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Physicochemical Changes in 'Kaew Kamin' Mango Fruit Illuminated with UltraViolet-C (UV-C) during Storage

S. Promyou[1], and S. Supapvanich[2*]

ABSTRACT

The effects of UV-C illumination at the dosage of 6.6 kJ m^{-2} on postharvest quality of mango fruit cv. 'Kaew Kamin' during storage at 25 or 12°C were investigated. The changes in fresh weight, texture, Ripening Index (RI), peel and pulp colours, visual appearance, Total Carotenoids (TC) and Ascorbic Acid (AsA) content were determined on days 0, 4, 8, 12 and 16 of storage. UV-C irradiation effectively maintained the fruit firmness and delayed the increase in RI and the loss of peel greenness over storage. No treatment had any effects on pulp yellowness over storage. The incorporation of UV-C illumination and refrigerated storage (12°C) prevented postharvest disease and maintained nutritional values such as TC and AsA content. In conclusion, UV-C irradiation appears an effective alternative approach to maintain postharvest quality and nutritional values and to extend shelf-life of 'Kaew Kamin' mango fruit.

Keywords: Mango, Postharvest quality, UV-C light.

INTRODUCTION

Recently, the demand of exotic fruits has dramatically increased, due to the change in diet habits, attractive organoleptic properties and beneficial health purposes. Mango (*Mangifera indica* L.) is a popular commercial tropical fruit. In addition to the usual nutrients such as vitamins, minerals and dietary fiber, mangoes are also a rich source of bioactive compounds such as carotenoids, phenolic compounds and flavonoids (Schieber *et al*., 2003). Mango is an export fruit of Thailand. The export of the mango fruit was 11,272.201 tons in year 2007 and increased to 33,035.207 tons in year 2013 (Office of Agricultural Economics, Thailand, 2014). 'Kaew Kamin' is one of the commercial mango fruits in Thailand following 'Nham Dok Mai', 'Fha-Lhan' and 'Kiew Saweuy' cultivars. The mango fruit has been produced for industrial processing and fresh consumption. 'Kaew Kamin' which originated from Cambodia has been spread to Thailand and become a commercial mango cultivar. Because of firm texture, yellow flesh and sweet and slightly sour taste, the mango fruit has been consumed at full mature and ripe stages and the demand of Kaew Kamin mango fruit has increased dramatically. In developing countries, the loss of mango fruit in market was reported as over 50% (Kader, 2002), which is mainly due to rapid ripening and fungi attack (Johnson *et al*., 1993). To extend shelf life and maintain quality of fruit during storage and transportation, a range of physical and chemical methods, such as controlled atmosphere storage, high temperature, calcium dip, sodium carbonate and bicarbonate immersion and ethanol

[1] Faculty of Natural Resources and Agro-Industry, Kasetsart University, Chalermprakiat Sakon Nakhon, Province Campus, Muang, Sakon Nakhon, 47000, Thailand.
[2] Department of Agricultural Education, Faculty of Industrial Education, King Mongkut's Institute of Technology Ladkrabang, Ladkrabang, Bangkok, 10520, Thailand.
[*] Corresponding author; e-mail: kusuriya@kmitl.ac.th

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exposure have been designed to delay the ripening and deterioration (Ketsa *et al*., 2000; Ortega-Zaleta and Yahia, 2000; Larrigaudiere *et al*., 2002; Gabler *et al*., 2004).

Recently, treatments based on UV-C illumination (190-280 nm wavelength) have been studied to delay ripening, inhibit fungi attack and maintain postharvest quality in many fresh fruits (Promyou and Supapvanich, 2012; Rivera-Pastrana *et al*., 2014; Bal and Kok, 2009; Kim *et al*., 2010; Obande *et al*., 2011) and become an effective alternative for postharvest application. Postharvest UV-C illumination also induces accumulation of defense mechanism, which positively correlated with the reduction of deterioration and physiological disorders and resistance against pathogens in fruits (Obande *et al*., 2011; Rivera-Pastrana *et al*., 2014; Escalona *et al*., 2010). Previous work had suggested that the use of UV-C illumination at 4.93 kJ m^{-2} can be a good alternative to increase shelf-life, maintain overall appearance and retard the decay of 'Haden' mango fruit (González-Aguilar *et al*., 2007a). Moreover, the maintenance quality and improving antioxidant capacity including bioactive compounds in 'Tommy Atkins' fresh-cut mango fruit by using UV-C irradiation had been also reported (González-Aguilar *et al*., 2007b). Promyou and Supapvanich (2012) reported that UV-C illumination at the dosage of 6.6 kJ m^{-2} successfully extended shelf-life, reduced softening and enhanced bioactive compounds of yellow bell pepper.

