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Original Research Article

Effects of Intermittent Warming on Quality of Papaya Fruit cv. Holland during Storage

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ABSTRACT

Papaya (*Carica papaya* L.) is a tropical fruit grown widely in Thailand. However, the export volume is low which could be due to temperature mismanagement during storage and transportation that lead to low quality fruit. This research investigated the effects of intermittent warming (IW) on 'Holland' papaya during storage. Papayas with 25% peel yellowing were submitted to four conditions: untreated fruit stored at 5°C (control), 15°C, IW1 condition (5°C for 4 days then subjected to 15°C for 1 day, 1 cycle) and IW2 condition (5°C for 4 days and moved to 15°C for 1 day, 2 cycles) then stored at 5°C, 90% RH until the end of storage. The quality of papayas was evaluated periodically at 0, 5, 10, 15 and 20 days of storage. The results showed that weight loss of fruit in all treatments was lower than 1.2% throughout the storage period. Fruit stored at 15°C, 80% RH had significantly ($p < 0.05$) higher in peel color changes (L* and a* values) compared with other treatments at 5 and 10 days of storage. Total soluble solids and titratable acidity revealed non-significant differences among treatments throughout the storage period. The fruit stored at 15°C had the highest vitamin C content of 34.3 mg 100 g^{-1} FW, but they could be kept for 10 days. The control fruit could be stored for only 5 days due to the unacceptable chilling injury (CI) index (>2) was observed since 10 days of storage. The more severity of CI symptoms for the control fruit developed quickly after that. In contrast, the quality of fruit stored under IW1 and IW2 were still acceptable with the CI index of 1.8 and 0.8, respectively at 20 days of storage. The IW2 treatment potentially reduced the severity of CI and retained storage quality of fruit for 20 days.

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INTRODUCTION

Papaya (*Carica papaya* L.) fruit is one of the most important commodities produced, consumed and exported by tropical countries. It is a popular and economically important fruit tree that is typically planted in tropical and subtropical zones. Thailand ranked number eighth among nations with papaya producing regions in Asia, South America, North Central America and Africa (FAO, 2013). In Thailand, papaya production shows continuous harvest all year-round. Thus, papaya is considered as an important commercial and popular fruit crop cultivated widely in several regions i.e., Ratchaburi, Nakornpathom, Saraburi, and Nakornratchaseema (Somsri, 2014). The quality acceptance of Thai papaya fruit in both local and overseas markets has been recently increased. Thailand, papaya fruits cv. Kaek Nuan, Kaek Dam and Holland are the most popular commercial varieties. Recently, 'Holland' papaya fruit became the most popular cultivar in Thailand (Supapvanich and Promyou, 2017). Papaya fruit, like other tropical fruits, are sensitive to chilling temperatures (below 10°C) and might develop chilling injury (CI) symptoms such as pitting of the skin, scald, hard lumps in the pulp around the vascular bundles (Chen and Paull, 1986). For instance, 'Exp. 15' papayas stored at 5°C obtained acceptable rating up to 8 days, afterward CI symptoms, such as subtle surface pitting developed on the skin (Proulx et al., 2005). The authors also observed that the color indices of papayas stored at 0, 5 or 10°C did not change much during storage compared with the papayas stored at 15 or 20°C which continue to ripen normally after 6 days, and their color change from a light yellowish-green to a yellowish-orange with slight traces of green and the fruit remain acceptable for visual quality until 10 days of storage.

Kluge et al., (2003) reported that intermittent warming (IW) regime increased fruit resistance to low temperatures, enabling 'Tahiti' lime fruit to be stored at temperatures below those normally recommended. Furthermore, a wide range of CI symptoms can be reduced following IW during storage, include internal breakdown and woolliness in peaches and nectarines (Lill 1985; Fernández-Trujillo et al., 1998; Zhou et al., 2001), superficial scald in apples (Alwan and Watkins 1999), blotchy or uneven red coloration in tomatoes (Artés and Escriche 1994; Biswas et al., 2012) and pitting and husk scald in pomegranates (Artés et al., 2000).

