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# Quality During Storage of Fresh-Cut Papaya (*Carica papaya* L.) in Various Shapes

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**This research work was conducted to study the effect of the cut type (cube, rectangular parallelepiped, cylinder and sphere) on the quality and shelf life of fresh-cut papaya (*Carica papaya* L. cv. Sunrise Solo) stored at 10 °C. Physico-chemical analyses were carried out during 10 d of storage; the color, firmness, pH, titratable acidity, total soluble solids, weight loss and ascorbic acid content of the fresh-cut fruits were determined. Microbiological analysis was also performed.**

**The most favorable physico-chemical and microbiological results were observed in sphere-shaped (1.55 cm radius) papaya: smaller changes in L*, a*, hue angle and chroma color coordinates; firmer texture; lower increases in pH; higher values and lower decrease of titratable acidity; reduced weight loss; lowest decrease in ascorbic acid content; and lower microbial loads. Based on the results of microbiological evaluation, less than 8 d would be the recommended time for storage of any cut type of fresh papaya.**

Key Words: color, cut type, firmness, microbiology, papaya, storage temperature, vitamin C

## INTRODUCTION

While conventional food processing methods extend the shelf life of fruits and vegetables, minimal processing may render them highly perishable, requiring refrigerated storage to ensure a reasonable shelf life (Garcia and Barrett 2002). Low temperature reduces respiration, inhibits microbial growth and retards metabolic activity, ripening and senescence (Wiley 1994). In fact, storage temperature is the most important factor affecting spoilage of minimally processed fruit and vegetables (Brackett 1987).

The effect of different storage temperatures (4–5 ºC, 10 ºC, 13 ºC and 20 ºC) on the shelf life of minimally processed papaya has been reported in the literature (O'Connor-Shaw et al. 1994; Rivera-Lopez et al. 2005). Several researchers have also investigated the storage of different shapes of cut papaya such as cubes, slices, cylinders, halves and chunks (Almeida et al. 2006; O'Connor-Shaw et al. 1994; Rivera-Lopez et al. 2005; Tapia et al. 2007; Teixeira et al. 2001). Rivera-Lopez et al. (2005) determined the over-all quality of fresh-cut papaya as a function of cutting shape (cubes or slices) and storage temperature (5 ºC, 10 ºC and 20 ºC). Parameters such as $CO_2$ production, color, firmness, total soluble solids, weight loss, sensorial quality, ascorbic acid, β-carotene and antioxidant capacity were evaluated during storage. Argañosa et al. (2008) also studied the effect of cutting shape (cube, cylinder, rectangular parallelepiped and sphere) on the physico-chemical, microbiological and sensory qualities of fresh-cut papaya stored at 4 °C. In addition, Teixeira et al. (2001) determined the effects of cutting dimensions of chunks (2.5 cm x 2.5 cm *vs*. 2.5 cm x 5.0 cm) and storage temperature (3 ºC, 6 ºC and 9 ºC) on atmosphere modification rate and chemical characteristics of fresh-cut 'Formosa' papaya packed in 500-mL plastic cups.

The main objective of this research work was to determine the effect of a 10 °C storage temperature on the quality and the shelf life of 'Sunrise Solo' papaya cut in different shapes (cube, rectangular parallelepiped, cylinder and sphere). Physico-chemical and microbiological analyses were performed on the different papaya cut types. Results were compared with those of previous experiments using a storage temperature of 4 °C (Argañosa et al. 2008). The use of 10 °C instead of 4 °C as storage temperature would have more potential application since it is less costly to store produce at a relatively higher temperature, as long as good quality fresh-cut papaya is assured.

## MATERIALS AND METHODS

### Plant Material

The papayas (cv. Sunrise Solo) were grown and harvested in Brazil and imported by Paula and Amaro, LDA, located in Mercado Abastecedor do Porto (MAP), Porto, Portugal. Fruit acquisition was based on visual and color characteristics (70–80% skin yellowness, ¾ ripe). Following transfer to the Plant Biotechnology Laboratory of Centro de Biotecnologia e Química Fina (CBQF) of Escola Superior de Biotecnologia of Universidade Católica Portuguesa, the papayas were stored at 20 ºC and 50% RH overnight prior to use in the experiments.