A postharvest research in 'Kaew Kamin' mango has not been found. From our preliminary work, UV-C illumination at the dose of 6.6 kJ m^{-2} was the optimum dose without any superficial damage on the mango fruit skin. Therefore, this study was undertaken to investigate the effect of UV-C illumination at the dosage of 6.6 kJ m^{-2} on postharvest quality of 'Kaew Kamin' mango fruit during storage at 25 and 12˚C.

MATERIALS AND METHODS

Plant Material

Mature-green 'Kaew Kamin' mango fruits were obtained from a wholesale market in Bangkok, Thailand. The fruit were harvested and delivered to the market on the same day of purchase. Fruits with uniform maturity stage, peel colour, size and free from physical damage and diseases were selected. The fruits were cleaned with tap water (at 25°C) and dipped in 100 µL L^{-1} sodium hypochlorite for 5 minutes. After cleaning, the fruits were air-dried at room temperature.

UV-C Treatment

The fruits were randomized into four groups of 80 pieces: untreated fruits (control) stored at 25°C, untreated fruits (control) stored at 12°C, UV-C treated fruits stored at 25°C and UV-C treated fruits stored at 12°C. For UV-C treatment, fruits were placed in a plastic box (1.32 m length, 1.85 m wide and 0.8 m deep) containing two germicidal UV lamps (TUV 30W, Salvania, Japan) and irradiated at a distance of 70 cm above and below fruit for 90 minutes to obtain the dosage of 6.6 kJ m^{-2}. The dose of UV-C light was measured using a UV light meter model UVC-580010 (Sper Scientific, USA). Non-irradiated fruits were considered as control. Both treated and untreated fruits were placed in perforated PVC bags and held at 25 or 12°C in the absence of light for 16 days. Physicochemical changes such as weight loss, firmness, RI, colour and bioactive compounds (TC and AsA content) were investigated on days 0, 4, 8, 12 and 16.

Weight Loss, Firmness, Ripening Index and Colour Parameters

Fresh weights of the mango fruits were recorded at 0, 4, 8, 12 and 16 days of

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storage. The percentage of the loss of fresh weight during storage was calculated and the data were expressed as % weight loss compared to the initial day. Firmness of the fruits was measured using a TA-XT II texture analyzer (Stable Micro Systems, Surrey, England), equipped with a 2 mm diameter probe. The probe was driven at a crosshead speed of 10 mm s^{-1} to a depth of 5 mm. The maximum force exerted expressed in terms of Newtons (N) was used as firmness data.

Total Soluble Solids (TSS) content of the mango juice was measured using a hand-held refractometer (ATAGO MNL-1125, Japan). Titratable Acidity (TA) of the fruit juice was determined using the standard method of AOAC (1995). The Ripening Index (RI) was expressed as the ratio of *TSS/TA*.

The colours of both peel and pulp were measured using a HunterLab MiniScan@XE Plus (Hunter Associates Laboratory Inc., USA). The peel colour was interpreted as greenness (-a* value) and yellowness (b* value) and the colour of pulp was presented as brightness (L* value) and yellowness (*b** value).

Total Carotenoid and Ascorbic Acid Content

Total Carotenoid (TC) content of the mango fruit pulp was determined using the method described by Hornero-Mendez and Miguez-Mosquera (2001). Two grams of the fruit pulp were extracted with 10 mL of 100% acetone using a homogenizer (Daihan Scientific, Korea). Samples were centrifuged at 12,000×*g* for 10 minutes at 4°C by using a refrigerated centrifuge machine model L535R (ProSciTech, Australia). The supernatant was collected and the pellet was again extracted with the same extract solution for 4 times. The collected supernatant was brought to 100 ml with 100% acetone before measurement. Absorbance at 472 nm was recorded by using a Heλios UV–visible spectrophotometer (Thermo Spectronic, UK). The results were calculated as OD_{472} per 100 grams of fresh weight (OD_{472} 100 g^{-1} FW) (Promyou and Supapvanich, 2012).