Although many studies describe quality changes of several fruits during cold storage, no information was reported on the physiological and biochemical quality changes for 'Holland' papaya stored at chilling temperature with the application of IW regime. Thus the objective of this work was to determine the effects of IW on the storability of 'Holland' papaya and the reduction of physiological disorders during low temperature storage.

MATERIALS AND METHODS

Raw materials

Papaya fruit cv. Holland used in this work received from a commercial orchard located in Chiang Rai province, Thailand. The papayas were transported within 2 hours to the postharvest laboratory, School of Agro–Industry, Mae Fah Luang University in Chiang Rai. The fruit were selected according to export grade (size code 4: 801–1,100 g) (Thai Agricultural Standard; TAS 24, 2015) and color (25% peel yellowing). Afterward, the fruit were sanitized with 200 ppm chlorinated water for 1 min, and then dried for ~1 hour at room temperature (27±1°C) before storage.

Storage procedure

The papayas were divided into 4 treatments with 3 replicates of each and 2 fruits per replicate. All the stored fruit were packed in foam boxes with size (60 cm X 45 cm X 30 cm) according to the treatments. The treatments were (1) untreated control fruit continuously held at 5°C, 90% RH, (2) fruit stored continuously at 15°C, 80% RH. (3) IW condition 1 (IW1); fruit were stored at 5°C for 4 days then moved to 15°C for 1 day (only 1 cycle) after that stored at 5°C until the end of storage, and (4) IW condition 2 (IW2); fruit were kept at 5°C for 4 days and moved to 15°C for 1 day (for 2 cycles) then stored at 5°C until the end of storage. The quality of stored fruit was evaluated periodically at 0, 5, 10, 15 and 20 days of storage.

Weight loss (%)

The weight of the fruit was recorded at the initial day of storage and every 5 days of storage. The percentage of the fruit weight loss was calculated by comparing with the weight on the initial day (Khurnpoon et al., 2014).

Peel color

The peel color of fruit was measured using a color reader (model CR-10, Konica Minolta Inc., Osaka, Japan) and reported as L*, a* and b* values in which the L* value represents the lightness of the peel, where 0 = black and 100 = white, a* value represents greenness (negative value) and redness (positive value), b* represents yellowness (positive value) and blueness (negative value) (Abbott, 1999). Peel color was measured at the central part of the fruit with 4 positions in the opposite direction (Khurnpoon et al., 2014).

Total soluble solids (TSS)

Total soluble solids were measured from fruit juice of 5 g papaya pulp. A few drops of fruit juice were used for determination of the TSS content by using a digital refractometer (PAL-1, Atago, Japan) and reported as total soluble solids (%).

Titratable acidity (TA)

The titratable acidity was analyzed using the titration method described by Ranganna, (1986). TA was calculated and expressed as the percentage of citric acid (meq. citric acid = 0.064).

Ascorbic acid (AA)

Ascorbic acid was determined by 2, 6 dichlorophenolindophenol dye titration method (Nielsen, 2010). An aliquot of the sample (2 ml) was taken and titrated against 2, 6, dichlorophenolindophenol dye until a pink color persisted for 15 s. The AA content was expressed as mg per 100 g fresh weight (mg 100 g^{-1} FW).

Chilling injury (CI) index

Chilling injury index of papaya for skin pitting and scald was assessed on 6 fruits per treatment according to the following visual rating scale modified from Proulx et al., (2005). 0 = no abnormality (0%), 1 = trace symptoms, small pits (~1 - 10%), 2 = moderate symptoms, small to medium pits, blotchy appearance (~11 - 25%), 3 = moderate to severe symptoms (~26-50%) and 4 = severe symptoms (>50%). The CI index was calculated according to Concellón et al., (2004). In this study, the CI index 2 was considered as a limit of acceptability for sale.

Statistical analysis

Treatments were conducted in a completely randomized design (CRD) with three replicates. Experimental data were subjected to analysis of variance (ANOVA) using the statistical software SPSS version 20. Significance between means was assessed using Duncan's test at 5% confidence level ($p < 0.05$).