### Sample Preparation and Storage Conditions

The fruits were washed first with tap water, and then with chlorinated water (100 ppm) for 5 min (Chauhan et al. 2006). The excess water remaining on the surface of the fruits was dried off with paper towels. The papayas were peeled, deseeded and cut into various shapes (cube, rectangular parallelepiped, cylinder and sphere) by using a sharp, sterilized knife. Figure 1 shows the dimensions of the papaya cut types (pre-formed templates were used) and their corresponding surface area and the ratio of surface area to volume (A/V). Sphere dimensions varied (whole *vs.* half) depending on the size of papaya acquired in MAP. The length of the rectangular parallelepiped cut was adjusted to have almost the same A/V as that of the cylinder cut. The samples were then placed in rigid plastic containers (100 mm x 70 mm x 55 mm) with the lid on but not closed so as not to create a modified atmosphere.

Three replicates per cut type, per day and per type of analysis were prepared and stored at 10 ºC and 60% RH for 10 d. Preliminary assays performed to determine probable shelf life resulted in early mold formation on the 11th day at 10 ºC.

### Quality Evaluation

The fresh-cut types (cube, rectangular parallelepiped, cylinder and sphere) were separately examined for color, firmness, pH, titratable acidity, total soluble solids, weight loss and L-ascorbic acid during storage at 10 ºC. Microbial analysis was subsequently performed at days 1, 3, 8 and 10.

*Color assessment.* The surface color of the sample was measured by using a hand-held tritimulus reflectance colorimeter (Minolta CR-300, Minolta Corporation, Ramsey, USA). Color was expressed as the CIE: L* a* b* uniform color space, where L* indicates luminosity, a* corresponds to chromaticity on a green (-) to red (+) axis and b* the coloration on a blue (-) to yellow (+) axis (Francis 1980). Whiteness index (WI) was calculated by using the formula $WI = 100 – [(100-L^*)^2 + a^{*2} + b^{*2}]^{1/2}$. Numerical values of a* and b* were converted into hue angle ($Hue = \tan^{-1} (b^*/ a^*)$). Chroma (C) was calculated by using the formula $C = (a^{*2} + b^{*2})^{1/2}$. A total of ten color measurements were performed on each piece of cut type papaya. Three pieces were evaluated per replicate. Measurements on the cylinder cut fruit were done on the top flat surfaces and on the rectangular parallelepiped, on the bigger surfaces.

*Firmness measurement.* Texture was measured by using an Instron Universal Testing Instrument (model 4501, Instron Corporation, Canton, Ohio, USA). A 5-kg load cell was used while the crosshead speed was 10 mm $min^{-1}$. Texture was expressed as the resistance (hardness) of the fresh-cut papaya flesh to deformation by a 1-mm diameter probe and was expressed in Newton (N). Three punctures were made on each of the three pieces of one replicate.

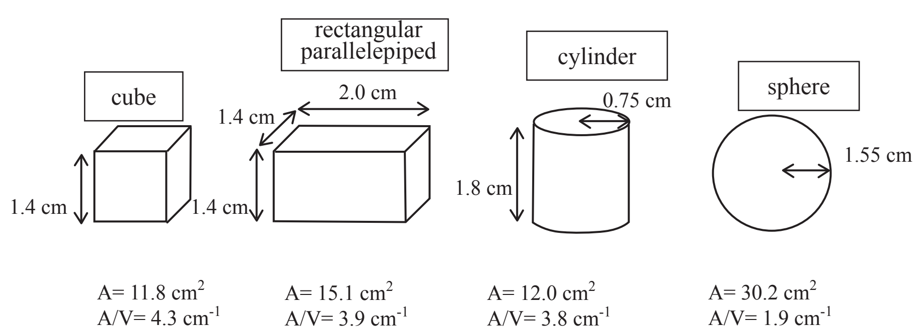


**Fig. 1**. Dimensions of fresh-cut papaya (A=surface area; V= volume).

*Weight loss*. Different weights (cube: 2.0–2.5 g, rectangular parallelepiped: 4.0–4.5 g, cylinder: 3.5–4.5 g, and sphere: 9–10 g) of each sample were weighed in a tared glass dish. The dishes were placed in an oven (WTC Binder, 7200 Tuttlingen, Germany) at 70 ºC for 48 h and weighed again. A balance (Sartorius basic, Sartorius, Goettingen, Germany) was used to determine weight loss that corresponded to the weight of the water that evaporated. Subtraction of the initial weight of the dish containing the sample from the weight after drying, divided by the weight of the initial sample, multiplied by 100 gave the moisture content. Weight loss was calculated by using the formula: $WL = 100 - (100 \times \%DM_{(0)} / \%DM)$, where $\%DM_{(0)}$ is the average dry matter at day 0, and %DM is the dry matter on the succeeding days of analysis.