Ascorbic Acid content (AsA) in the mango pulp was determined using 2,6-dichloroindophenol titrimetric method (AOAC, 1995). The data were expressed as mg ascorbic acid per 100 g of fresh weight (mg AsA 100 g^{-1} FW)

Statistical Analysis

A factorial with completed randomized design and four replications was used in this experiment. Statistical analysis was carried out using the Analysis Of Variances (ANOVA) performed in SAS 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±Standard Deviation (SD).

RESULTS AND DISCUSSION

Weight Loss, Firmness and Ripening Index

The loss of fresh weight, softening and the increase in ripening are the main factors limiting postharvest quality and shelf life of fruit. As shown in Figure 1-A, the weight loss of the mango fruit of all treatments increased continuously throughout storage. The highest weight loss was detected in the untreated fruit held at 25°C, which reached 10.2% on day 16 of storage. The lowest weight loss was found in the untreated fruit held at 12°C. The loss of fresh weight of both UV-C treated fruits was significantly lower than that of the untreated fruit held at 25°C ($P < 0.05$). The results also showed that refrigerated storage is a necessary technique to prevent the loss of moisture from the fruit. Previous UV-C research results on different species conducted by Erkan *et al.* (2008), Bal and Kok (2009) and Promyou and Supapvanich (2012) showed that UV-C

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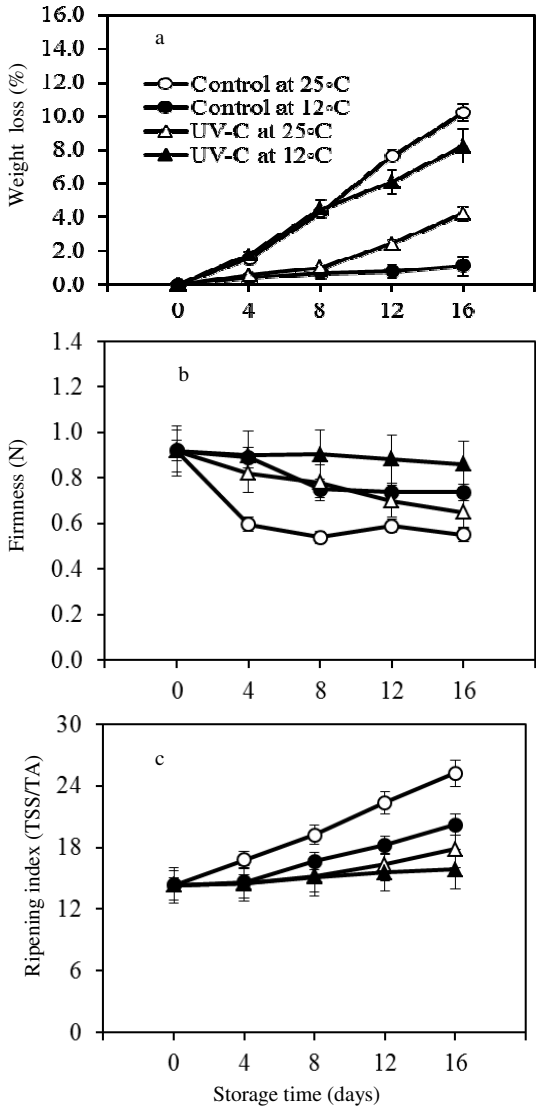

Figure 1. Weight loss (%) (a), firmness (b) and ripening index (c) of untreated and UV-C treated 'Keaw Kamin' mango fruit stored at 25 or 12°C for 16 days. Data are the mean of four replications and vertical bars represent standard deviation.

illumination led to less weight loss in fruits than the untreated fruits. However, Vunnan *et al.* (2014) suggested that the loss of fresh weight from tomato fruit was unaffected by UV-C illumination.