RESULTS AND DISCUSSION

Weight loss (%)

The present study revealed that weight loss of fruit in all treatments was maintained lower than 1.2% throughout the storage period (Figure 1). The fruit stored under both IW conditions showed slightly lower weight loss (~0.8%) especially at 15 and 20 days of storage compared with the control fruit stored at 5°C (Figure 1). However, in this work, no significant differences in weight loss were observed in papaya fruit stored under these storage conditions. In general, excessive weight loss was a major concern in fruit treated by IW conditions. The higher weight loss after fruit were treated following IW conditions compared with controls was reported for pomegranate (Artés et al., 2000) and a few vegetables such as eggplant, pepper and okra (Kluge et al., 1998). In contrast to this, Biswas, (2012), observed no significant differences in weight loss of New Zealand tomatoes cv. Cedrico stored under IW and constant cold storage conditions at either 2.5 or 6°C. The weight loss of tomato was less than 2.5% during 30 days of storage. This is similar to the result obtained from our work.

Paull and Chen (1989) reported that mature green papayas cv. Sunset and Sunrise lost approximately 8% of the initial weight resulted in rubbery texture, low-gloss, slight to moderate skin shrivel, and unsalable fruit. In this work, weight loss of almost all the fruit did not reach 8% but only 1.2% of weight loss was observed after 20 days. This is possible that all of the tested fruit in this work were kept in the unsealed foam boxes that may help to maintain the humidity around the fruit during storage.

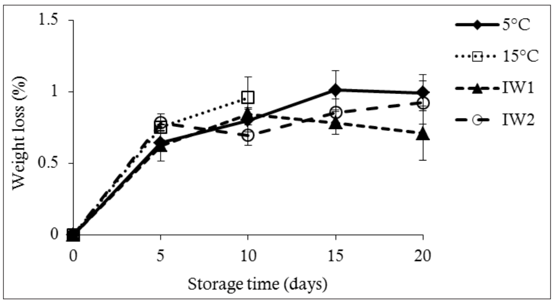

Figure 1. Weight loss (%) of 'Holland' papaya fruit stored at 5°C, 15°C and intermittent warming (IW) conditions (fruit stored at 5°C, 4 days then moved to 15°C, 1 day) with different warming conditions for 1 (IW1) or 2 cycles (IW2) then stored at 5°C until the end of storage. Vertical bars represent ±SE (n= 6).

Peel color changes

The peel color changes of papaya fruit separately kept at constant temperatures at 5, 15°C and IW conditions (IW1 and IW2) during storage for 20 days were expressed as L*, a*, b* (Figure 2A, B and C). The average initial L* value (46.5) of all stored papaya fruit sharply increased to the ranges of about 56-61 after 10 days of storage. At 5 days of storage, the L* value (60.0) of the peel of fruit stored at 15°C was significantly ($p < 0.05$) higher than the L* value (55.8) of the fruit stored under IW1 condition. However, no significant differences in L* value changes were observed in papaya fruit stored under these conditions since 10 days until the end of storage.

In general, the peel color changes of 'Holland' papaya fruit visually illustrate the changing from green to yellow (Khurnpoon et al., 2014). For peel lightness, the control fruit stored at 5°C showed lower L* values ranging between 44.9 and 57.2 during 20 days of storage whereas the L* values of the fruit stored at 15°C or under IW conditions were in the ranges of 46.1-60.7 and 46.6-58.4, respectively (Figure 2A). Proulx et al., (2005) reported that papaya fruit stored at chilling temperatures maintained a dull greenish color and failed to ripen normally. Furthermore, Lam, (1990) postulated that papaya fruit affected by CI did not change their color indices even when transferred from cold storage to 25°C.

