hunter Lab) at 4 points on each side of 9 fruits per treatment.

Respiration rate was determined with gas chromatography (model 7890, AGILENT) using 4 fruit per treatment. Each mango fruit were sealed in plastic container at 21 °C for 3 h.

Fruit firmness was determined in Newton (N) by using texture meter (Texture Analyzer, TA.XT plus, Stable Micro Systems Texture Technologies) equipped with 2 mm cylindrical probe. Each fruit was penetrated 5mm at a speed of 1.5 mms^{-1} and the maximum force developed during the test was recorded. Three measures were made in each side of fruit with peel at different points along equatorial zone. Results were means of 9 fruits for each sampling period and for each treatment.

Total soluble solid (TSS) was determined by digital hand-held pocket refractometer (Model PAL1, Atago, Japan). Titratable acidity

(TA) was determined by titration fruit juice with 0.1 N of NaOH (phenolphthalein as indicator) and the result was expressed as % of citric acid equivalent. Results were means of 3 replications (a total of 9 fruits) for each sampling period and for each treatment.

The dry matter content (DM) was gravimetrically determined following Kienzle *et al*. (2011) with a slight modification. Dry matter was resulted as the residue from drying 5.0 ± 0.5 g of mesocarp cubes in a dry aluminium dish at 105 °C for 3 h and recooling in a desiccator until constant weight.

Sample preparation

Frozen pulps (5.0 ± 0.5 g) were homogenized in 95% methanol 20 ml, using an Ultra Turrax for 2 min at room temperature. Then, the preparation was centrifuged in 4 °C; 5,000 x *g* for 10 min. The supernatant was taken and filtered through Whatmann filter paper no.1, and then the volume was adjusted with 95% methanol to 25 mL. The extract was diluted with distilled water to get five fold.

Antioxidant capacity assessment

Analysis of DPPH scavenging activity (2,2-diphenyl 1-picrylhidrazyl) was determined using spectrophotometry method (517 nm) with trolox (6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic) as standard. The results were expressed as mol trolox equivalent 100 g^{-1} of dry basis. Total reducing power of fruit extract was determined using spectrophotometry method (725 nm) as described by Saha *et al.* (2008). The results were expressed as mg ascorbic acid equivalents (AA) 100 g^{-1} of dry basis. Total phenolics were determined according to ISO 14502-1 (ISO, 2005) spectrophotometry method (765 nm) using gallic acid as standard. The results were expressed as mg gallic acid equivalents (GAE)/100 g^{-1} of dry basis.

Statistical analysis

All samples were analyzed in triplicate, and expressed as mean ± SD. Analysis of variance (ANOVA) were conducted and compared significance of difference within samples using Duncan's multiple range tests. To compare significance of difference between two samples, the t-test was conducted. Differences of $P < 0.05$ were considered to be significant (SPSS 16.0 for Windows, SPSS Inc., IL, USA).

RESULTS AND DISCUSSION

Initial quality of mangoes

At commercial stage, mango cv Nam Dok Mai Si Thong had 0.981 ± 0.074 g/mL of specific gravity with yellow peel color quantified as 76.88 ± 2.49 of L* value, 4.78 ± 0.97 of a* value, and 81.63 ± 1.58 of hue angle. The mangoes had initial respiration rate at 0.51 ± 0.10 mL CO_2 /kg/h. The fruit presented 24.413 ± 1.391 N of firmness, 8.2 ± 0.9 °Brix of total soluble solid, 1.84 ± 0.6 % of titratable acidity, and 19.24 ± 2.19 % of dry matter.

Color

Figure2 and Figure3 depict the changes in peel color on the normal ripening and UV-C treated Nam Dok Mai Si Thong. During ripening process, the lightness of control samples, which showed as L* value remained relatively steady at 75. By day-20, it had decreased slightly to 72.04. On the other hand, the L* values of UV-C treated samples had suffered a significant decline (*P<0.05*), particularly by day-10 when numbers fell to 57.38. There was also a significant fall (*P<0.05*) in hue angle from 81.63 at 0 day to 71.79 at the 5th day of observation. As ripening progressed, the hue angle value decreased steadily throughout the period. Similar to L* value and hue angle trends, the changes of a* value was also significantly different (*P<0.05*) between control and UV-C treated mangoes. In UV-C samples, the a* values rose significantly (*P<0.05*) from 4.78 to 13.70. The value was still increasing to 18.11 at the end of storage, but at a slower pace. The a* value of control samples rose slightly over the whole storage period. However, by the end of storage time, the values were still less than 9. This showed that UV-C treatment produced a significant difference (*P<0.05*) in L* value, a* value, and hue angle compared with control.