The results shown in Figure 1-B indicate that storage at 12°C and UV-C treatment delayed the mango fruit softening. Firmness of the untreated fruit held at 25°C decreased sharply and was significantly lower than those of other treatments ($P< 0.05$). A slight decrease in firmness was detected in the untreated fruit held at 12°C and the UV-C treated fruit stored at 25°C whilst the firmness of UV-C treated fruit held at 12°C remained constant over storage. We also found that the increased weight loss might be a minor factor affecting the fruit softening. Thus, cell wall degradation and cell membrane dysfunction might be the key factors affecting the fruit softening as described by Brummell (2006). The delayed softening of the UV-C treated mango fruit might be related to the reduction of cell wall degradation and cell membrane dysfunction. Previous works had reported that UV-C application delayed cell wall depolymerization, inhibited the activity of cell wall hydrolases such as polygalacturonase and pectinmethylesterase and consequently retarded softening of tomato fruit (Barka, *et al.*, 2000; Steven, *et al.*, 2004). Vincent *et al.* (2005) reported that UV-C treatment at 7 kJ m^{-2} delayed the increase in electrolyte leakage and alleviated chilling injury in pepper fruit. A similar result was also reported on yellow bell pepper treated with 6.6 kJ·m^{-2} UV-C (Promyou and Supapvanich, 2012). Moreover, retarding fruit softening by UV-C illumination was also reported on kiwifruit (Bal and Kok, 2009), strawberry (Erkan, *et al.*, 2008) and tomato (Obande, *et al.*, 2011). These suggest that the effect of UV-C treatment on maintaining the fruit firmness might be associated with the preservation of cell wall and membrane structures (Steven, *et al.*, 2004; Promyou and Supapvanich, 2012).

RI of the mango fruit was also delayed by cold storage at 12°C and UV-C illumination (Figure 1-C). RI of the untreated fruit held at 25°C increased markedly throughout storage, whilst the RI of the untreated fruit held at 12°C began after day 4. The RI of both UV-C treated fruits began on day 8 and then increased slightly. We found that UV-C treatment was a good alternative for retarding the increase in RI and also enhanced the efficiency of cold storage in

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delaying the softening on 'Kaew Kamin' mango fruit. Similar results were reported on 'Red Delicious' and 'Golden Delicious' apple fruits treated with UV-C (Hemmaty, *et al*., 2006; Hemmaty, *et al*., 2007).

Fruit Colour

The peel greenness reduction of UV-C treated mango fruit stored at 12°C was significantly (P< 0.05) lower than those of other treatments over storage (Figure 2-A). The greenness of both UV-C treated and untreated fruit stored at 25°C markedly decreased after day 4 of storage whilst those of the both UV-C treated and untreated fruit stored at 12°C decreased rapidly after day 8. At the end of storage, greenness (-a* value) of the UV-C treated fruit held at 12 and 25°C was -8.20 and -4.11 and that of untreated fruit held at 12 and 25°C was -5.19 and -2.00, respectively. These data showed that greenness loss of 'Kaew Kamin' mango fruit was delayed by UV-C treatments. This might be related to the reduction of chlorophyll degradation as described by Costa *et al*. (2006) where UV-C application decreased the activity of chlorophyll oxidase and chlorophyllase, resulting in the reduction of chlorophyll degradation and greenness maintenance of broccoli floret. Lemoine *et al*. (2007) also reported that the degradation of greenness and the increase in

