

QUALITY ATTRIBUTES LIMITING PAPAYA POSTHARVEST LIFE AT CHILLING AND NON-CHILLING TEMPERATURES

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Abstract. Papayas were harvested in April and May, at color break ripeness stage and held at constant temperatures of 0, 5, 10, 15 or 20 °C in order to determine the quality attributes that limit marketability. Evaluations of weight loss, instrumental and visual color, flesh firmness, shriveling, chilling injury (CI) symptoms, chemical composition, and decay were performed initially and every second day thereafter during 14 days of storage. Fruit stored at 0, 5 or 10 °C were transferred to 20 °C for 2 days at the end of storage to evaluate CI symptom development. A significant ripeness stage difference between the harvests affected CI susceptibility in that CI symptoms developed faster and were more severe in the less ripe fruit. At 15 and 20 °C, papaya marketability was limited primarily by flesh softening, followed by color change indicative of over ripeness and by shriveling; at 0, 5, and 10 °C, marketability was limited by development of CI symptoms and, to a lesser extent, by shriveling. Storage temperature had little effect on soluble solids, pH or titratable acidity. After 14 days at 0, 5 or 15 °C vitamin C content of papaya from the first harvest was reduced by 48, 36, and 42%, respectively. Papaya marketability in this study was not limited by decay except as a secondary manifestation of CI following transfer to 20 °C after 2 weeks of storage at chilling temperatures. The quality curves constructed for each temperature showed that a single quality attribute cannot be used to express loss of quality of papayas over the range of temperatures evaluated.

Following harvest the quality of papaya (*Carica papaya* L.) fruit may be considerably reduced by the adverse environmental and physical conditions encountered during transportation, distribution and retailing. Extreme or fluctuating temperatures and/or mechanical damage combined with im-

proper harvesting and handling practices may result in fruit with poor appearance, flavor, and nutritional value. If properly handled, papayas have a shelf life of 4 to 6 d under ambient tropical conditions (25 to 28 °C), or up to 3 weeks at lower temperatures (10 to 12 °C) (Paull et al., 1997). However, papaya fruit on supermarket shelves are frequently of very poor quality, with signs of chilling injury (CI), diseases, or shriveling, mechanical injuries, or combinations of these factors. As reported for other fruits (Nunes et al., 2003a,b; 2004; Proulx et al., 2001), marketability of papaya can be limited by changes in one or more quality characteristics. Papaya fruit may exhibit rapid yellowing, and decay has been observed after 8 d of storage at 15 °C (Abou Aziz et al., 1975). High storage temperatures lead to accelerated water loss and subsequently to shriveling and softening of the fruit, while after 7 d at 5 °C, discoloration (increase in L* value) of the skin increases significantly when compared to storage at 10 °C (Chan et al., 1985). Papaya fruit, like other tropical fruits, are sensitive to chilling temperatures (usually lower than 10 °C) and may develop CI symptoms such as pitting of the skin, scald, hard lumps in the pulp around the vascular bundles, water soaking of the flesh, abnormal ripening with blotchy discoloration, and increased susceptibility to decay (Ali et al., 1993; Chan et al., 1985; Chen and Paull, 1986; El-Tomi et al., 1974; Thompson and Lee, 1971). Papaya fruit at the color-turning ripeness stage stored at temperatures as low as 7 °C for not more than 14 d will ripen normally when transferred to room temperature (Chen and Paull, 1986; Thompson and Lee, 1971). Symptoms of chilling injury occur after 14 d at 7 °C for mature-green fruit, and after 21 d for 60% yellow fruit. Therefore, in addition to the quality and maturity of the fruit at harvest, the use of an optimum temperature during transportation, distribution, and retailing is a major factor that determines the quality of the fresh product.

Although some studies describe the quality changes in papaya during storage, no information was found regarding precise quality changes for papaya stored at chilling and non-chilling temperatures, or about which quality factor(s) is the most important with regard to determining the limit of marketability. The objective of this work was to define quality changes for papayas stored at chilling or non-chilling temperatures, and to identify for each temperature which quality factor(s) limits papaya marketability. Specifically, the effect of five different storage temperatures (0, 5, 10, 15, 20 °C) on quantitative (weight loss, instrumental color, composition) and qualitative (color, firmness, shriveling, chilling injury and decay) quality factors was evaluated.

