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Influence of Low Temperature Storage on the Postharvest Quality of Papaya Fruit (*Carica papaya* L.)

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Most of papaya (*Carica papaya* L.) produced in Brazil is exported to the United States and the European Union. Papaya fruit is commonly stored and transported at 10 ± 2 °C for 20 or more days. This period of cold storage can cause chilling injury in papaya fruit and a corresponding loss of economic value. This study aimed at identifying the effect of cold storage on papaya quality. Mature-green 'Golden' papayas were harvested in Brazil and handled in a packinghouse under the same conditions used for export. They were stored at 5 or 10 ± 2 °C for 20, 25, or 30 d and then transferred to 20 ± 2 °C for 3 d. Quality evaluations were performed at the end of every storage period. Firmness increased ($P \leq 0.05$) after 20 d at 5 °C and ascorbic acid decreased ($P \leq 0.05$) after 25 d at 5 °C and 10 °C. The soluble solids content (10 ± 1%) and color of papaya fruit (less than 25% yellow) was maintained throughout storage. Observed damage included the formation of granules in the pulp, peel depressions and detachment of peel from pulp. These results suggested that papaya postharvest quality decreases when fruit were stored for 20 d at 5 °C or 25 d at 10 °C.

Papaya (*Carica papaya* L.) fruit is one of the most important commodities produced, consumed and exported by tropical countries. Brazil is the second largest producer and the fourth largest exporter worldwide. Papaya is a high-value crop grown in tropical and subtropical regions with high consumer demand around the world. Like other climacteric fruits, papaya undergoes a series of biochemical changes after harvest. Cold storage is the main method used to reduce these changes. However, it may cause chilling injury. Due to fluctuating temperatures and/or extended cold storage, papaya fruits frequently exhibit very poor quality with signs of chilling injury upon reaching retail level (Proulx et al., 2005).

According to Kader et al. (2002) optimal storage temperature for papayas depends on the stage of development. For mature-green to one-fourth yellow papayas 13 °C is the recommended storage temperature for up to 21 d; 10 °C for partially-ripe (one-fourth to one-half yellow) papayas; and 7 °C for ripe (more than one-half yellow) papayas. In the export sector, one-fourth yellow papayas are typically stored and shipped at less than 10 °C and for more than 21 d, which can induce irreversible damage and economic loss. Chilling injury (CI) in papaya includes failure to ripen, increased susceptibility to fungal deterioration, off-odors, off-flavors, dark spots on the skin, pitting, blotchy coloration, hard core (hard areas in the flesh around the vascular bundles) and air pockets in the tissues (Ali et al., 1993; Chen and Paull, 1983; Kader et al., 2002; Siddiq et al., 2012). In most cases, CI symptoms are visible only when fruit are transferred to warmer temperatures (Wang, 1990). Papayas stored at 7 °C showed irregular and slow ripening and an increased susceptibility to fungal disease after 2 weeks and after 3 weeks at 10 °C (Chen and Paull, 1983; Wang, 1990).

'Golden' papaya is a new cultivar that has become predominant in the Brazilian export market. It is named 'Golden' because of the yellow golden peel color when the fruit is ripe. It is necessary to better understand the behavior for each papaya variety or cultivar during low temperature exposure. Our objective was to identify the effects of cold storage on 'Golden' papaya quality.

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Material and Methods

'Golden' papayas (*Carica papaya* L.) were harvested from a commercial farm in northern Espirito Santo state, Brazil (latitude 19°23'28"S and longitude 40°04'20"W), during Feb. and May 2012. Mature-green papayas were harvested with up to 15% yellow color. They were handled in a packinghouse under the same conditions used for export. Fruit were washed, heat treated according to APHIS requirements (APHIS, 2013), fungicide treated, sorted and packaged in corrugated cartons (11.25 lb). Initial destructive and nondestructive analyses were conducted immediately after harvest and remaining fruit were transported 12 h to the Plant Science Department, University of São Paulo (USP/ESALQ), Piracicaba, SP, Brazil, and stored at 10 °C overnight.

Papayas were randomized and divided into six groups according to the following storage conditions: 5 and 10 °C for 20, 25, and 30 d. After 20 or 25 d in cold storage, papayas were transferred to 20 °C for 3 d. Destructive and nondestructive measurements were conducted after each cold storage period and again after 3 d at 20 °C. Ten papayas from each group were analyzed at each evaluation and each day. This experiment was conducted two times in 2012 and the results were combined.