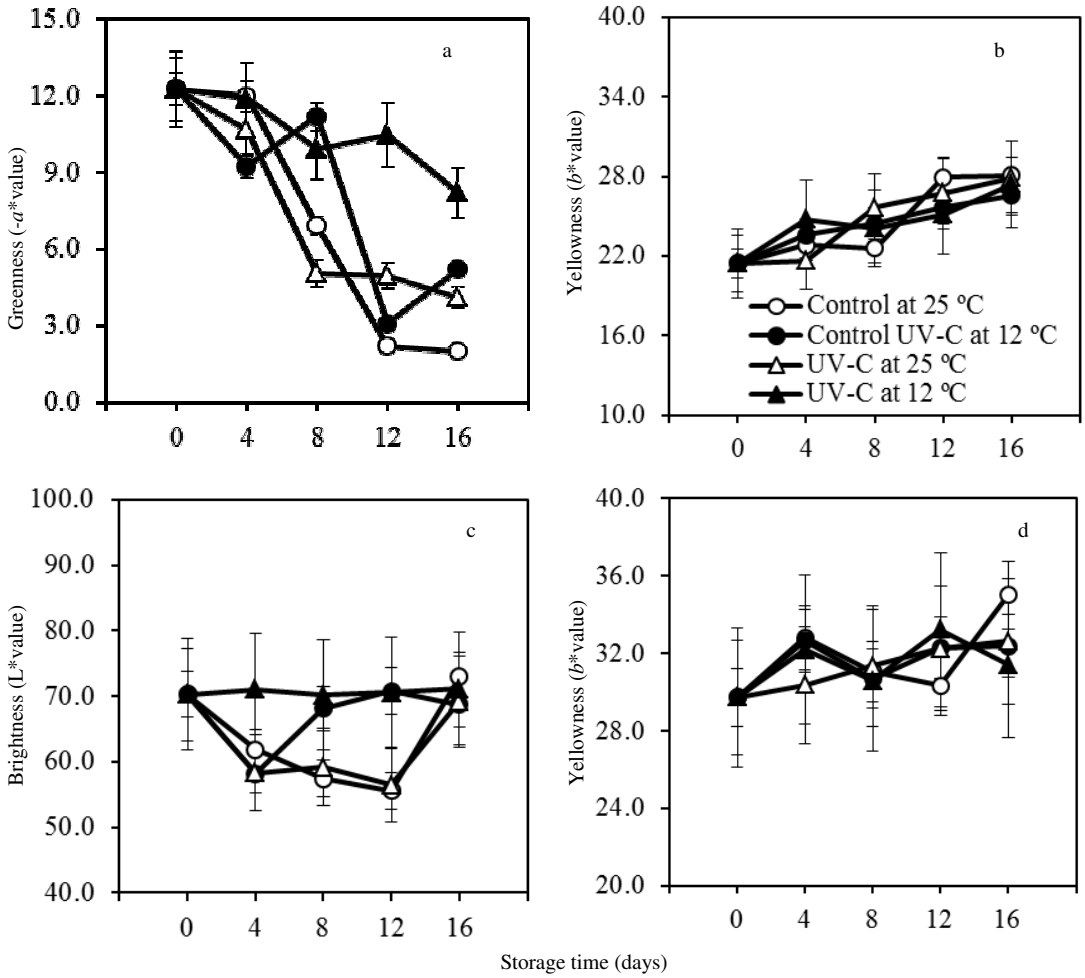

Figure 2. Peel (a, b) and pulp (c, d) colours of untreated and UV-C treated 'Keaw Kamin' mango fruit stored at 25 or 12°C for 16 days. Data are the mean of four replications and vertical bars represent standard deviation.

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yellowness of broccoli held at refrigerated storage were delayed by UV-C illumination. Obande *et al*. (2011) suggested that both low and high doses of UV-C treatment retarded the loss of green pigment in mature green tomato fruit during storage. The yellowness of the fruit peel increased slightly in all treatments and no significant difference was found among the treatments over storage (Figure 2-B). The peel yellowness of the fruit was approximately 21.42 on day 0 and reached about 27.50 on day 16 of storage.

Figures 2-C and -D present the brightness and yellowness of pulp colour during storage. The L^* value of the UV-C treated fruit held at 12°C remained constant over storage whilst those of other treatments decreased slightly; however, no significant difference in L^* value of the mango fruit pulp was found over storage. The yellowness of the fruit pulp also increased during storage but no significant difference in each treatment was found. The yellowness of the fruit pulp increased from 29.70 on day 0 to 32.84 on day 16 of storage; similar results were reported in yellow bell pepper treated with UV-C at the dosage of 6.6 kJ m^{-2} (Promyou and Supapvanich, 2012). The results suggest that UV-C treatment had no effect on the changes in yellowness of both peel and pulp but effectively delayed the loss of peel greenness.

Visual Appearance

Figure 3 shows the visual appearance of the mango fruit at day 0 and at the end of storage (day 16). At the end of storage, the disease appeared to be covering more than 20% of the surfaces of both treated and untreated fruits held at 25°C and a black spot of disease symptom was found in the untreated fruit stored at 12°C. No disease symptom occurred on the UV-C treated fruit held at 12°C. The acceptable appearance of mango fruit strongly correlated with fungal decay; UV-C illumination retarded the decay, fungi infection and the poor appearance of mango fruit during storage