*pH*. Ten grams of each replicate were homogenized with 100 mL deionized water in a 250-mL beaker, by using a homogenizer (Ultra-Turrax T25, Jank and Kunkel, IKA-Labortechnik, Breisgau, Germany). The pH of the homogenized solution was measured with a potentiometer, Crison, model Micron pH 2001 (Crison Instruments, S.A., Barcelona, Spain). The pH electrode was previously calibrated by using standard solutions of pH 4.0 and 7.0.

*Titratable acidity*. Ten grams of sample were homogenized with 100 mL of deionized water for each different cut type (cube, rectangular parallelepiped, cylinder and sphere), by using an Ultra-Turrax T25 homogenizer. The solution was titrated with 0.05 M NaOH solution until a pH of 8.3 was reached. A potentiometer with a combined electrode of pH Ingold 57/120 U402 and Crison MicropH 2001 (Crison Instruments, S.A., Barcelona, Spain) was used. The titratable acidity was expressed as mg citric acid/100 g fresh papaya.

*Total soluble solids*. Papaya samples were manually crushed, by using a mortar and pestle, to extract the juice. Soluble solids were determined by a hand-held refractometer (ATAGO – ATC1, Atago Co., Ltd., Tokyo, Japan).

*L-ascorbic acid*. The assay was performed according to the instructions included in the L-ascorbic acid determination test kit (Boehringer Mannheim, number 409 677 035). In order to ensure that the loss of L-ascorbic acid was minimal, all subsequent actions were carried out in an ice bath and with aluminum foil covering the goblets and funnel. A 2.50-g pulp was homogenized (Ultra-Turrax T25) with a small amount of meta-phosphoric acid. The homogenized sample was made up to a volume of 25.0 mL with meta-phosphoric acid (1.5% w/v). The papaya solution was poured into a funnel with filter paper to obtain a clear extract, as turbid extracts would interfere with spectrophotometric measurements. The pH of this extract was adjusted to 3.5–4.0, by using 10M KOH solution and a pH electrode (Crison micropH 2001) previously calibrated with buffer solutions of 4.0 and 7.0.

The absorbances were measured at 578 nm by using a spectrophotometer (Shimadzu UV-Vis 1601, Japan), and the blank used was de-ionized water.

L-ascorbic acid (L-AA) was expressed in mg/100 g fresh weight. Division of the amount of L-ascorbic acid (mg/100 g papaya) by the dry matter content (g dry matter/g papaya) resulted in mg L-ascorbic acid/100 g dry weight.

### Microbiological Analysis

Ten-gram sample of each cut type was placed in a bag, diluted with 90 mL of sterile NaCl solution and homogenized in a stomacher (400 classic BA6041, Seward, Norfolk,UK) for 30 s. The resultant slurry was then plated onto plate count agar (Merck, Darmstadt, Germany), de Man, Rogosa and Sharpe agar (Merck, Darmstadt, Germany), violet red bile agar (Merck, Darmstadt, Germany) and rose bengal chlorampenicol agar base (Oxoid Ltd., Basingstoke, Hampshire, England) supplemented with 5 mL chlortetracycline (Merck) by using a sterilized pipette. After incubation for 24 h (for fecal coliform analysis), 72 h (total count and lactic acid bacteria) and 5 d (yeasts and molds) at 44 ºC, 30 ºC and 25 ºC, respectively, manual plate counts of total microorganisms (ISO 4833 2003), yeasts and molds (IPQ 1987), lactic acid bacteria (ISO 15214 1998) and fecal coliform (IPQ 1986) were performed and reported as log CFU/g.

### Statistical Analysis

Data were analyzed by using SPSS for Windows (Version 11.5.0, SPSS Inc., USA). Treatment differences were tested by one-way ANOVA – Least Significant Difference (LSD) comparison ($p < 0.05$). All differences mentioned were significant at $p < 0.05$ unless stated otherwise.

## RESULTS AND DISCUSSION

### Color

The sphere-shaped papaya predominantly exhibited the highest lightness values and the cylinder shape the lowest among all cut types. Papaya sphere showed the highest ($p<0.05$) lightness values on days 0 and 2 (Fig. 2). Papaya cylinder, on the other hand, had the lowest