Materials and Methods

Plant material and storage conditions. Papaya fruit (*Carica papaya* L.) cv. 'Exp.15' were harvested at the 'color break' stage of ripeness, i.e., at the initiation of the change from green to yellow surface color. The fruit were obtained from a commercial field near Homestead, Florida. A total of two harvests (experiments) were conducted. Papayas were harvested on 21 Apr. and 8 May 2001 and transported at approximately 20 °C

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to the Postharvest Laboratory at the Horticultural Sciences Department, University of Florida, Gainesville, within 6 h after harvest. Upon arrival, the fruit were stored at 15 °C until the next morning (10 h). The day following harvest, the papayas were washed with tap water, selected for uniformity of shape, color, and size, and damaged fruit were removed. Fruit were then packed in corrugated boxes and distributed among five temperature-controlled rooms at: 0.5 ± 0.5 °C (RH 85-95%), 5 ± 0.2 °C (RH 88-95%), 10 ± 0.4 °C (RH 88-97%), 15 ± 0.2 °C (RH 86.5-92%) and 20 ± 0.2 °C (RH 82.5-84%) for a 14-d storage period. For nondestructive evaluations, the same three fruit at each temperature were evaluated every second day; three additional fruit per storage temperature were removed every second day for destructive analyses. At the end of the 14-d storage period, additional papayas stored at 0, 5 or 10 °C were removed from the chilling temperature and transferred to 20 °C (RH 82.5-84%) for 24 to 48 h in order to evaluate CI symptom development.

Weight loss. Weight loss was calculated from the initial weight of three individual papaya fruit per treatment and every 2 d during a 14-d storage period. Concentrations of chemical constituents were expressed in terms of dry weight in order to show the differences between handling treatments that might be obscured by differences in water content. The following formula was used for water loss corrections: [chemical component (fresh weight) × 100 g / 11.2 g (papaya average dry weight) + weight loss during storage (g)]. Dry weight was determined by drying three weighed aliquots of homogenized papaya tissue at 80 °C for 7 d and re-weighing.

Instrumental color. Surface color measurements (CIE L*, a*, b*) were taken with a hand-held tristimulus reflectance colorimeter (Model CR-200b, Minolta Corp., Ramsey, N.J.) on the opposite sides of three fruit per treatment at the equatorial region. Numerical values of a* and b* were converted into hue angle ($H^\circ = \tan^{-1}b^*/a^*$) and chroma [Chroma = $(a^{*2} + b^{*2})^{-1/2}$] (Francis, 1980).

Peel color. The color of three fruit per treatment was also determined subjectively using a 1 to 5 visual rating scale where 1 = more green than yellow (color break to quarter-ripe), 2 = half green and half yellow (half-ripe), 3 = more yellow than green (three-quarter ripe), 4 = fully yellow, 5 = fully yellow and overripe (Lam, 1990; Maharaj and Sankat, 1990).

Firmness. Firmness was determined subjectively using three fruit per treatment based on the whole fruit resistance to slight applied finger pressure and recorded using a 1 to 5 tactile rating scale where 1 = very firm to the touch, very hard fruit with no response to finger pressure, 2 = firm to the touch, substantial resistance to finger pressure, 3 = moderate signs of softness, moderate resistance to finger pressure, 4 = soft to the touch, slight resistance to finger pressure, 5 = very soft to the touch, does not offer any resistance to finger pressure (Miller and McDonald, 1999). A firmness rating of 3 was considered to be the limit of acceptability for sale while ratings of 4 or 5 encompass the range of acceptable eating ripeness.

Shriveling. Shriveling was determined subjectively on three fruit per treatment using a 1 to 5 visual rating scale where 1 = field-fresh, no signs of shriveling, 2 = minor signs of shriveling, 3 = shriveling evident but not serious, 4 = moderate shriveling, 5 = extremely wilted and dry (Quintana and Paull, 1993). A shriveling rating of 3 was considered to be the limit of acceptability for sale.

