# Effect of cut-type on quality of minimally processed papaya

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## Abstract

**BACKGROUND: This research was undertaken to study the effects of different cut-types (cube, parallelepiped, cylinder and sphere) on the quality and shelf-life of papaya cv. Sunrise Solo. Physicochemical analyses were carried out during 10 days of storage at 4 °C to determine colour, firmness, pH, titratable acidity, total soluble solids, weight loss and vitamin C content. Microbiological analysis and sensory evaluation were also performed.**

**RESULTS: Papaya spheres (1.55 cm radius) presented the most favourable physicochemical and microbiological properties (smaller changes in colour parameters $L^*$, $a^*$, $b^*$, chroma and hue angle, firmer texture, lower increase in pH, higher titratable acidity, almost constant total soluble solids, reduced weight loss, high vitamin C content and lower microbial loads) and sensory characteristics on day 10, while papaya cubes (1.4 cm side) proved to be the least acceptable.**

**CONCLUSION: The results of physicochemical, microbiological and sensory analyses performed on different cut-types of papaya indicated acceptable fresh-cut produce during 10 days of storage at 4 °C. The potential shelf-life at 4 °C is therefore 10 days, provided that no contamination occurs in the postharvest period and during minimal processing operations.**

## Introduction

Operations involved in the preparation of fresh-cut products are expected to induce a rapid enzymatic depletion of natural antioxidants as a response to injury.[1] For example, retention of ascorbic acid is dependent on tissue integrity.[2] Cut tissues have lower barriers to gas diffusion as a result of faster deterioration and increased respiration activity compared with intact commodities.[3] Fresh-cut tropical fruits, including papaya, were found to be of unacceptable quality after only 2 days of storage at 4 °C, primarily owing to tissue softening.[4,5]

The use of fresh-cut papaya in food service institutions is very limited owing to the many technical problems involved in maintaining its quality and microbiological safety during storage.[6] A recent study by Rivera-Lopez *et al*.[7] determined the effects of cutting shape (cubes or slices) and storage temperature (5, 10 or 20 °C) on the overall quality of fresh-cut papaya. Parameters such as $CO_2$ production, colour, firmness, total soluble solids, weight loss, sensory quality, ascorbic acid content, $\beta$-carotene and antioxidant capacity were evaluated during storage. In addition, Teixeira *et al*.[8] studied the effects of cutting dimensions (2.5 cm × 2.5 cm *vs* 2.5 cm × 5.0 cm) and storage temperature (3, 6 or 9 °C) on the atmospheric modification rate and chemical characteristics of 'Formosa' fresh-cut papaya chunks packed in 500 mL plastic cups.

According to Watada,[9] cutting of produce results in a large surface area being exposed to the air without any skin for protection against water loss and attack by micro-organisms.[10] Different shapes of cut papaya already studied include cubes, slices, cylinders, halves and chunks.[4,7,8,11,12] The surface area/volume ratio of a commodity is a relevant factor influencing evaporation.[13]

Ripening is an important process directly related to papaya quality. Chonhenchob and Singh[14] and Karakurt and Huber[15] found that papaya is a fruit that shows a rapid decrease in firmness after cutting. This may be due to a wound-induced increase in the activity of enzymes targeting cell walls and membranes contributing to the rapid deterioration of fresh-cut papaya (as compared with intact fruits stored under the same conditions). The rate of softening after processing depends on many factors related to the product and to the processing and storage conditions.[16] The stage of maturity of the fruit at cutting is of particular importance, since it affects post-cutting quality and shelf-life. Peleg and Gomez-Brito[17] suggested that grading of the state of maturity

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of papaya should be based on three parameters, namely total soluble solids, textural strength and internal colour. Paull and Chen[5] determined the stage of papaya suitable for minimal processing and the effect of processing on the physiology of the halved fruit. They found that papaya fruit with 55–80% skin yellowing and less than 50 N flesh firmness was suitable for minimal processing when combined with a low storage temperature (4 °C) to inhibit ethylene production and respiration. Low temperature reduces respiration, inhibits microbial growth and retards metabolic activity, ripening and senescence.[18] Minimal processing may increase microbial spoilage of fruits through transfer of skin microflora to the fruit flesh, where micro-organisms can grow rapidly upon exposure to nutrient juices. Recommended tests for assessment of sanitation and manufacturing practices for fruits are enumeration of yeasts and moulds and enumeration of lactic acid bacteria.[19] Coliforms are part of the normal microflora of fruits and processing lines.[4] Lowering the temperature reduces microbial proliferation in minimal processing of fruits and vegetables. O'Connor-Shaw *et al.*[4] reported that temperatures higher than 4 °C enhance microbial growth in minimally processed honeydew melon, papaya and pineapple.