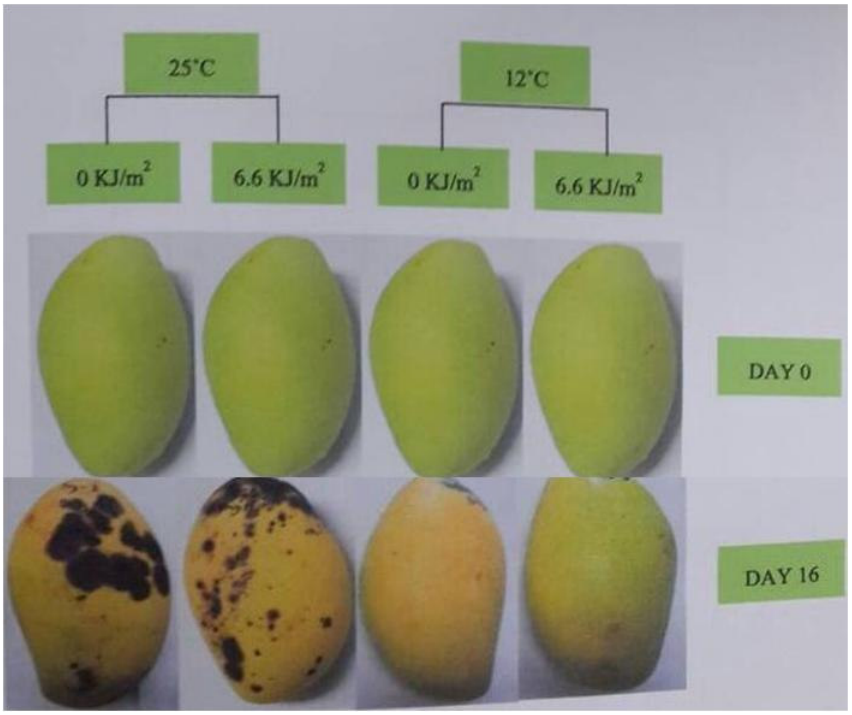

Figure 3. Visual appearance of untreated and UV-C treated 'Kaew Kamin' mango fruit stored at 25 or 12°C for 16 days.

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(Gonźalez-Aguilar *et al*., 2007a). Obande *et al*. (2011) and Steven *et al.* (2004) mentioned that UV-C treatment retarded the Rhizopus soft rot development and induced pathogen resistance in tomato fruit during storage. Thus, we suggest that UV-C treatment incorporated with refrigerated storage delayed the fruit ripening (Figure 1-C) and the loss of peel greenness (Figure 2-A) and inhibited postharvest disease in 'Kaew Kamin' mango fruit as shown in Figure 3.

Total Carotenoids and Total Ascorbic Acid Content

It has been widely accepted that TC and AsA content are the main nutrients found mango fruit and also act as biologically active compounds promoting human health. TC content decreased in 'Kaew Kamin' mango fruit continuously throughout storage (Figure 4-A), which was similar to the result in fresh-cut 'Tommy Atkins' mango fruit (Gonźalez-Aguilar *et al*., 2007b). A marked decrease in TC content was detected in the untreated fruit stored at 25°C, which decreased from 1.85 on day 0 to 0.62 on day 16 of storage. TC content of UV-C treated fruit held at 12°C was higher than those of other treatments and remained constant for 8 days before it decreased to 1.18 at the end of storage. There was no significant difference in TC content of both UV-C treated fruit held at 25°C and untreated fruit held at 12°C over storage. This shows an interaction between UV-C treatment and cold storage in reducing the decrease of TC content. The result was similar to our previous work in which TC content of UV-C treated yellow bell pepper fruit held at 12°C was higher than that of untreated fruit (Promyou and Supapvanich, 2012). Moreover, Lui *et al.* (2009) also reported that TC content in 'Red ruby' tomato fruit was enhanced by UV-C illumination.

As shown in Figure 4-B, UV-C treatment significantly reduced the loss of AsA content in the fruit when compared to the untreated fruit during storage ($P< 0.05$). AsA content of the UV-C treated fruit held at 12°C remained constant over storage whilst that of UV-C treated fruit held at 25°C decreased slightly but no significant difference in AsA content of both treatments was found. A marked loss of AsA content was found in the untreated fruit stored at 25°C, which was significantly lower that other treatments ($P< 0.05$). This shows that UV-C illumination maintained AsA content over cold storage alone. Our previous work also found that UV-C illumination at 6.6 kJ m^{-2} could maintain total AsA content in yellow bell pepper during cold storage (Promyou and Supapvanich, 2012). In the same vein, 4.8 kJ m^{-2} UV-C illumination delayed the