Chilling injury severity. Chilling injury symptoms were assessed on three fruit per treatment using a 1 to 5 visual rating

scale for symptom severity where 1 = no abnormality, 2 = trace symptoms, small pits, 3 = moderate symptoms, small to medium pits, blotchy appearance, 4 = moderate to severe symptoms, 5 = severe symptoms. A CI rating of 3 was considered to be the limit of acceptability for sale.

Decay severity. Decay severity was recorded according to the area affected on three fruit per treatment using a 1 to 5 visual rating scale where 1 = 0%, no decay, 2 = trace, 1% to 10% decay, spotting first appearing, 3 = slight, 11% to 25% decay, spots increasing in size and number, 4 = moderate, 26 to 50% decay, small to large brownish sunken spots with slight to moderate mycelium growth, 5 = severe, greater than 51% decay, large spots with widespread mycelium growth, fruit is partially or completely rotten (Maharaj and Sankat, 1990).

Soluble solids. After the peel, placenta and seeds were removed, the flesh of papaya halves from three fruit per treatment was homogenized separately in laboratory blenders at high speed for 2 min. The homogenates were centrifuged at 800 g_n for 30 min, filtered through cheesecloth, and the soluble solids content (SSC) of the resulting clear juice samples was measured with a digital refractometer (Palette PR-101, 0-45 °Brix, Atago Co. LTD, Tokyo). The SSC of the papaya fruit was expressed in terms of fresh and dry weight.

pH and titratable acidity. The pH of the juice samples (see above) was determined using a pH meter (Accumet model 15, Fisher Scientific, Arvada, Colo.). Aliquots (6.00 g) of the juice were diluted with 50 mL distilled water and the titratable acidity (TA) determined by titration with 0.1 N NaOH to an end point of pH 8.1 with an automatic titrimeter (Titroline 96, SCHOTT-GERÄTE GmbH, Germany). The results were converted to percent citric acid [(mL NaOH × 0.1 N × 0.064 meq•6.00 g of juice⁻¹) × 100] and expressed in terms of fresh and dry weight.

Total ascorbic acid content. For total ascorbic acid analysis, 5 g of homogenized pulp tissue from each of three fruit per treatment were used. Each pulp sample was combined with 100 mL of a mixture of 6% metaphosphoric acid and 2N acetic acid. The fruit-acid mixtures were centrifuged for 20 min at 5,000 g_n. Ascorbic acid was determined by the dinitrophenylhydrazine method of Terada et al. (1978). The concentration of total ascorbic acid was calculated from absorbance measured at 540 nm using a standard curve. Concentration of ascorbic acid was expressed in terms of dry weight.

Quality limiting factors. For each storage temperature, the limiting quality factor(s) was determined based on which factor(s) was first to reach a rating value of 3 - the limit of acceptability for sale.

Statistical analysis. Initial analysis of the data for the combined harvests by analysis of variance (ANOVA) indicated a significant harvest effect. Consequently, data for the different harvests were analyzed separately. The Statistical Analysis System computer package (SAS Institute, Inc., 1982) was used. In order to determine the primary limiting factor(s), quality attributes for each temperature were compared using the Least Significant Difference (LSD) at the 5% significance level.

Results and Discussion

Weight loss of papaya fruit increased during storage at all temperatures (Fig. 1). Slightly riper fruit (first harvest) lost more weight compared with less ripe fruit (second harvest) handled likewise. Paull and Chen (1989) reported that the