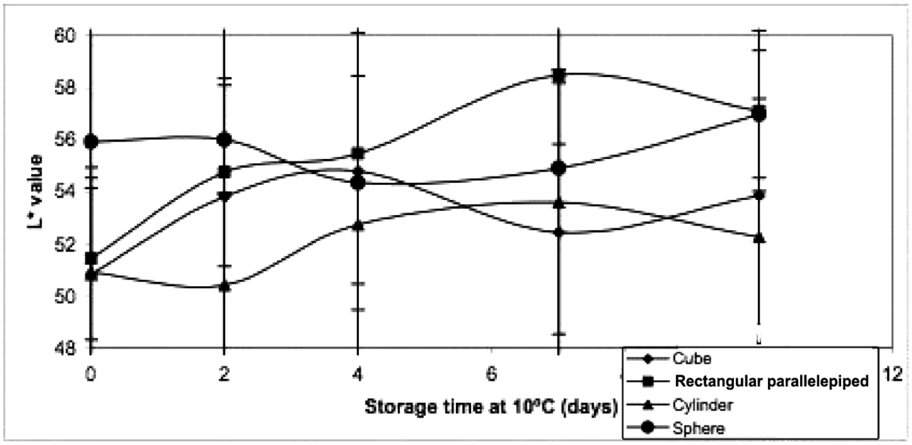


**Fig. 2**. L* values of fresh papaya cut in different shapes and stored at 10 °C.

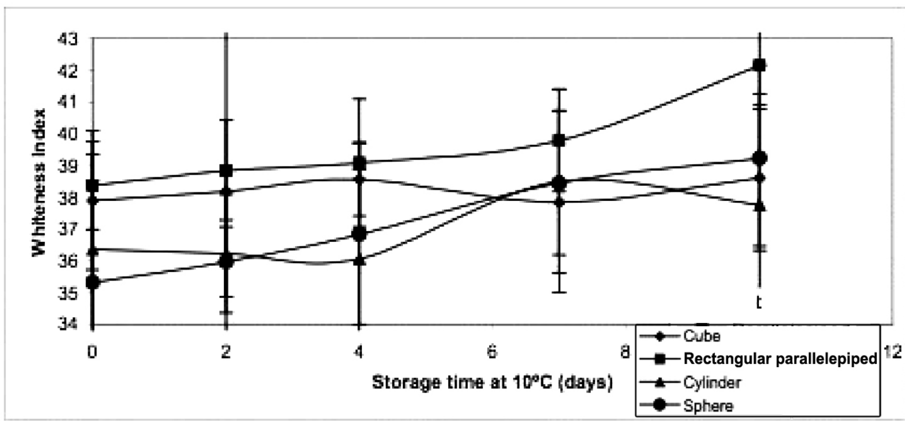


**Fig. 3**. Whiteness index of fresh papaya cut in different shapes and stored at 10 °C.

($p < 0.05$) lightness values on days 2, 7 and 10. There was generally an increase in the whiteness index during storage (Fig. 3).

Spheres had one of the highest ($p<0.05$) a* values (Table 1). On the other hand, cylinders showed one of the lowest ($p<0.05$) a* values among all cut types during storage. There was no difference ($p<0.05$) between hue values of all cut types after 10 d of storage. Papaya sphere presented one of the highest ($p<0.05$) chroma values throughout storage, with a relative decrease during storage compared with alternate increase/decrease in values of the three other cut types.

Compared with discoloration in some crops, such as white blush in carrots and browning in apples (Toivonen and Brummel 2007), visually, there was no evidence of browning of all papaya cut types during storage. The relative increase in the L* value of papaya sphere indicated a lighter shade of yellow color development during 10 d of storage at 10 ºC. Color parameters of all cut types did not drastically change during storage and, therefore, color was not a relevant factor in the quality of fresh-cut papaya in the present study.

**Texture**

No significant differences ($p<0.05$) were noticed in firmness between different cut types during storage, except on day 7 when cylinders were firmer than cubes (Table 2). Though sphere presented the lowest ($p < 0.05$) firmness values at day 0, it recovered after only 2 d of storage, exhibiting values similar to those of the other cut types. The decrease in firmness of spheres was the lowest after 10 d, only 46%, compared with 55% in rectangular parallelepiped, 60% in cylinder and 63% in cube. The higher decrease in firmness of papaya cube compared with the other cut types, which indicated a lower rate of ripening, may be attributed to its relatively high ratio of surface area to volume.

The storage temperature may significantly influence fruit firmness and the loss increases with storage time (Paull et al. 1999). Rapid decrease of fresh-cut papaya firmness at high temperature conditions is consistent