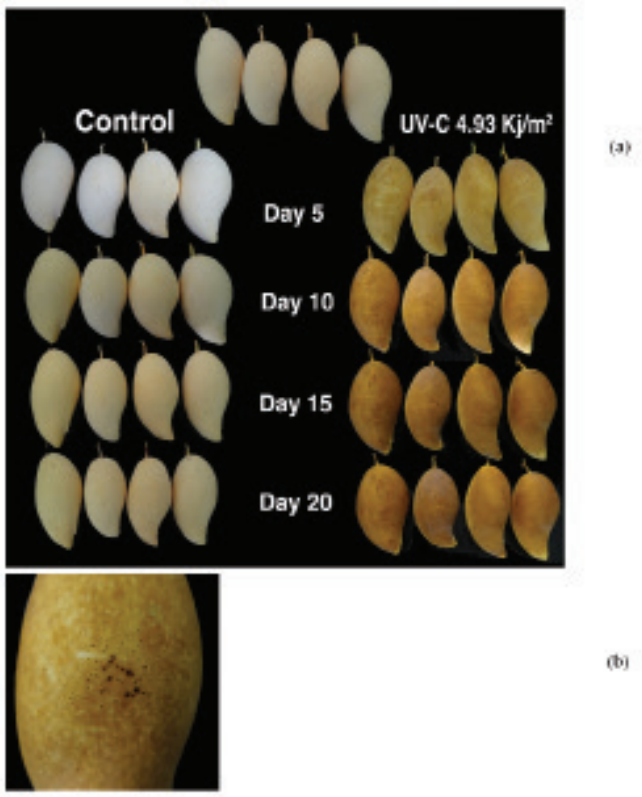

Figure 2 Visual appearance of Nam Dok Mai Si Thong mango; (a) head-to-head visual appearance comparison during storage; (b) blackened lenticel and abnormal skin browning appeared in the peel

The external color of mango is an important factor in consumer preference (Gonzalez-Aguilar *et al.*, 2001). Overall, the UV-C treated mangoes had poor visual quality due to accumulation of skin browning and blackened lenticels throughout the peel with the color worsening as ripening progressed. However, no harmful effects were exhibited on the mango pulp, regardless of the investigated dose used. Similar UV-C damage to peel color was found in papaya (Cia *et al.*, 2007). Likewise, Maharaj *et al.* (1999) reported that higher dose of UV caused abnormal browning and manifested as sun scalding of the tomato's surface.

Respiration rate

Study on the pattern of respiration rate after UV-C irradiation in Nam Dok Mai Si Thong mangoes was shown in Figure 4. Started at day-10, the respiration rate of control samples sharply increased

from 2.11 to 6.91 mL CO_2 /kg/h. Following this sharp increase, the respiration rate of control samples rose more slowly to 7.35 mL CO_2 / kg/h at day-15 and declined to 4.96 ml CO_2 /kg/h at the end of storage time. The respiration rate in UV-C treated mango rose steadily from day-5 to day-15, reaching a peak of 6.69 mL CO_2 /kg/h at day-15. The respiration rate then dropped to 3.85 mL CO_2 /kg/h by the end of storage period. The differences between treated and untreated fruits on respiration rate were, however, not statistically significant (*P>0.05*). These patterns indicated that at the investigated dose, UV-C treatment did not significantly suppress respiration rate in mango. In contrast, Maharaj et al. (1999) reported that UV-C treatments at 3.7 kJ/m^2 and 24. 4 kJ/m^2 were able to shift tomato's respiration peak to the right and lowered its peak. Furthermore, Costa *et al.* (2006) also mentioned that at day 4 after UV-C irradiation (10 kJ/m^2) in broccoli, the respiration rate found significantly different compared to control, while at 0 day and 2 day after irradiation, there was no significant UV-C effect to respiration rate.