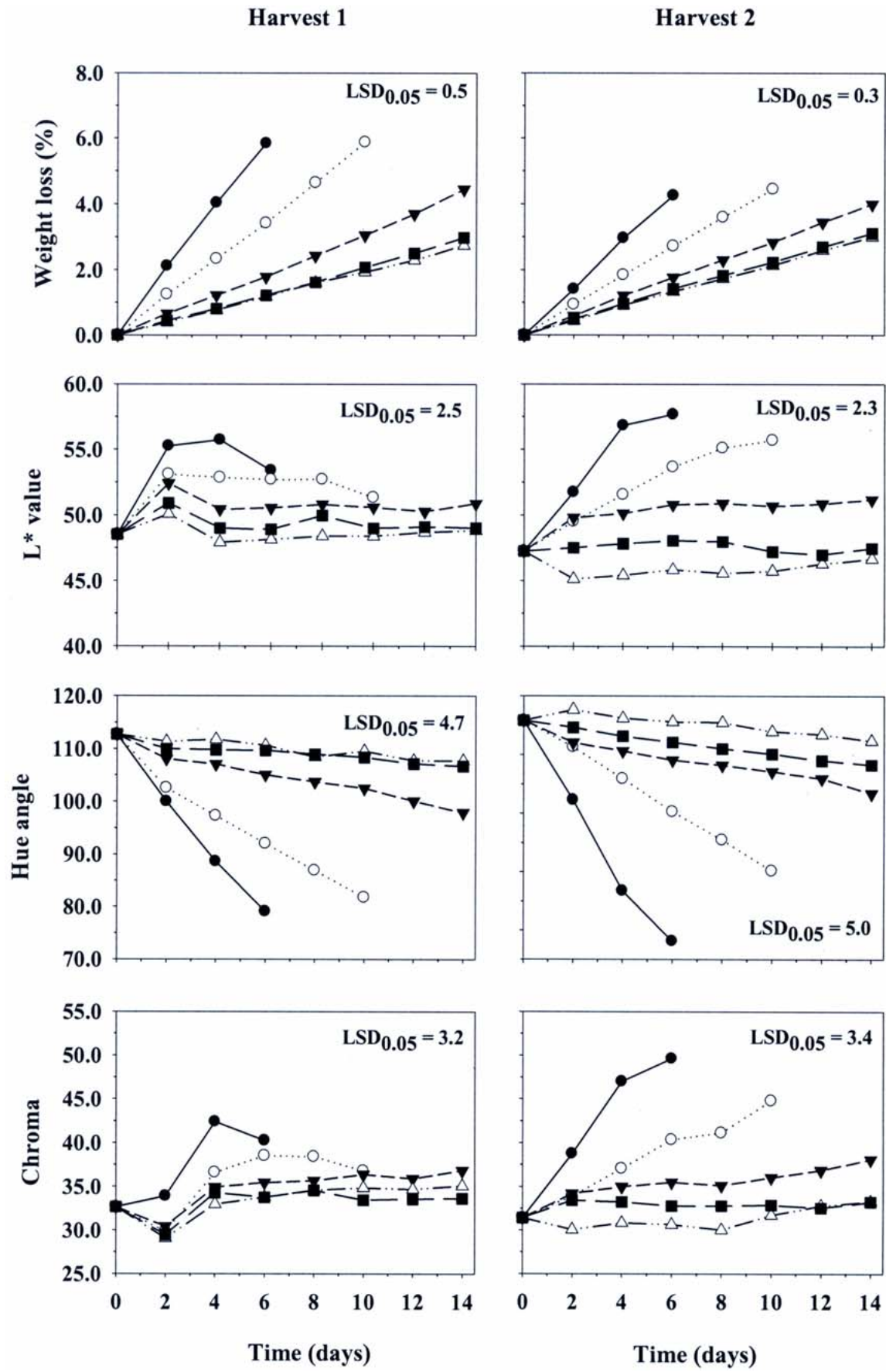


Fig. 1. Weight loss and color (L*, hue angle and chroma) changes in papaya fruit cv. Exp. 15 during storage at chilling or non-chilling temperatures. (●) 20 °C; (○) 15 °C; (▼) 10 °C; (△) 5 °C; (■) 0 °C.

loss of approximately 8% of the initial weight from 'Sunset' and 'Sunrise' mature-green papayas results in 'rubbery' texture, low-gloss, slight to moderate skin shrivel, and un-salable fruit. In the present study, weight loss of papayas never reached the 8% limit. Papayas stored at 20 °C lost 5 to 6% weight after 6 d depending on the harvest time, whereas papayas stored at 0 °C lost 3% after 14 d.