**Table 1**. Color parameters a*, hue angle and chroma of fresh-cut papaya stored at 10 ºC.

| Cut Type | Day 0 | Day 2 | Day 4 | Day 7 | Day 10 |
|---|---|---|---|---|---|
| | | | **a* Value** | | |
| Cube | 14.29 ± 1.50 b | 14.96 ± 1.80 ab | 14.60 ± 1.48 a | 12.90 ± 2.41 ab | 15.13 ± 3.02 a |
| Rectangular parallelepiped | 13.80 ± 1.68 b | 15.09 ± 1.81 a | 15.84 ± 1.29 a | 15.06 ± 2.07 a | 12.55 ± 1.06 b |
| Cylinder | 14.31 ± 1.43 b | 13.97 ± 1.46 b | 14.61 ± 1.66 a | 11.27 ± 1.58 b | 12.81 ± 2.23 b |
| Sphere | 15.72 ± 3.30 a | 17.96 ± 0.96 a | 17.23 ± 3.20 a | 14.53 ± 3.85 a | 14.15 ± 4.53 a |
| | | | **Hue Angle** | | |
| Cube | 67.83 ± 2.69b | 68.10 ± 2.50ab | 68.89 ± 2.29 b | 70.78 ± 3.11 b | 69.15 ± 2.98 a |
| Rectangular parallelepiped | 67.07 ± 3.38b | 68.20 ± 1.55ab | 67.20 ± 2.11 b | 69.77 ± 2.44 b | 70.97 ± 2.03 a |
| Cylinder | 69.14 ± 1.87ab | 69.95 ± 1.40 a | 69.89 ± 2.69 a | 73.53 ± 2.60 a | 71.05 ± 2.22 a |
| Sphere | 70.5 ± 3.94 a | 67.31 ± 1.68 b | 68.21 ± 4.05ab | 70.69 ± 5.47 b | 69.06 ± 1.77 a |
| | | | **Chroma** | | |
| Cube | 37.83 ± 2.13 b | 41.40 ± 6.42 b | 40.96 ± 5.54 b | 39.40 ± 5.53 b | 41.81 ± 5.62 a |
| Rectangular parallelepiped | 36.04 ± 3.69 b | 40.57 ± 4.42 b | 41.14 ± 4.42 b | 43.51 ± 2.24 a | 38.63 ± 2.46 b |
| Cylinder | 40.22 ± 4.23 b | 39.65 ± 2.96 b | 42.70 ± 3.03 b | 40.02 ± 3.67ab | 39.48 ± 5.02 b |
| Sphere | 47.02 ± 3.76 a | 46.45 ± 1.96 a | 46.50 ± 2.73 a | 42.09 ± 3.70 a | 42.41 ± 5.90 a |

Values followed by a common letter within a column are not significantly different ($p$<0.05).

**Table 2**. Firmness, weight loss, pH, titrable acidity and total soluble solids of fresh-cut papaya stored at 10 ºC.

| Cut Type | Day 0 | Day 2 | Day 4 | Day 7 | Day 10 |
|---|---|---|---|---|---|
| | | | **Firmness (N)** | | |
| Cube | 0.86 ± 0.06 b | 0.58 ± 0.08 a | 0.50 ± 0.11 a | 0.42 ± 0.09 b | 0.32 ± 0.07 a |
| Rectangular parallelepiped | 0.82 ± 0.08 b | 0.62 ± 0.10 a | 0.50 ± 0.07 a | 0.44 ± 0.06 ab | 0.37 ± 0.07 a |
| Cylinder | 0.97 ± 0.08 a | 0.63 ± 0.08 a | 0.54 ± 0.09 a | 0.49 ± 0.11 a | 0.39 ± 0.09 a |
| Sphere | 0.72 ± 0.06 c | 0.63 ± 0.05 a | 0.52 ± 0.06 a | 0.45 ± 0.07 ab | 0.39 ± 0.06 a |
| | | | **Weight Loss (%)** | | |
| Cube | 0 | 7.86 ± 0.16 a | 9.75 ± 0.20 b | 13.10 ± 1.94 a | 15.38 ± 1.08 a |
| Rectangular parallelepiped | 0 | 6.68 ± 0.83 b | 8.58 ± 0.24 c | 10.30 ± 0.44b | 13.33 ± 0.71b |
| Cylinder | 0 | 9.14 ± 2.21 a | 11.39 ± 0.8 a | 13.17 ± 2.21a | 16.18 ± 1.61a |
| Sphere | 0 | 5.10 ± 0.11 c | 6.72 ± 0.14 d | 8.21 ± 0.12 c | 9.18 ± 0.36 c |
| | | | **pH** | | |
| Cube | 5.44 ± 0.02 c | 5.46 ± 0.02 c | 5.52 ± 0.02 d | 5.64 ± 0.03 c | 5.78 ± 0.02 a |
| Rectangular parallelepiped | 5.52 ± 0.02 b | 5.55 ± 0.01 b | 5.60 ± 0.02 c | 5.62 ± 0.02 c | 5.71 ± 0.01 b |
| Cylinder | 5.55 ± 0.03 b | 5.56 ± 0.01 b | 5.65 ± 0.02 b | 5.69 ± 0.02 b | 5.74 ± 0.02 b |
| Sphere | 5.61 ± 0.01 a | 5.66 ± 0.02 a | 5.69 ± 0.03 a | 5.72 ± 0.04 a | 5.76 ± 0.01 a |
| | | | **Titratable Acidity (mg Citric Acid/100 g FW)** | | |
| Cube | 84.74 ± 0.92 a | 83.28 ± 0.38 a | 82.11 ± 0.60 a | 78.30 ± 0.49 a | 73.98 ± 0.78 b |
| Rectangular parallelepiped | 79.22 ± 0.50 b | 78.21 ± 0.15 b | 78.18 ± 0.32 b | 77.90 ± 0.35 a | 76.14 ± 0.73 a |
| Cylinder | 79.82 ± 1.01 b | 78.02 ± 0.24 b | 76.94 ± 0.24 c | 75.49 ± 1.08 b | 75.21 ± 0.83 a |
| Sphere | 76.81 ± 0.63 c | 75.96 ± 0.67 c | 75.45 ± 0.94 d | 74.97 ± 0.97 b | 74.12 ± 0.94 b |
| | | | **Total Soluble Solids (ºBrix)** | | |
| Cube | 13.1 ± 0.1 b | 13.7 ± 0.1 a | 14.1 ± 0.1 a | 13.3 ± 0.1 a | 13.5 ± 0.1 a |
| Rectangular parallelepiped | 12.8 ± 0.2 c | 11.8 ± 0.2 c | 13.3 ± 0.1 b | 13.3 ± 0.1 a | 12.3 ± 0.2 c |
| Cylinder | 13.3 ± 0.1 ab | 11.7 ± 0.1 c | 13.5 ± 0.1 b | 12.3 ± 0.1 c | 12.9 ± 0.1 b |
| Sphere | 13.5 ± 0.1 a | 12.5 ± 0.3 b | 12.3 ± 0.2 c | 12.9 ± 0.1 b | 12.3 ± 0.1 c |