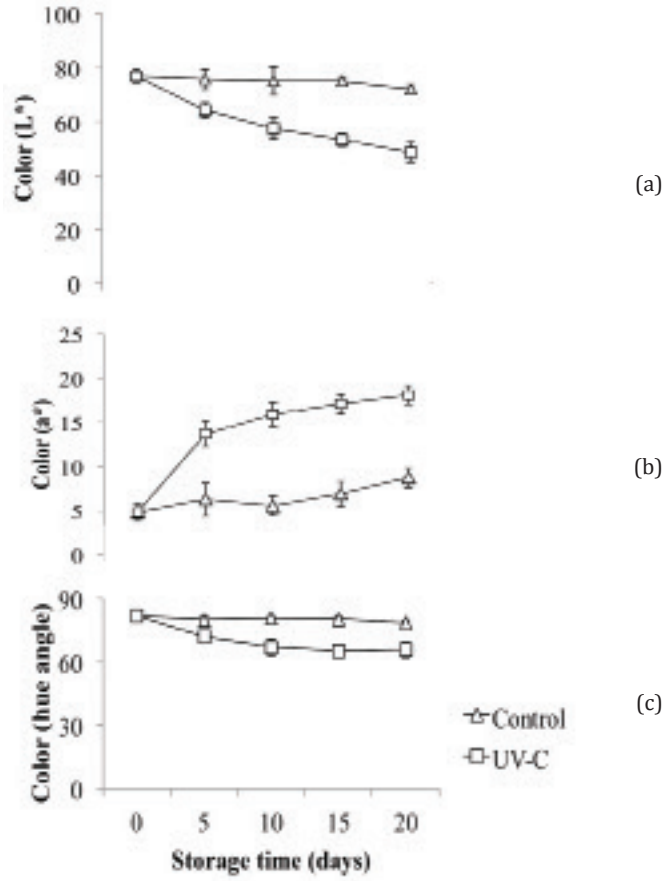

Figure 3 Changes in color parameters in the peel of Nam Dok Mai Si Thong mango between control and UV-B treatment; (a) Changes in lightness parameter (The L* value indicated black=0 to white=100); (b) Changes in a* parameter (The a* value indicated positive number indicates red and a negative number indicates green); (c) Changes in hue angle parameter (Hue angle (^{o}hue) represents different color, 00 = red-purple, 450 = orange, 900 = yellow, 1800 = bluish green, and 2700 = blue). Vertical bars represent the SD

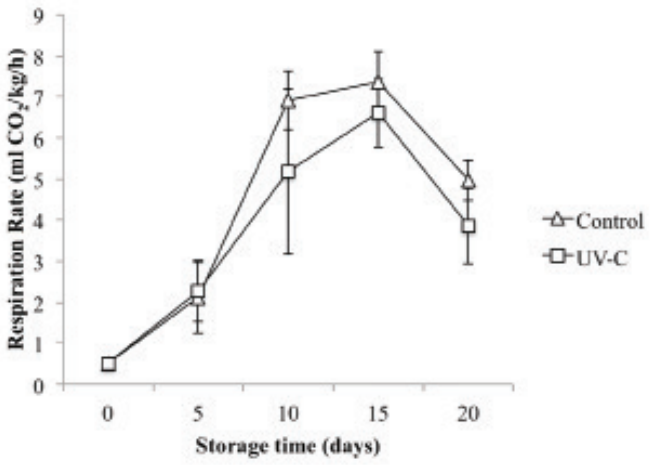

Figure 4 Effects of UV-C irradiation on respiration rate of Nam Dok Mai Si Thong mango during storage at 14 ^{o}C. Vertical bars represent the SD