In this work, the a* values of the fruit stored at 15°C was -11.7 at initial day and increased rapidly to approximately 6.4 and 12.2 after 5 and 10 days of storage, respectively. The a* values of the fruit stored at 15°C were significantly ($p < 0.05$) higher than other treatments over this storage period of 10 days. The fruit stored at 15°C ripened normally because the peel of fruit became yellowing within 10 days of storage (Figure 2B). Likewise, an increase in the ground color as measured by a* values has been reported elsewhere during the maturation and ripening of papaya cv. Maradol stored at 23°C, 70% RH for 13 days (Santamaría Basulto et al., 2009) and Thai papaya cv. Holland stored at 25°C±1°C for 6 days (Khurnpoon et al., 2014). On the other hand, an unusual change in a* value of the control fruit was observed after 15 days of storage, resulting in the remaining of a more green color than other treatments. The a* values of the fruit stored under both IW conditions slightly increased from the initial day until 10 days of storage and still remained until the end of storage (Figure 2B).

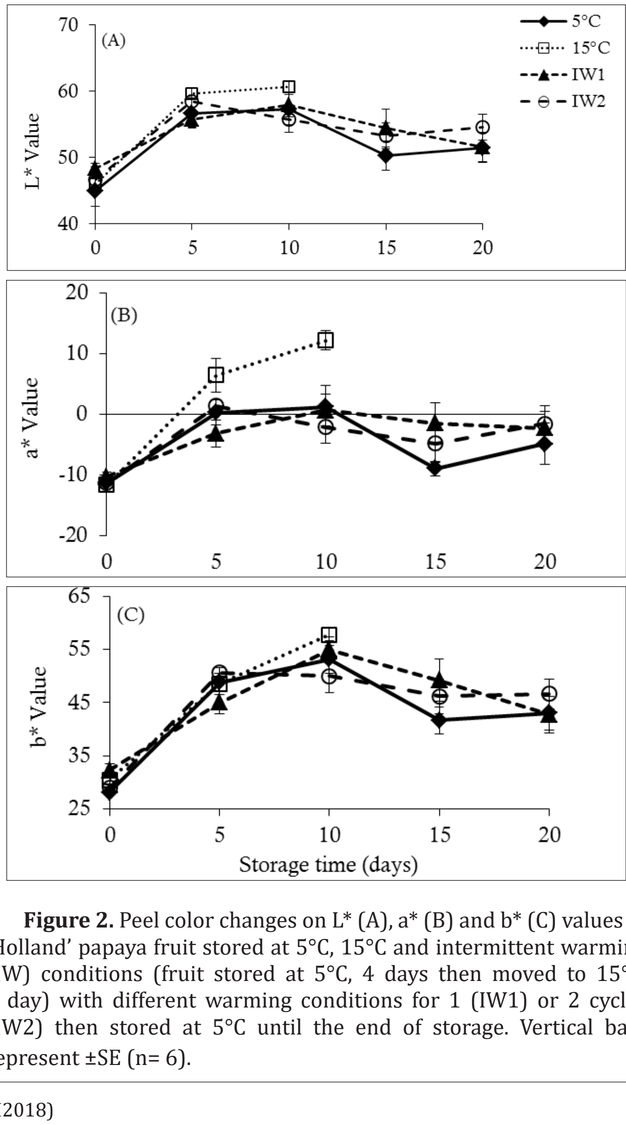

Figure 2. Peel color changes on L* (A), a* (B) and b* (C) values of 'Holland' papaya fruit stored at 5°C, 15°C and intermittent warming (IW) conditions (fruit stored at 5°C, 4 days then moved to 15°C, 1 day) with different warming conditions for 1 (IW1) or 2 cycles (IW2) then stored at 5°C until the end of storage. Vertical bars represent ±SE (n= 6).

A significant lower in the b* value was only detected in the fruit stored under IW1 condition compared with other treatments at 5 days of storage. Overall, no significant differences in the b* value changes were observed in papaya fruit stored under these conditions since 10 days until the end of storage (Figure 2C). Khurnpoon et al., (2014) reported that the b* values of the 'Holland' papayas stored at 25°C±1°C for 6 days were in the ranges between 30.6 and 50.3. However, the b* values of the fruit tested in this work were slightly lower than that of the b* values previously reported. This possibly due to the unusual color development caused by CI when the fruit were stored at too low temperature (5°C) or a slower color development when the fruit were stored at 15°C compared with 25°C.