Values followed by a common letter within a column are not significantly different ($p$<0.05).

with other reports (O'Connor-Shaw et al. 1994; Paull and Chen 1997). Water loss in fresh-cut fruits and vegetables is rapid due to damaged and exposed cuticle and sub-epidermal layers and lack of protective skin, leading to greater losses in firmness associated with factors such as temperature and storage time (Watada et al. 1996).

**Weight Loss**

Surface-area-to-volume ratio of a commodity is a relevant factor influencing evaporation of water (Paull 1999). Papaya cylinder had a surface-area-to-volume ratio double that of sphere (Fig. 1), which might have resulted in a higher weight loss in cylinder. Papaya cylinder and cube showed the highest ($p$<0.05) weight loss of 16% and 15%, respectively, while sphere had the lowest ($p$<0.05), 9%, after 10 d (Table 2).

Fresh-cut produce has a large surface area without skin, and has the potential to lose a substantial amount of weight, particularly at higher temperatures where a vapor pressure deficit is large (Watada et al. 1996). Current results were in agreement with those of other work, as papaya cubes and slices stored at 5 ºC had the lowest weight loss after 18 d compared with those stored at 10 ºC and 20 ºC (Rivera-Lopez et al. 2005).

Weight loss results for spheres were in agreement with findings for firmness: lower weight losses in sphere corresponded with lower losses in firmness. For many fresh commodity storage studies, the impact of quality attributes such as appearance and texture was ascribed to water loss (Paull 1999).

**pH**

Significant increases in pH of all the cut-type papaya studied were observed after 10 d. Papaya sphere had the lowest pH increase of 2.7%, and cube the highest increase of 6.3%. The small pH increase of the sphere-shaped papaya pieces during storage (Table 2) was in agreement with the change in firmness. Papaya sphere did not differ that much from its initial ripening stage as it had a very low pH increase and change in firmness, which might be due to its smaller ratio of surface area to volume (1.9–2.9 $cm^{-1}$).

Papaya cube had the lowest ($p$< 0.05) pH values among all cut types at day 0. After 7 d of storage it was not different from the pH of rectangular parallelepiped. However, after 10 d of storage, the pH of cubes was the highest ($p$<0.05), which was not significantly different from that of the sphere type.

In fresh-cut fruits, low pH is preferred because it is better against microbial growth, although differences among the cut types in the present study were relatively small.

The results of the present study were similar to those of the research work on mountain papaya (*Vasconcellea pubescens*) treated with 1-MCP right after harvest, showing a slow increase in pH after 15 d of storage at 20 ºC (Moya-Leon et al. 2004). On the other hand, the pH of papaya slices minimally processed by using a combination of methods (mild heat treatment, $a_w$ reduction, pH decrease and addition of potassium sorbate and sodium bisulfite) remained almost constant (Lopez-Malo et al. 2003).