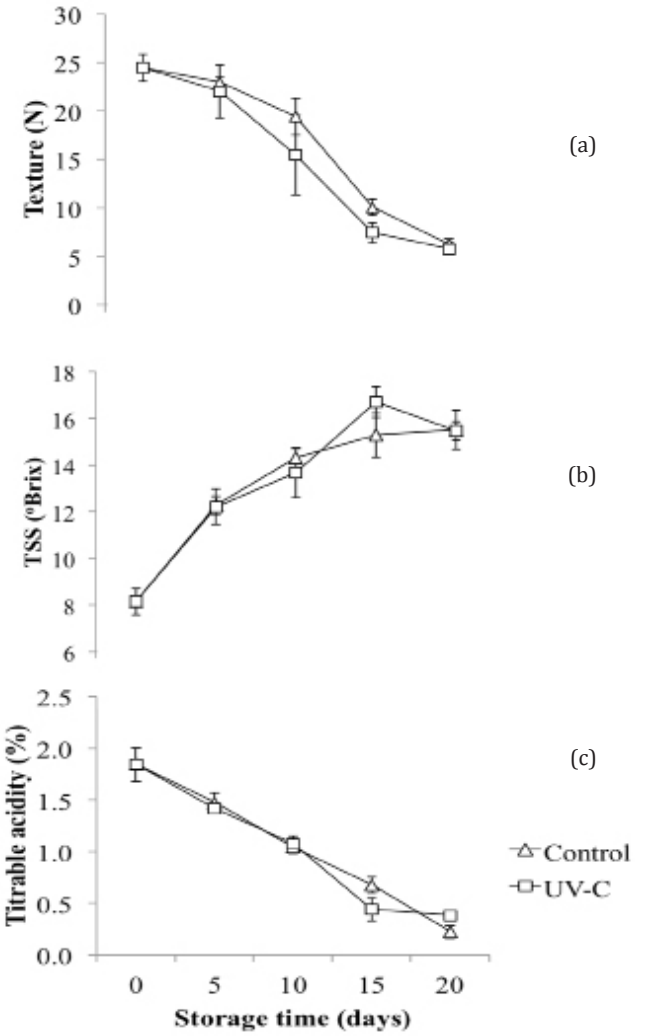

Figure 5 Effects of UV-C irradiation on internal quality of Nam Dok Mai Si Thong mango; (a) Firmness; (b) Total soluble solids (TSS); (c) Titratable acidity. Vertical bars represent the SD

Firmness

The firmness of the mangoes (Figure 5a) during storage showed no significant overall difference between control and irradiated samples despite a significant difference (*P<0.05*) at day-10, when control fruit was firmer than UV-C treated fruit. In pear (Syamaladevi *et al.*, 2014) and sweet cherries (Marquenie *et al.*, 2002) also showed no significant texture changes due to irradiation. Khademi *et al.* (2013) suggested that UV-C treatment must be integrated with other effective postharvest treatments for maintaining firmness in peach fruit. On the other hand, several reports of UV-C treatment showed positive effect for maintaining fruit firmness in tomato (Bu *et al.*, 2013) and strawberry (Pombo *et al.*, 2009). However, Marquenie *et al*. (2002) reported that although UV-C can retard softening in strawberry, the same doses also contributed negative effect on calyx color, causing drying and staining of the leaves.

Total soluble solid (TSS) and titratable acidity (TA)

The changes of TSS and TA in Nam Dok Mai mangoes after UV-C irradiation are shown in Figure 5b and 5c. Figures 5b and 5c show that there were no significant differences in total soluble solid and titratable acidity changes during storage between the control and irradiated fruits. This is in agreement with results reported by Syamaladevi *et al.* (2014) for pears and Perkins-Veazie *et al.* (2008) for blueberry. A decrease in acidity during storage coincide with the reports by Jacobi *et al.* (2000) and Tovar *et al.* (2001) that fruit acids are used as substrates for respiration during storage.

Antioxidant capacity properties

Changes in antioxidant capacity of mango treated with UV-C irradiation were presented in Figure 6. By day 5 both treatments showed consistent decline in all 3 parameters then, the antioxidant capacity values of both samples had increase significantly (*P<0.05*) by day 10. The authors are unable to explain regarding the occurring phenomenon at day 5 and day 10. However, overall, these 3 parameters show consistent trend on the difference between irradiated and control fruits (Figure 6).

The gap emphasized UV-C, at the investigated dose, caused lower in DPPH values compared to the control. The result differs from Gonzalez-Aguilar *et al.* (2007a), who found that exposure to UV-C for 10 minutes (dose not reported) contributed to the high DPPH value (as % radical scavenging activity) in fresh cut 'Tommy Atkins' mango.