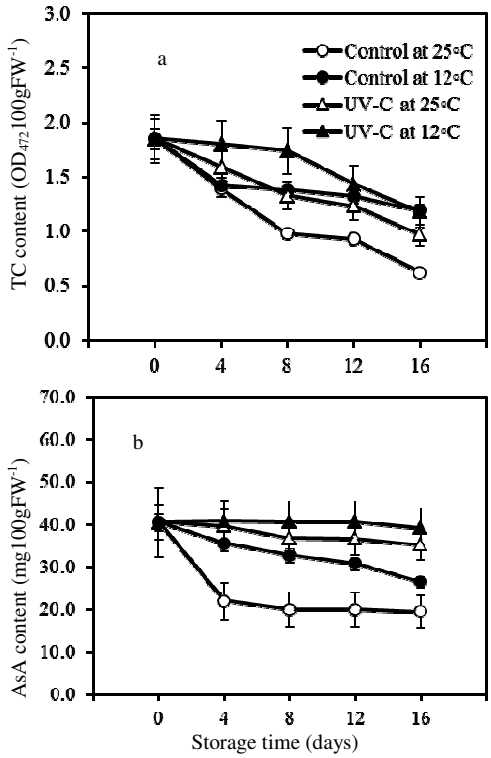

Figure 4. Total carotenoids (TC) (A)and ascorbic acid (AsA) (B) content of untreated and UV-C treated 'Keaw Kamin' mango fruit stored at 25 or 12°C for 16 days. Data are the mean of four replications and vertical bars represent standard deviation.

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loss of vitamin C content in fresh-cut watermelon (Artés-Hernández *et al*., 2010) and kiwifruit (Bal and Kok, 2009) and enhanced AsA content in sweet pepper (Martínez *et al*., 2005) and red pepper (Andrade Cuvi *et al*., 2011). However, using 7.2 kJ m^{-2} UV-C illumination could increase the loss of AsA content in fresh-cut watermelon (Artés-Hernández *et al*., 2010). Gonźalez-Aguilar *et al.* (2007b) had reported a contrasting result in which UV-C treatment decreased AsA content in fresh-cut 'Tommy Atkins' mango fruit. However, we suggest that UV-C illumination could preserve certain nutrients such as AsA content in 'Kaew Kamin' mango fruit during storage.

CONCLUSIONS

UV-C illumination and cold storage promoted the maintenance of postharvest quality of 'Kaew Kamin' mango fruit. This study shows that the main effects of UV-C illumination were delaying fruit ripening, the loss of fruit firmness and peel greenness, inhibiting postharvest disease occurrence and maintaining certain bioactive compounds such as total carotenoids and ascorbic acid content of 'Kaew Kamin' mango fruit during refrigerated storage. We suggest that UV-C illumination is a good alternative to maintain postharvest quality including bioactive compounds and to prevent postharvest diseases of 'Kaew Kamin' mango fruit during refrigerated storage.

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تغییرات فیزیکوشیمیایی در میوه انبه Kaew Kamin تیمار شده با اشعه ماورای بنفش (UV-C) در طول ذخیره سازی

س. پرومیو، و س. سوپاپوانیچ

چکیده

اثرات تابش UV-C در دوز ۶.۶ kJ m-2 بر روی کیفیت پس از برداشت میوه انبه رقم "Kaew Kamin"در طول ذخیره سازی در دمای ۲۵ درجه سانتیگراد یا ۱۲ درجه سانتیگراد مورد بررسی قرار گرفت. تغییرات در وزن تر، بافت، شاخص رسیدن(RI) ، رنگ پوست و پالپ ، ظاهر بصری، میزان کل کاروتنوئیدها (TC) و اسید اسکوربیک (AsA) در روز ۰، ۴، ۸، ۱۲ و ۱۶ از ذخیره سازی تعیین شد. تابش UV-C به طور موثری سفتی میوه را حفظ کرد و افزایش RI و از دست رفتن سبزی پوست در طول ذخیره سازی را به تاخیر انداخت. هیچ تیماری اثری بر روی زردی پالپ در طول ذخیره سازی نداشت. ترکیب تابش UV-C و نگهداری در یخچال (۱۲ درجه سانتیگراد) موجب جلوگیری از بیماری پس از برداشت و حفظ ارزش تغذیه ای مانند TC و میزان AsA گردید. در نتیجه، به نظر می رسد تابش اشعه UV-C یک روش جایگزین موثر برای حفظ کیفیت پس از برداشت و ارزش تغذیه ای و بهبود ماندگاری میوه انبه Kaew Kamin باشد.

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