Total soluble solids (TSS)

The results on TSS for papayas from the present study are in agreement with Paul et al., (1997) who reported that the TSS of immature and ripe papaya was between 5 and 19%, respectively. The maturity of papaya fruit used in this study was between these two maturity stages and the TSS at the time of harvest was approximately 12%. Supapvanich and Promyou (2017) reported that the TSS of 'Holland' papaya fruit harvested at 5% peel yellowing increased from ~9 to ~12% after storage at room temperature (30±2°C) for 6 days. However, the TSS of the fruit stored at 5 or 15°C used in this work declined steadily from 12 or 11.6% to about 9.6 or 9.7%, respectively within 20 days of storage. This reduction on TSS was in a range between 1.9 and 2.4% compared with their initial values (Figure 3). The lower loss of TSS observed in the fruit stored under both IW conditions was approximately 1.6% after 20 days of storage. Santamaría Basulto et al., (2009) reported that the TSS of papaya fruit depended on the stage of maturity. In addition, papaya at this stage (25% yellowing), some of the sugar might be consumed to synthesis sucrose for the respiration activity (Gómez et al., 2002; Yao et al., 2014).

From this work, IW conditions seemed to delay the loss of TSS after 10 days of storage when compared with the control fruit stored at 5°C which affected by CI development (Figure 3). The delay of TSS loss by IW conditions could be referred to warming and cooling processes of IW which might reduce the ripening process as well as the respiration activity and in turn the consumption of sugar to synthesis sucrose was delayed or reduced as reported above by Gómez et al., (2002) and Yao et al., (2014). However, no significant differences in the changes of TSS were observed in papaya fruit stored under these conditions during 20 days of storage.

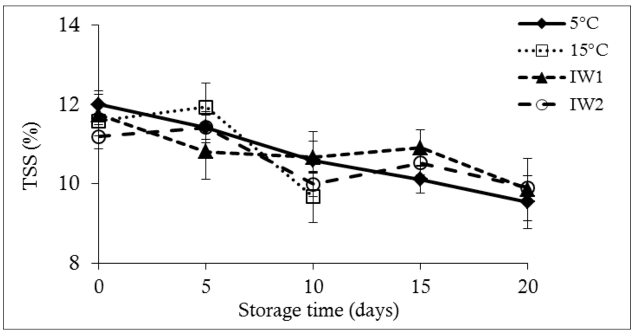

Figure 3. Total soluble solids (TSS) of 'Holland' papaya fruit stored at 5°C, 15°C and intermittent warming (IW) conditions (fruit stored at 5°C, 4 days then moved to 15°C, 1 day) with different warming conditions for 1 (IW1) or 2 cycles (IW2) then stored at 5°C until the end of storage. Vertical bars represent ±SE (n= 6).

Titratable acidity (TA)

IW conditions (1 & 2) employed in this work caused no significant effect on the titratable acidity (TA) of papaya fruit (Figure 4). In this work, the TA of 'Holland' papaya fruit ranged between 0.2 and 0.3%. No significant differences in the changes of TA were observed among the treatments during storage for 20 days. This is similar to the work of Maharaj and Sankat, (1989) who conducted an experiment on papaya cv. Tainung No. 1 grown in Trinidad and Tobago. The authors found no significant effect of the storage time or temperature on the TA of papaya fruit treated under several postharvest treatments for a month. Furthermore, Proulx et al., (2005) also found that the papaya fruit cv. 'Exp.15' harvested at the color break stage then stored at 0, 5, 10, 15 or 20 °C showed no significant difference in the change of TA. The general trend of either negligible decrease or no change in TA was also observed during ripening of several papaya cultivars (Singh and Sudhakar, 2011). In this study, ripening signs of 'Holland' papaya fruit were observed during storage such as yellowing and softening yet with no effect on the acidity of the fruit even when stored at 15°C for 10 days.