At the time of harvest, the papaya fruit from the first harvest were slightly yellower (higher L* and chroma, and lower hue angle) than the slightly greener fruit from the second harvest (Fig. 1). 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. The papayas stored at 20 °C became very orange-yellow colored after 3 or 6 d of storage for the first and second harvests, respectively, corresponding to decreases in hue values from about 115 to 80 degrees (Fig. 1). The visual color ratings reached the maximum acceptable rating after approximately 3 d at 20 °C and after 7 or 9 d at 15 °C for the first and second harvests, respectively (Fig. 2). Lam (1990) pointed out that the color of papaya fruit affected by chilling injury does not change even after transfer from cold storage to 25 °C. This could explain why both the color indices (Fig. 1) and visual color ratings (Fig. 2) of papayas stored at 0, 5 or 10 °C in the present study changed little during storage. After transfer to 20 °C, those papayas maintained a dull greenish color and did not ripen normally.

Firmness of the fruit flesh decreased during storage, particularly in fruit stored at 15 or 20 °C (Fig. 2). After 2 to 3 d, the firmness of papayas stored at 20 °C was no longer considered acceptable while the firmness of fruit stored at 15 °C was acceptable for 7 d. The firmness of papayas stored below 10 °C never reached the acceptable rating limit even after storage for 14 d.

Shriveling of papayas from the first harvest stored at 10, 15 or 20 °C reached the acceptable rating limit after 12, 9 and 5 d of storage, respectively (Fig. 2). In papayas from the second harvest stored at 10, 15 or 20 °C, shriveling was objectionable after 12, 8 and 4 d of storage (Fig. 2). Fruit from the second harvest stored at 0 °C attained the maximum acceptable shriveling score after approximately 13 d. Since little or no ripening occurred at 0 °C and weight loss was not considered a limiting factor for papaya salability, shriveling of fruit stored at 0 °C might represent severe CI symptoms.

In papayas from the first harvest stored at 0 or 5 °C, CI symptoms became evident after 2 d and reached the maximum acceptable rating after approximately 8 d of storage (Fig. 2). Likewise, papayas from the second harvest showed signs of CI after 2 d, reaching the maximum acceptable rating after 4 d at 0 °C and after approximately 5 d at 5 °C. Papayas stored at 10 °C developed symptoms of CI after 13 or 7 d for the first and second harvests, respectively. The chill-injured fruit developed sunken areas on the skin followed by development of decay before being ripe enough to eat. As reported previously, temperatures below 12 °C during handling of papaya fruit cause CI (Chen and Paull, 1986; El-Tomi et al., 1974; Thompson and Lee, 1971). Nazeeb and Broughton (1978) also reported that mature-green 'Bentong' and 'Taiping' papayas from Malaysia developed CI symptoms after storage for 7 d at 15 °C. Papayas from the second harvest in the present study, which were less ripe than those from the first harvest, developed CI at 15 °C. Less mature or less ripe papaya fruit are known to be more sensitive to CI than more mature fruit (Chen and Paull, 1986).

Colletotrichum gloeosporioides, which causes anthracnose rot, was reported to be the most important cause of fungal rots on harvested papayas (Alvarez and Nishijima, 1987). Although in the present study decay never increased above a rating of 2 even for papayas stored at higher temperatures (Fig. 2), when chilled papayas were transferred to ambient temperatures decay developed rapidly in the lesions caused by exposure to chilling temperatures.

The pH values of papayas from the present study were comparable to the values earlier reported by Imungi and Wabule (1990). Fruit from the first and second harvest had at the time of harvest a pH of 5.6 and 5.3, respectively. In both harvests, there was a slight decrease in the pH of the fruit stored at 15 or 20 °C. However, the pH of papaya fruit stored at lower temperatures remained quite stable throughout storage.