The main objective of this research was to determine the effects of different cut-types (cube, parallelepiped, cylinder and sphere) on the quality and shelf-life of papaya cv. Sunrise Solo stored at 4 °C. Physicochemical, microbiological and sensory analyses were performed on the different papaya cut-types. Minimal processing of fresh-cut papaya combined with low-temperature storage will hopefully boost the prospective market for this product.

## Experimental

### Plant material

Papayas (cv. Sunrise Solo) grown and harvested in Brazil were imported (air-shipped) by (1) Ercilia M Santos Carneiro and Frias, LDA and (2) Paula & Amaro, LDA located in Mercado Abastecedor do Porto (MAP), Porto, Portugal. Fruit acquisition was based on visual and colour characteristics (70–80% skin yellowness, 3/4 ripe). The papayas were stored at 20 °C and 50% relative humidity (RH) overnight before being used in the experiments. Each experiment was performed 5 days after harvest and duplicated after a 1 month interval.

### Sample preparation and storage conditions

Following transfer to the Plant Biotechnology Laboratory of Centro de Biotecnologia e Química Fina (CBQF), Escola Superior de Biotecnologia, Universidade Católica Portuguesa, the fruits were washed first with tap water and then with chlorinated water ($0.1\,g\,L^{-1}$) for 5 min.[20] 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, parallelepiped, cylinder and sphere) using a sharp, sterilised knife. Table 1 shows the dimensions of the different papaya cut-types (pre-formed templates were used) and their corresponding surface areas and surface area/volume ($A/V$) ratios. The sphere dimensions varied (whole *vs* half) depending on the size of papaya acquired in MAP. The length of parallelepipeds was adjusted to result in almost the same $A/V$ ratio as that of cylinders. All samples were then placed in rigid plastic containers.

Three replicates per cut-type, per day and per type of analysis were prepared and stored at 4 °C and 60% RH for 10 days.

### Quality evaluation

The fresh-cut papaya cubes, parallelepipeds, cylinders and spheres were examined separately for colour, texture, pH, titratable acidity, total soluble solids, weight loss and L-ascorbic acid content during storage at 4 °C and 60% RH. Microbial and sensory analyses were subsequently performed on days 1, 3, 8 and 10 and days 8 and 10 respectively. Three replicates per cut-type, per day and per type of analysis were performed. Each replicate was in a plastic container covered with a lid but not hermetically sealed in order that the atmosphere inside the container was normal atmosphere.

#### Colour assessment

Sample surface colour was measured using a hand-held Minolta CR-300 tristimulus reflectance colorimeter (Minolta Corp., Ramsey, NJ, USA) and expressed in terms of the CIE $L^*$, $a^*$, $b^*$ uniform colour space, where $L^*$ represents lightness, $a^*$ represents chromaticity on a green (−) to red (+) axis and $b^*$ represents chromaticity on a blue (−) to yellow (+) axis.[21] Chroma ($C$) was calculated using the formula $C = (a^{*2} + b^{*2})^{1/2}$. Hue angle ($H$) was determined as $H = \tan^{-1}(b^*/a^*)$; it ranges from $H = 0°$ on the $+a^*$ axis (red colour) to $H = 90°$ on the $+b^*$ axis (yellow colour).

A total of ten colour measurements were performed on each piece of papaya cut-type. Three pieces were evaluated per replicate.

#### Firmness measurement

Texture was measured using an Instron 4501 universal testing instrument (Instron Corp., Canton, OH,

**Table 1.** Dimensions of fresh-cut papaya pieces and their corresponding surface area/volume ($A/V$) ratios

| Parameter | Cube | Parallel-epiped | Cylinder | Sphere (half-sphere) |
|---|---|---|---|---|
| Side (cm) | 1.4 | | | |
| Length (cm) | | 2.0 | 1.8 | |
| Width (cm) | | 1.4 | | |
| Height (cm) | | 1.4 | | |
| Radius (cm) | | | 0.75 | 1.55 |
| Surface area ($cm^2$) | 11.8 | 15.1 | 12.0 | 30.2 (22.6) |
| $A/V$ ratio ($cm^2$) | 4.3 | 3.9 | 3.8 | 1.9 (2.9) |

USA) with a 5 kg load cell at a crosshead speed of 10 mm $min^{-1}$. A 2 mm diameter cylindrical probe was employed. Texture was expressed as the resistance (firmness, N) of the fresh-cut papaya flesh to deformation by the probe. Three punctures were performed per replicate.