Nondestructive analyses

Color. External color was measured on opposite sides at the equator of 10 papayas using a Minolta Chroma Meter model CR-400 (Konica Minolta Sensing Inc., Osaka, Japan) set for CIELAB color space and D65 light source. Color measurements were expressed in terms of hue angle.

Symptoms of chilling injury. Symptoms were visually characterized and identified on individual fruit (n=10 papayas).

Destructive analyses

Pulp firmness. Measurements were conducted on opposite sides of each fruit (n=10 papayas) at points equally distant from the middle of the fruit after the peel was removed. Firmness was determined by a digital penetrometer (53200-Samar, Tr-Turoni, Forli, Italy) fitted with an 8-mm-diameter probe and results were expressed in Newton (N).

Soluble solids content. Soluble solids content (SSC) was determined by placing several drops of juice from each fruit (n=10 papayas) on the prism of a digital refractometer (Atago PR-101, Atago, Japan) and reported as percent soluble solids.

Ascorbic acid. Ascorbic acid (AA) was determined using 5 g of juice from each fruit (n=10 papayas) diluted in 25 mL of 1% oxalic acid. Titration was performed with a solution of 2.6-dichlorophenol–indophenol. Calculations were performed according to AOAC (1995) and results expressed in mg·100 g^{-1} fresh weight.

Statistical analyses. The experiment was performed twice according to a completely randomized design, with 10 replications per each treatment, each evaluation and each day. Data were analyzed by ANOVA and means were compared using Tukey test at a significance level of 0.05. The software used was SAS 9.2.

Results and Discussion

Color changes were observed during storage ($P \leq 0.05$), but no differences were found between treatments. Hue angle decreased from day 0 to 20, 25 and 30 d for each treatment at 5 and 10 °C following 3 d at 20 °C (Fig 1). Color did not change after 3 d at 20 °C for fruit that were stored at 5 °C (Fig. 1A).

During cold storage, hue angle ranged from 109.58 °h initially to 104.51 °h after 30 d at 5 °C and to 98.55 °h after 30 d at 10 °C (Fig. 1). When fruits were transferred to 20 °C from 10 °C, hue angle ranged from 104.26 to 88.36 °h (Fig. 1B). This change is normal for climacteric fruit, which ripen faster at this temperature than nonclimacteric fruits. After 30 d, fruit that were stored at either 5 or 10 °C decayed within 3 d of room temperature (20 °C).

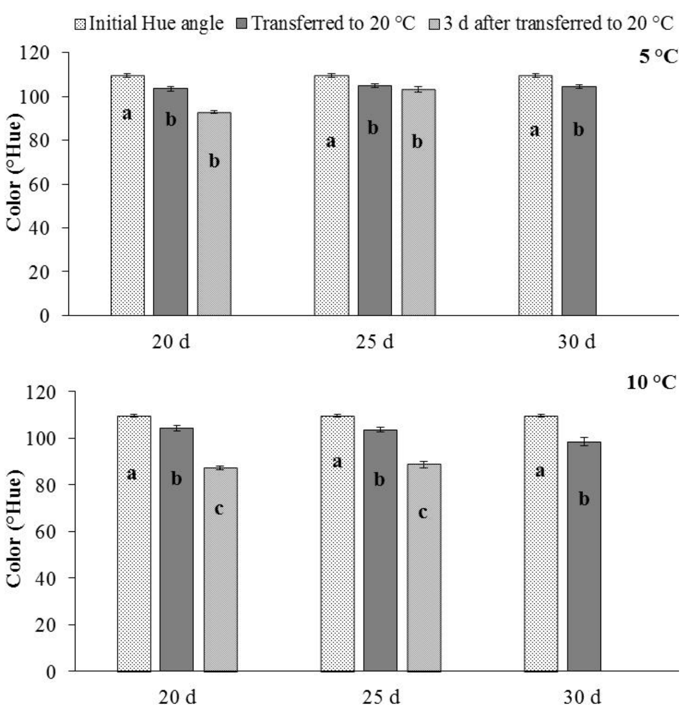

Fig.1. Hue angle values of 'Golden' papaya fruits stored during 20, 25, and 30 d at 5 °C (**A**) and at 10 °C (**B**) followed by 3 d at 20 °C (n = 10 fruits, 2 readings/fruit). Values with the same letter on the same day are not different according to the Tukey test ($P \leq 0.05$). Vertical bars represent ±SD.