The water loss that occurred during handling of papaya fruit tended to mask real losses of SSC, TA and AA expressed on a fresh weight basis; in some cases seeming to show no difference, or even greater retention of the chemical constituents compared to the papaya fruit at the time of harvest (data not shown). Therefore, the compositional data was expressed on a dry weight basis in order to show the actual losses that occurred in such constituents irrespective of the concentration effect imposed by water loss. No significant difference was observed in the TA of the papaya from the different storage temperatures (data not shown). Results from the present study agree with those published by Maharaj and Sankat (1990) who reported no significant effect of the storage time or temperature on the TA of papayas. Changes in the ripeness of papaya observed during storage such as yellowing and decreased firmness, did not seem to have had an effect on the acidity of the fruit even when stored at 20 °C for 14 d.

Results from the present study obtained for the SSC of papaya, are in agreement with values previous published by Paul et al. (1997) where the SSC for immature and ripe papaya was 5 and 19%, respectively. Fruit used in our study were between these two maturity stages and the SSC of papaya fruit from the first and second harvests was at the time of harvest approximately 10.8 and 10.7% of the fruit fresh weight, respectively. However, the SSC of the fruit decreased regardless of the storage temperature (Fig. 3). After storage for 6 d at 20 °C, the SSC of the fruit decreased by 42% and 30% compared to initial values for the first and the second harvest, respectively. After the end of the storage period, SSC of papayas from the first and the second harvests stored at 0 °C decreased by 30% and 20%, respectively, compared to initial values. Papaya fruit from the second harvest retained higher SSC when compared to fruit from the first harvest.

Initial AA content was higher in fruit from the first harvest compared to the second harvest (Fig. 3), corresponding to the difference in ripeness stage between the two harvests and in agreement with previous reports indicating that papaya AA content increases during ripening (Lee and Kader, 2000). In the fruit from the first harvest, AA decreased from 750 mg/100g dry weight to 393 mg/100g dry weight after 14 d at 0 °C. In the second harvest, there was not a significant difference in the AA content of papayas stored at different temperatures (Fig. 3). Papayas from the first harvest stored at different temperatures showed similar reductions of about 40-50% in their AA contents during storage while papayas from the second harvest showed little change in AA content.

For each storage temperature, the quality factors that limited the salability of the papayas were used to calculate the