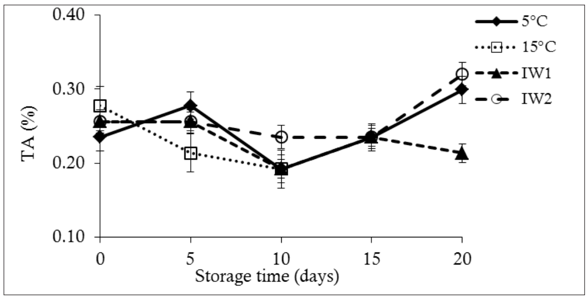

Figure 4. Titratable acidity (TA) of 'Holland' papaya fruit stored at 5°C, 15°C and intermittent warming (IW) conditions (fruit stored at 5°C, 4 days then moved to 15°C, 1 day) with different warming conditions for 1 (IW1) or 2 cycles (IW2) then stored at 5°C until the end of storage. Vertical bars represent ±SE (n= 6).

Ascorbic acid (AA)

Papaya is a good source of vitamin C (Iamjud, et al., 2017; Vinci et al., 1995). Lee and Kader, (2000) reported that the AA contents of 'Solo' papaya fruit at green, half-ripe and ripe stages were 72, 95 and 102.2 mg 100 g^{-1} FW, respectively whereas the AA contents of 'Pirie' mango fruit at green, half-ripe and ripe stages were 60, 50 and 14 mg 100 g^{-1} FW, respectively. The authors point out that the AA contents of these fruits could be influenced by their maturity stages. Schweiggert et al., (2012) reported that the AA contents of papaya fruit (at color break) from different genotypes grown in Costa Rica, stored at approximately 25°C for 5-7 days until peel color was >90% yellow, were in the range from 24.9-72.9 mg 100 g^{-1} FW. For the 'Holland' papaya grown in Thailand, Supapvanich and Promyou (2017) reported that the AA content of this cultivar at initial day (~45 mg 100 g^{-1} FW) stored at room temperature (30±2ºC) increased slightly to ~47 mg 100 g^{-1} FW after 6 days. The slightly increased trend of AA contents was also observed in the papaya fruit tested in this study, but the overall AA content of these fruits was slightly lower than the data previously reported by Supapvanich and Promyou (2017). The AA content of the fruit in this work tended to increase from the initial day (~14.6 mg 100 g^{-1} FW) to the ranges of 24-26 mg 100 g^{-1} FW and 23-34 mg 100 g^{-1} FW after 5 and 10 days, respectively. Slight losses of AA content of fruit were observed at 15 days of storage, by then the AA contents of fruit in all treatments were maintained until 20 days of storage (Figure 5). However, the AA contents of papaya fruit stored under IW conditions were not significantly different compared with the control treatment kept at 5°C since the initial day until the end of storage. Likewise, (Pranamornkith, 2009) who reported that 'Tahiti' lime fruit stored under different IW conditions retained AA content similar to the control fruit stored at 5°C during storage for 12 weeks. Lee and Kader, (2000) and Ali et al., (2014) reported that the environmental factors such as high carbon dioxide (CO_2) or stress that increase the activity of some enzymes such as ascorbate peroxidase and ascorbate oxidase (a copper-containing enzyme) may be responsible for enzymatic degradation of ascorbic acid.

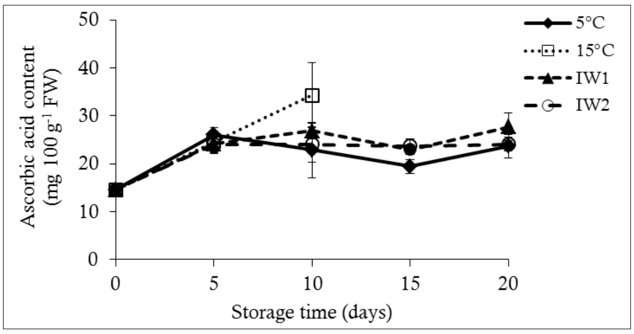

Figure 5. Ascorbic acid (AA) content of 'Holland' papaya fruit stored at 5°C, 15°C and intermittent warming (IW) conditions (fruit stored at 5°C, 4 days then moved to 15°C, 1 day) with different warming conditions for 1 (IW1) or 2 cycles (IW2) then stored at 5°C until the end of storage. Vertical bars represent ±SE (n= 6).