#### pH

Each replicate (10 g) was homogenised with deionised water (100 mL) in a 250 mL beaker using an Ultra-Turrax T25 (Janke and Kunkel, IKA-Labortechnik, Breisgau, Germany). The pH of the homogenised solution was measured with a Crison MicropH 2001 potentiometer (Crison Instruments, SA, Barcelona, Spain). The pH electrode had previously been calibrated using standard solutions of pH 4.0 and 7.0.

#### Titratable acidity

Each sample (10 g) was homogenised with deionised water (100 mL) in a 250 mL beaker using an Ultra-Turrax T25 (Janke and Kunkel, IKA-Labortechnik). The solution was titrated with 0.05 mol $L^{-1}$ NaOH solution until a pH value of 8.3 was reached. A combined electrode of pH Ingold U402 57/120 and a Crison MicropH 2001 potentiometer (Crison Instruments, SA) was used. Titratable acidity was expressed as mg citric acid per 100 g fresh papaya.

#### Total soluble solids

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

#### Weight loss

Three pieces from each cut-type were taken for L-ascorbic acid determination. Different amounts (cube, 2.0–2.5 g; parallelepiped; 4.0–4.5 g; cylinder, 3.5–4.5 g; sphere, 9–10 g) of each sample were weighed in tared glass dishes using a basic balance (Sartorius, Göttingen, Germany). The dishes were placed in an oven (WTB Binder, Tuttlingen, Germany) at 70 °C for 48 h and then weighed again. Moisture content (g $kg^{-1}$) was calculated as [(initial weight of dish with sample − weight of dish with sample after drying)/initial weight of dish with sample] × 1000. Weight loss (%) was calculated as $100 - (100 \times DM_0/DM)$, where $DM_0$ (g $kg^{-1}$) is the dry matter content on day 0 and DM (g $kg^{-1}$) is the dry matter content on subsequent days of analysis.

#### L-Ascorbic acid

This assay was performed according to the manual included in the L-ascorbic acid (L-AA) determination test kit (Number 409 677 035, Boehringer Mannheim, Mannheim, Germany). In order to ensure that the loss of L-AA was minimal, all procedures were carried out in an ice bath and with aluminium foil covering the goblets and funnel. Three replicates from each cut-type were analysed. A pulp sample of 2.5 g was homogenised (Ultra-Turrax T25, Janke and Kunkel, IKA-Labortechnik) with a small amount of metaphosphoric acid. The homogenised sample was then made up to a volume of 25 mL with metaphosphoric acid (15 g $L^{-1}$). The papaya solution was filtered to obtain a clear extract, as a turbid extract would interfere with spectrophotometric measurements. The pH of this extract was adjusted to 3.5–4.0 using 10 mol $L^{-1}$ KOH solution and a pH electrode (Crison MicropH 2001, Crison Instruments, SA) previously calibrated with buffer solutions of pH 4.0 and 7.0.

Absorbances were measured at 578 nm using a Shimadzu 1601 UV–visible spectrophotometer (Shimadzu, Kyoto, Japan) with deionised water as blank.

L-AA content was expressed as mg L-AA per 100 g fresh weight and also, by dividing the amount of L-AA (mg L-AA per 100 g papaya) by the DM content (g DM $g^{-1}$ papaya), as mg L-AA per 100 g dry weight.