**Titratable Acidity (TA)**

Decreases were observed in the titratable acidity of all the cut types until the 10$^{th}$ day of evaluation. TA of papaya cube decreased by 13% while that of papaya sphere decreased by only 3.5% during the 10-d storage (Table 2). Cubes had the highest ($p$< 0.05) TA values and sphere the lowest ($p$< 0.05) on days 0, 2 and 4.

The decrease in titratable acidity was in agreement with the research work on 'Formosa' papaya chunks (2.5 cm x 5.0 cm) where a higher reduction in titratable acidity was observed at 6 ºC and 9 ºC than at 3ºC (Teixeira et al. 2001).

In general, titratable acidity values were in agreement with those of pH: lower TA for higher pH and vice versa.

**Total Soluble Solids (TSS)**

Cube-shaped papaya was found to have the highest ($p$ < 0.05) TSS values on days 2, 4 and 10 (Table 2). No particular trend was noticed in TSS for all cut types during storage. TSS values seemed approximately constant. The results of the present study are in contrast with those of another study where TSS in ¾ ripe papaya cubes and slices decreased after 18-d storage at 5 ºC, 10 ºC and 20 ºC (Rivera-Lopez et al. 2005). They explained this finding on the assumption that sugars are the first substrates used during respiration.

**L - Ascorbic Acid Content (L-AA)**

Vitamin C content on a dry weight basis decreased by 26% for papaya sphere, by 29% for cylinder, 33% for cube and 39% for rectangular parallelepiped after 10 d of storage (Table 3). Rivera-Lopez et al. (2005) reported that fresh-cut papaya cubes and slices stored at 5 ºC had higher ascorbic acid levels than those stored at 10 ºC: after 6 d, no changes in vitamin C content were observed in cubes and slices at 5 ºC, whereas those stored at 10 ºC had an average of 5% lower vitamin C content in the same period. Loss of vitamin C is generally more rapid at higher storage temperatures and slower in acid fruit than in more neutral commodities (Watada 1987). Papaya is poor in acids (Lancashire 2006) and, therefore, high losses were expected, especially at 10 °C. Vitamin C content of kiwifruit slices stored under

**Table 3**. L-ascorbic acid content (mg L-AA/100 g dry weight) of fresh-cut papaya stored at 10 ºC.

| Cut Type | Day 1 | Day 4 | Day 7 | Day 10 |
|---|---|---|---|---|
| Cube | 429.0 ± 7 a | 360.7 ± 8 a | 325.1 ± 7 a | 285.6 ± 34 a |
| Rectangular parallelepiped | 422.3 ± 9 a | 340.2 ± 12 b | 324.8 ± 34 ab | 257.9 ± 27 b |
| Cylinders | 405.5 ± 8 b | 362.5 ± 13 ab | 301.7 ± 15 b | 285.1 ± 12 a |
| Spheres | 393.9 ± 13 b | 364.2 ± 22 ab | 328.5 ± 10 a | 290.1 ± 27 a |

Values followed by a common letter within a column are not significantly different ($p<0.05$).

**Table 4**. Total count of microorganisms, yeasts and molds, fecal coliforms and lactic acid bacteria of fresh-cut papaya stored at 10 ºC.

| Cut Type | Day 1 | Day 3 | Day 8 | Day 10 |
|---|---|---|---|---|
| | Total Count of Microorganisms (log CFU/g) | | | |
| Cube | 2.6 a | 3.15 a | 6.9 a | 7.5 a |
| Rectangular parallelepiped | < 2.5 a | 2.6 b | 6.7 b | 7.4 b |
| Cylinder | < 2.5 a | 2.7 b | 6.7 b | 7.4 c |
| Sphere | < 2.5 a | < 2.5 b | 6.0 c | 7.3 d |
| | Yeast and Mold Counts (log CFU/g) | | | |
| Cube | 1.0 a | 1,7 a | 5.0 a | 5.2 a |
| Rectangular parallelepiped | 1.0 a | 1.6 a | 4.8 b | 5.1 c |
| Cylinder | 1.0 a | 1.5 a | 4.85 b | 5.1 b |
| Sphere | 1.0 a | 1.3 a | 4.1 c | 4.6 d |
| | Fecal Coliform Count (log CFU/g) | | | |
| Cube | < 2.2 a | < 2.2 a | 4.0 a | 5.2 a |
| Rectangular parallelepiped | < 2.2 a | < 2.2 a | 3.9 b | 5.1 b |
| Cylinder | < 2.2 a | < 2.2 a | 3.8 b | 5.1 c |
| Sphere | < 1.0 a | < 1.0 a | 3.2 c | 4.5 d |
| | Lactic Acid Bacteria Count (log CFU/g) | | | |
| Cube | < 2.2 a | < 2.2 a | 4.9 a | 5.3 a |
| Rectangular parallelepiped | < 2.2 a | < 2.2 a | 4.9 a | 5.0 b |
| Cylinder | < 1.0 a | < 2.2 a | 4.9 a | 5.0 b |
| Sphere | < 1.0 a | < 1.0 a | 3.6 b | 4.3 c |