Papaya fruit color maintained less than 25% yellow color during storage regardless of treatment. Low temperatures can affect ripeness by reducing color change and high temperatures increase ripeness by increasing external color in papayas. Rocha et al. (2005) observed intensive changes in Formosa-type fruit color during storage at temperatures greater than 10 °C. Almeida et al. (2005) did not observe color changes during cold storage at 6 and 13 °C for 'Golden' papaya fruit. However, Rivera-Pastrana et al. (2010) observed lower carotenoid content after cold storage at 1 °C of 'Maradol' papaya fruit.

Papaya CI symptoms developed during storage, especially after transfer to 20 °C. Treatments at 5 and 10 °C for more than 25 d resulted in unripe fruit, decay, dark spots on the skin, hard areas in the mesocarp around the vascular bundles, and separation of peel from pulp tissue (Fig. 2). Almeida et al. (2005) and Rocha et al. (2005) observed similar symptoms during cold storage in 'Golden' and Formosa-type papaya fruit, respectivily.

Pulp firmness increased during cold storage at 5 °C, mainly between 20 and 25 d. This difference in firmness also was present after transfer to 20 °C (Fig. 3A). The increase in firmness was associated with the development of hard areas in the pulp tissue. Firmness values after 20 and 25 d at 5 °C, plus 3 d at 20 °C, were 23.5 and 101.7 N, respectively (Fig. 3A). For fruit stored at 10 °C, progressive flesh softening occurred even after transfer to 20 °C (Fig. 3B). After 30 d, when fruit were transferred to 20 °C, firmness decreased in relation to initial level ($P \leq 0.05$) but fruit decayed before 3 d at 20 °C (Fig. 3).

During papaya fruit ripening progressive flesh softening has been reported. Basulto et al. (2009) observed 140 N in green fruits and 16 N in fruits with more than 50% yellow color. Bron and Jacomino (2009) observed extreme firmness decrease in the first days of storage at 23 °C for 'Golden' papaya. Papaya stored below 15 °C preserved initial firmness for longer than those stored at higher temperatures (Almeida et al., 2005; Rocha et al., 2005).

The SSC average was 10.7% at 5 °C and 10.1% at 10 °C. Statistical differences were found due to storage temperature and duration (Table 1). However, the range of SSC was no more than

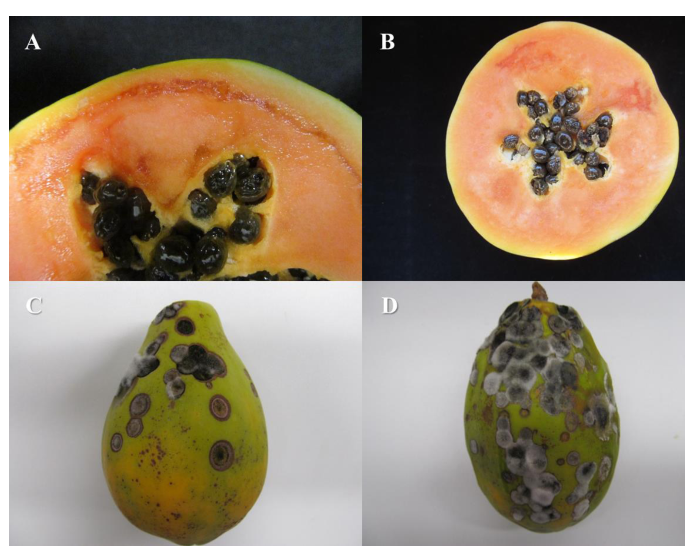

Fig. 2. Symptoms of chilling injury in 'Golden' papaya stored during 20 or 25 d at 5 °C plus 3 d at 20 °C or 30 d at 10 °C. (**A**) Separation of peel from pulp; (**B**) Hard areas in the mesocarp; (**C**) Initial fungal deterioration; (**D**) Complete fungal deterioration.