Chilling injury (CI) index

The results obtained from the present study for CI development showed that the CI symptoms occurred continuously within 5 days in the control fruit and became more visible within hours after the fruit were removed from cold storage to ambient temperature (27±1°C) witnessed by dark spots on the skin. However, some CI symptoms were also detected in the fruit stored under IW conditions (1 & 2) at the scale; CI index <1 (trace symptoms, small pits) within 15 days of storage which was significantly ($p < 0.05$) lower than the control fruit stored at 5°C that reached the CI index at scale 3 after 20 days of storage (Figure 6). The mechanisms that IW regime has potential in lessening CI development was reported by Wang (1990) and Wang (1993) who noted that intermittent warming has a potential to restore the metabolite concentrations during the warming phase that were disturbed during the cool storage. This restoration of metabolites could occur by allowing tissue to activate appropriate metabolic enzymes and synthesize compounds at a rate not possible during chilling and, thus, allowing tissues to restore substances that were depleted. In other words, it allowed the tissues to catabolize excess intermediates accumulated during the chilling. However the acquired results from this study were similar to Huajaikaew et al., (2000) who reported that papaya fruit cv. Khakdum initially stored at 15°C or 20°C (warming) for 3 days, then held at 5°C for 2 days developed less CI symptoms whereas the fruit stored continuously at 5°C showed a greater extent of pitting and remained unripe when moved to room temperature. In this study, the fruit stored continuously at 15°C continued to ripen normally within 6 days of storage and maintained acceptable for 10 days with no signs of CI, by then mycelia developed on the collapsed cell due to fruit quality deterioration.

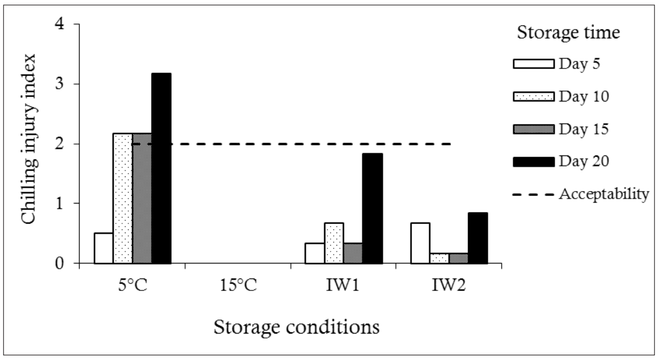

Figure 6. Chilling injury (CI) index of 'Holland' papaya fruit stored at 5°C, 15°C and intermittent warming (IW) conditions (fruit stored at 5°C, 4 days then moved to 15°C, 1 day) with different warming conditions for 1 (IW1) or 2 cycles (IW2) then stored at 5°C until the end of storage (n= 6). The CI index was assessed according to the following scales: 0 = no abnormality (0%), 1 = trace symptoms, small pits (~1-10%), 2 = moderate symptoms, small to medium pits, blotchy appearance (~11- 25%), 3 = moderate to severe symptoms (~26-50%) and 4 = severe symptoms (> 50%). The horizontal dashed line (---) shows the acceptability.

CONCLUSIONS

The IW conditions (1 and 2 cycles) effectively minimized CI development and extended storage life of 'Holland' papaya fruit when compared with the control fruit stored at constant temperatures of 5 and 15°C. The IW 1 cycle could reduce the severity of CI and delay fruit ripening by 20 days but not as effective as the IW 2 cycles. Thus, it is essential to select the suitable temperature range, timing, and interval of IW to extend the storage life of this fruit.

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