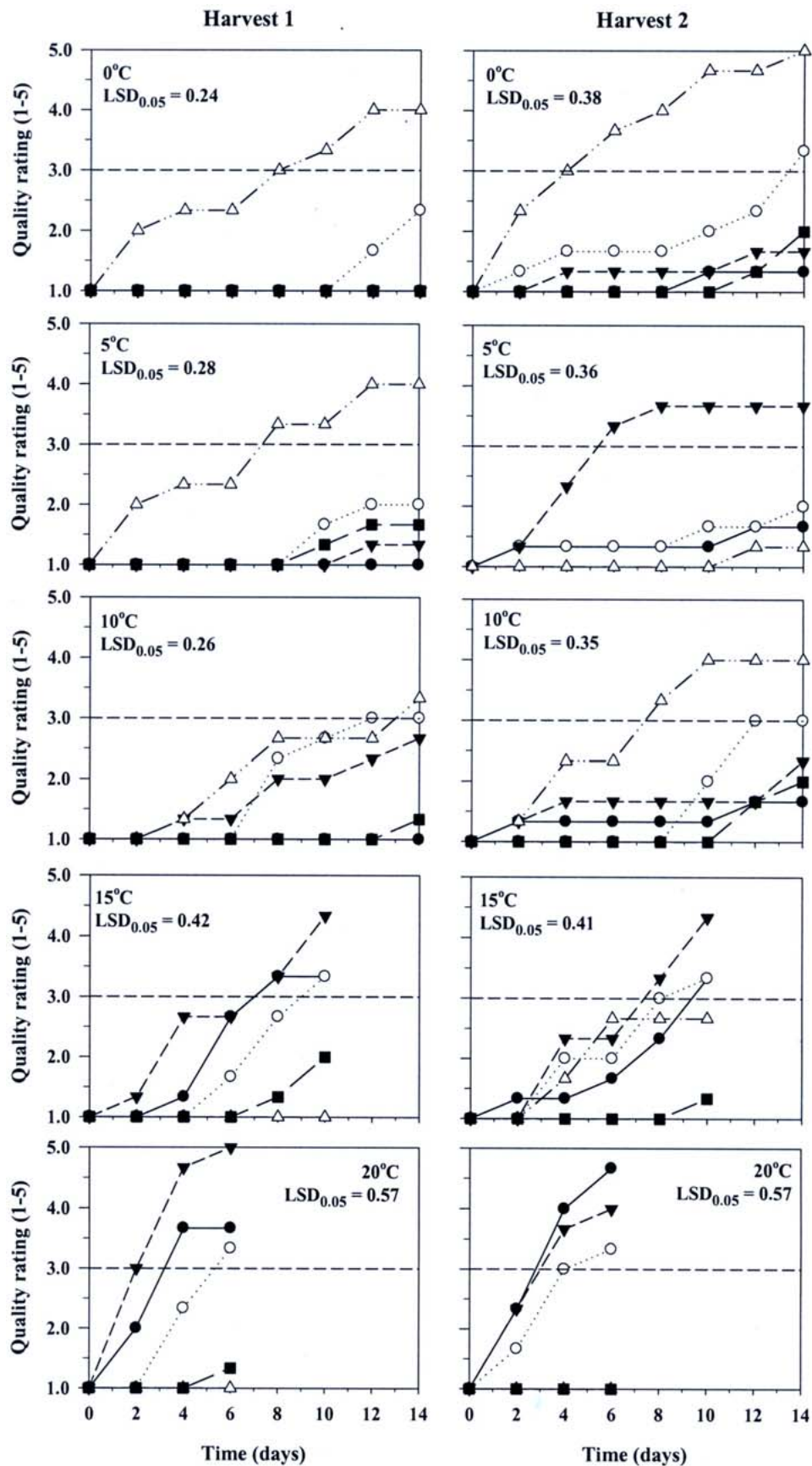


Fig. 2. Quality characteristics of papaya fruit cv. Exp. 15 stored at chilling or non-chilling temperatures; chilling injury was the limiting quality factor for papayas stored at 0 or 5 °C; Chilling injury and shrivelling were the limiting factors for papaya stored at 10 °C; flesh softening and shrivelling were the limiting quality factors for papaya stored at 15 °C; flesh softening and color changes (over ripeness) were the quality limiting factors for papaya stored at 20 °C (the dotted line corresponds to the limit of acceptability before the quality of the fruit became unacceptable). (●) Color; (○) Shrivelling; (▼) Firmness; (△) Chilling injury; (■) Decay.