Values followed by a common letter within a column are not significantly different ($p<0.05$).

0.5, 2 and 4 kPa $O_2$ decreased by 7%, 12% and 18%, respectively, after 12 d storage at 10 ºC (Agar et al. 1999).

## Microbiological Analysis

Physical injury received by minimally processed refrigerated fruits and vegetables during size reduction operations will result in a complex series of physiological and microbiological events (Wiley 1994). Temperatures higher than 4 ºC enhance microbial growth in minimally processed honeydew, melon, papaya and pineapple (O'Connor-Shaw et al. 1994).

Sphere-shaped fresh-cut papaya had the least ($p<0.05$) counts among all cut types on days 8 and 10 (Table 4). This result might be attributed to the fact that the ratio of surface area to volume of the spheres is the smallest among all the cut types (1.9–2.9 $cm^{-1}$).

The critical limit for total microbial loads of vegetables is at 8 log CFU/g (Jacxens et al. 2002), higher than the values obtained in the present study. All yeast and mold counts were lower than the critical limits of 5 log CFU/g for yeasts (Jacxens et al. 2003) for 8 d of storage, except for cube-cut papaya.

On the $10^{th}$ day of storage, relatively higher counts of fecal coliforms were registered. The critical limit for *Escherichia coli* (an indicator of fecal coliforms) in fresh-cut fruits and vegetables is 3 log CFU/g (CE 2005); fecal coliform counts were already higher than this value on the 8th day of storage. The critical limits for lactic acid bacteria in vegetables is 7 log CFU/g (Jacxens et al. 2002), much higher than the values obtained in the present study.

The shelf life of fresh-cut papaya at 10 °C was, therefore, limited to less than 8 d by yeasts and molds and fecal coliform counts.

Fresh-cut 'Formosa' papaya hygienically prepared during processing resulted in low microbial count ($10^3$ CFU $g^{-1}$) in chunks stored at 9 ºC during 7 d (Teixeira et al. 2001).

Argañosa et al. (2008) also studied the effect of a 4 °C storage temperature on the quality and shelf life of 'Sunrise Solo' papaya with the same set of different cut types (cube, rectangular parallelepiped, cylinder and sphere). Color results (L*, a*, chroma) followed similar trends at 10 °C and 4 °C; firmness decreases and weight losses were higher at 10 °C than at 4 °C; increases in pH of all cut types were observed during storage at 4 °C as in the present study; titratable acidity decreased at both temperatures until the $10^{th}$ day of evaluation; decreases in vitamin C content on a dry weight basis throughout the storage period were higher than at 4 ºC; the microbiological evaluation in the present study resulted in much higher counts at 10 °C than at 4 °C (for sphere on day 10: log CFU $g^{-1}$ = 2 for yeast and mold counts and lactic acid bacterial count, log CFU $g^{-1}$ = 2.2 for fecal coliform count, and log CFU $g^{-1}$ = 2.5 for total microorganism count) (Argañosa et al. 2008).

## CONCLUSION

The effect of cut type (cube, rectangular parallelepiped, cylinder and sphere) on the quality and shelf life of papaya cv. Sunrise Solo was determined at 10 ºC. Sphere-shaped papaya presented better physico-chemical and microbiological results than the other cut types: there were smaller changes in L*, a*, hue angle and chroma color coordinates; firmer texture; lower increases in pH; higher values and lower decrease of titratable acidity, reduced weight loss; lowest decrease in ascorbic acid content; and lower microbial loads.

Similar results for storage at 4 °C were obtained for color of all cut types, but there were greater losses in firmness, vitamin C and weight, and higher increases in pH, which might result in early and higher microbial proliferation. Based on the results of microbiological evaluation, less than 8 d would be recommended for storage of any cut type of fresh-cut papaya at 10 °C, while at 4 °C the fresh-cut papaya was acceptable for 10 d.

Minimal processing of fresh-cut papaya, combined with low temperature storage, will hopefully boost a prospective market for this product.

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