Similar to DPPH, FRAP analysis in UV-C treated mango also show the same downward trend (Figure 6b). Even though at day 10, UV-C seem to had higher FRAP value, but the effect was no longer. Along with ripening, UV-C treated sample had lower value significantly (*P<0.05*) than control. In contrast, control sample also show the decreasing trend, but the value was higher than UV-C treated sample. Overall, UV-C treatment at the investigated dose, causing negative response of antioxidant capacity. This negative response was described as 5.7 mg AAE 100/g of dry basis and 11.8 mg AAE 100/gof dry basis for UV-C treated fruit and control fruit, respectively. It was double that what was in UV-C. However, a study on minimally processed citrus fruit found that UV-C treatment did not affect the antioxidant activity, as ascorbic acid was not greatly affected by UV-C (Shen *et al.*, 2010). Previous study in mango shows that ascorbic acid was highly correlated with antioxidant capacity (Shivashankara *et al.*, 2004). On the other hand, Gonzales *et al.* (2007a) reported that application of UV-C had negative effect which causing declining in ascorbic acid content in fresh-cut mangoes during storage.

Whereas Liu *et al.* (2012), showed that UV-C irradiation significantly increased phenolic compounds in tomato, Figure 6c shows UV-C treated fruit undergoing significant loss (*P<0.05*) throughout the storage time. The result is also in contrast with Gonzalez *et al.* (2007b), who found that UV-C treatment (4.93 kJ/m^2) in 'Haden' mango increased total phenols during storage at 25 °C for 18 days. In addition, Perkins-Veazie *et al.* (2008) reported that, effective UV-C dosage depends on crop types, and doses that are too high may cause deleterious effects on fruit quality.

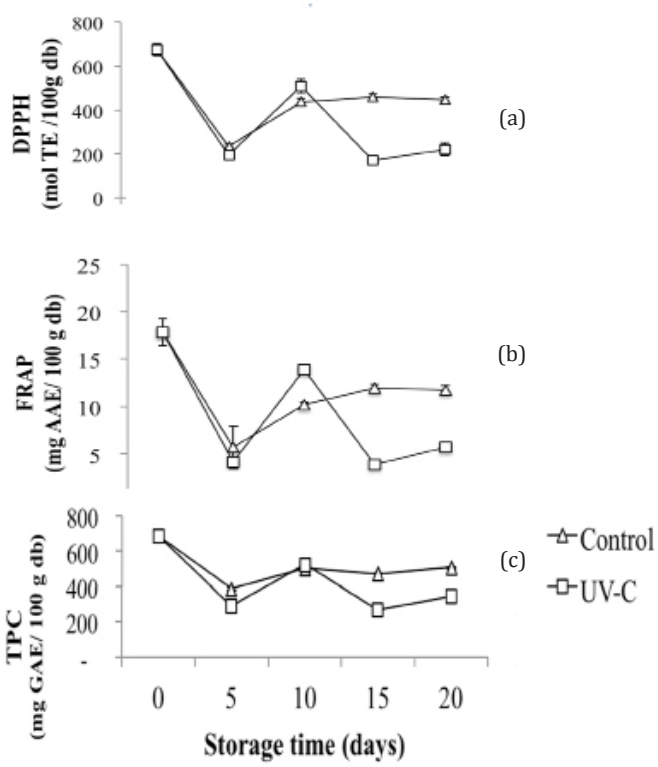

Figure 6 Effects of UV-C irradiation on antioxidant capacity in Nam Dok Mai Si Thong mango; (a) 2,2-Diphenyl-1-pycrylhidrazil (DPPH); Trolox equivalent (TE); (b) Ascorbic acid equivalent (AAE); (c) Total phenolic compounds (TPC); Gallic acid equivalent (GAE). Vertical bars represent the SD

CONCLUSION

In the present study, fruit color and antioxidant capacity changes were the most marked effects of the 4.93 kJ/m^2 UV-C treatment. UV-C irradiation, at the investigated dose, was not able to retain antioxidant compounds in Nam Dok Mai Si Thong and caused harmful effects to the visual appearances, but not contributes to the internal color quality. The changes in respiration rate, texture, TSS, and TA values were not much affected by the irradiation. It must be integrated with other effective postharvest treatments to reduce its undesirable effects.

ACKNOWLEDGEMENT

This research was financially supported by Mae Fah Luang University, Thailand.

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