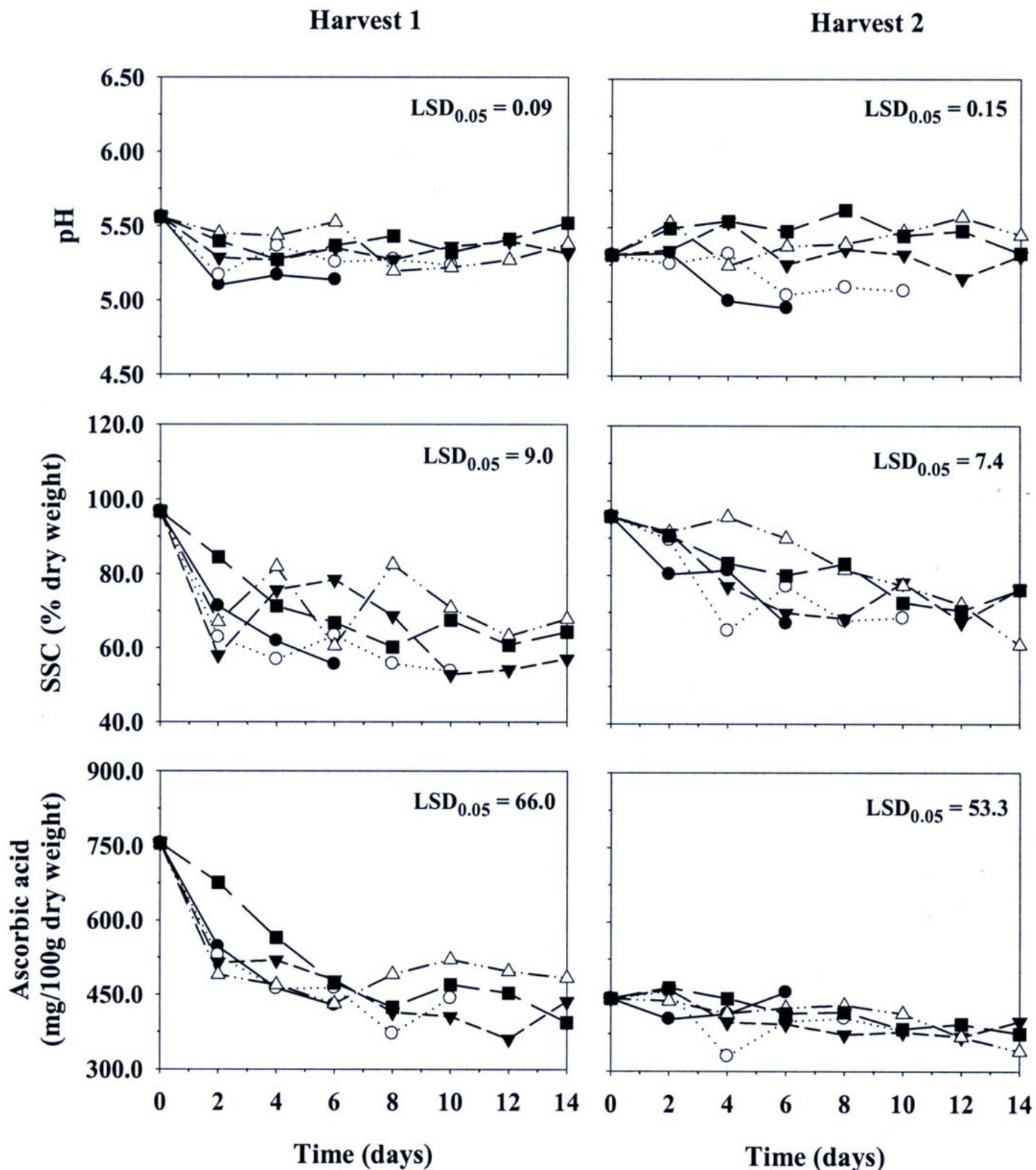


Fig. 3. Chemical composition of papaya fruit cv. Exp. 15 stored at chilling or non-chilling temperatures. (●) 20 °C; (○) 15 °C; (▼) 10 °C; (△) 5 °C (■) 0 °C.

maximum shelf life of the fruit at each temperature. Chilling injury was the primary limiting quality factor in fruit from the first and second harvest stored at 0 or 5 °C as well as for fruit from the second harvest stored at 10 °C. Papaya fruit from the

first harvest stored at chilling temperatures had longer shelf life than fruit from the second harvest. The less ripe fruit of the second harvest developed more severe CI symptoms than the riper fruit of the first harvest. Shriveling and CI simulta-

neously limited the salability of the papayas from the first harvest stored at 10 °C. At 15 and 20 °C, softening of the flesh limited the shelf life of the fruit from the first harvest to 7 and 2 d, respectively; the longest shelf life in the first harvest (13 d) was obtained for the fruit stored at 10 °C. In the second harvest, softening and shriveling were simultaneously the primary quality limiting factors at 15 °C while changes in color (over ripeness) and softening simultaneously limited the shelf life of the fruit stored at 20 °C. For the second harvest, the longest shelf life obtained was 8 d for the fruit stored at 15 °C.

Storage of color break 'Exp. 15' papayas at 0, 5 or 10 °C resulted in the development of CI. However, decay was a problem when papayas were stored for more than 8 d at 15 °C. Thus, storage of papaya fruit between 10 and 15 °C is recommended for maximum storage life. The quality curves obtained from quality evaluations for each temperature showed that a single quality factor cannot be used to express loss of quality of papaya fruit over the normal physiological range of temperatures.

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