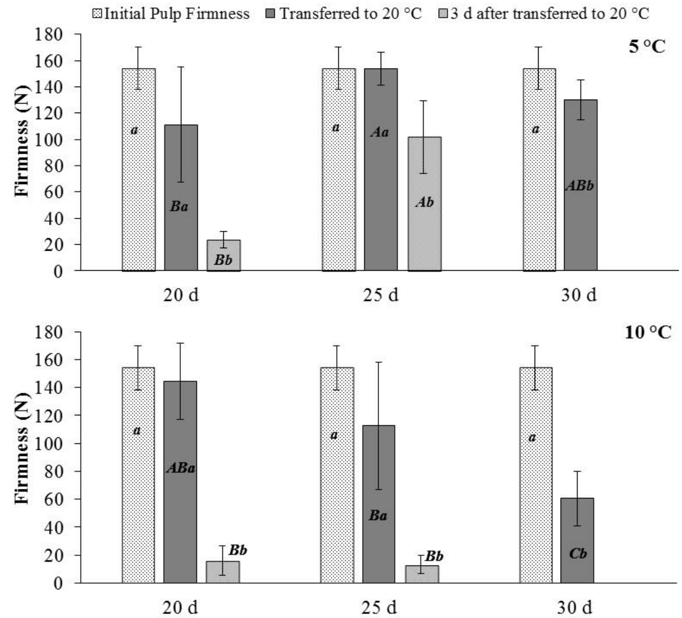

Fig. 3. Pulp firmness of 'Golden' papaya stored during 20, 25, or 30 d at 5 °C (**A**) or 10 °C (**B**) followed by 3 d at 20 °C (n=10 fruits, 2 readings/fruit). Values with the same capital letter in the same treatment or small letter in the same day are not different according to the Tukey test ($P \leq 0.05$). Vertical bars represent ±SD.

1.5% from initial to final values. The SSC depends on the stage of maturity (Basulto et al., 2009) and increases proportionally with decrease in firmness and increase in sugar synthesis (Bron and Jacomino, 2006). Ascorbic acid content ranged from 75.9 to 58.1 mg·100 g^{-1} (Table 1). Similar values were reported by Frank et al. (2004) and Wall (2006). Stage of development, harvest method and postharvest handling can also affect AA content in horticultural products (Lee and Kader, 2000). In papaya fruit AA content increased with maturity on the plant and ripening (Kader, 1988; Wall, 2006), then decreased in ripe fruit (Bron and Jacomino, 2006; Wills and Widjanarko, 1995). Furthermore, CI can accelerate losses in AA, which can occur before any visible symptoms of chilling (Lee and Kader, 2000).

This experiment showed that 'Golden' papaya postharvest quality is affected by extended storage at low temperatures. The majority of chilling symptoms occurred after 20 d at 5 °C or 25 d at 10 °C. These results suggest more studies should be conducted to investigate new technologies to extend papaya postharvest quality, such as application of 1-methylcyclopropene, modified atmosphere packaging, or plant growth regulators.

Table 1. Soluble solids content (SSC) and ascorbic acid content (AA) of 'Golden' papaya stored during 20, 25, and 30 d at 5 and 10 °C + 3 d at 20 °C (n=10 fruits).

Storage	Time	SSC (%)		AA (mg 100 g^{-1})	
		Initial day	Final day	Initial day	Final day
5 °C + 20 °C	20 d	11.8 a[z]	10.7 b B	75.9 a[z]	69.1 a A
	25 d	11.8 a	10.7 b B	75.9 a	68.2 a A
	30 d	11.8 a	10.2 b B	75.9 a	58.1 b B
5 °C + 20 °C	20 d + 3 d	11.8 a	11.5 a A	75.9 a	67.7 a A
	25 d + 3 d	11.8 a	10.2 b B	75.9 a	61.0 b B
	30 d + 3 d	11.8 a	***	75.9 a	***
10 °C + 20 °C	20 d	11.8 a	9.2 b B	75.9 a	67.2 a A
	25 d	11.8 a	10.0 b B	75.9 a	58.1 b B
	30 d	11.8 a	11.0 a A	75.9 a	67.9 a A
10 °C + 20 °C	20 d + 3 d	11.8 a	10.8 b B	75.9 a	69.6 a A
	25 d + 3 d	11.8 a	9.5 b B	75.9 a	59.3 b B
	30 d + 3 d	11.8 a	***	75.9 a	***

[z]Values followed by the same small letter within the row and the same capital letter within the column are not significantly different according to Tukey test ($P < 0.05$).
***No values due to fruit decayed.

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