#### Microbiology

A 10 g sample of each cut-type was placed in a bag, diluted with 90 mL of sterile NaCl solution and homogenised in a stomacher 400 Circulator (Seward, Thetford, Norfolk, UK) for 30 s. Using a sterilised pipette, the resultant slurry was plated onto plate count agar (Merck, Darmstadt, Germany), de Man–Rogosa–Sharpe agar (Merck), violet red bile agar (Merck) and rose bengal chloramphenicol agar base (Oxoid Ltd, Basingstoke, UK) supplemented with 5 mL of chlortetracycline (Merck). After incubation for 24 h (faecal coliforms), 72 h (total micro-organisms and lactic acid bacteria) and 5 days (yeasts and moulds) at 44, 30 and 25 °C respectively, manual plate counts of total micro-organisms,[22] yeasts and moulds,[23] lactic acid bacteria[24] and faecal coliforms[25] were performed and reported as log colony-forming units (CFU) $g^{-1}$. Microbiological analysis was performed only on days 1, 3, 8 and 10 of storage at 4 °C.

#### Sensory analysis

Following microbiological analysis, sensory evaluation of fresh-cut papaya was performed according to Rocha *et al.*[26] by 12 or 13 trained panellists on samples that had been cut into cubes, parallelepipeds, cylinders and spheres and stored at 4 °C. Sensory analysis was performed only on days 8 and 10 of storage. The parameters evaluated were global appreciation, general appearance, odour, texture and flavour. The following scale was used for scoring these attributes: 1, very bad; 3, neither good nor bad; 5, very good.

### Statistical analysis

Data were analysed using SPSS for Windows Version 11.5.0 (SPSS Inc., Chicago, IL, USA). Treatment differences were tested by one-way analysis of variance (ANOVA) and least square difference (LSD) comparison ($P < 0.05$). All differences mentioned were significant at $P < 0.05$ unless stated otherwise.

## Results and discussion

### Colour

Papaya spheres showed the highest and papaya cylinders the lowest lightness ($L^*$) values during 10 days of storage at 4 °C (Fig. 1), though the differences were not significant throughout all storage.

Papaya spheres also had high chromaticity ($a^*$ and $b^*$) values throughout storage, showing the highest $a^*$ values on days 0, 2 and 4 and the highest $b^*$ values on days 0, 2, 4 and 7 (Table 2). The lowest $a^*$ values were observed for papaya cylinders.

Similarly, the chroma ($C$) values of papaya spheres were highest throughout storage, except on day 10 (Table 2). In addition, papaya spheres exhibited steady decreases in $C$ value with increasing storage time, whereas the other three cut-types showed inconsistent decreases and/or increases. Papaya cylinders had the lowest $C$ values throughout storage.

Papaya cylinders generally presented the highest and papaya parallelepipeds the lowest hue angle ($H$) values throughout storage (Table 2). The difference in surface area between these two cut-types (cylinder, 12.0 $cm^2$; parallelepiped, 15.1 $cm^2$) may have contributed to the differences in $H$ value. Meanwhile, the $H$ values of papaya cylinders and spheres showed relative increases on days 2, 4 and 7. In connection with this, Chauhan *et al.*[20] reported that the ratio of $a^*$ and $b^*$ values in pretreated papaya slices stored for 60 days at 6 °C also showed an increasing trend, like $L^*$, indicating less redness and more yellowness.

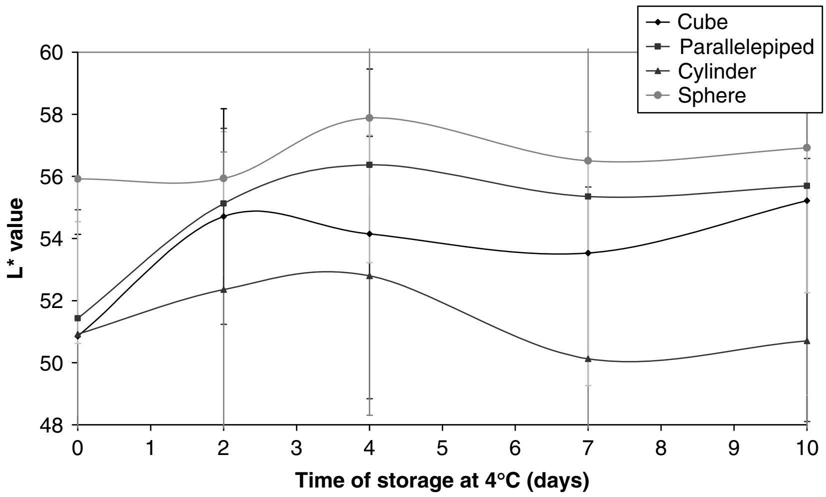


**Figure 1.** $L^*$ values of different shapes of fresh-cut papaya stored at 4 °C.

**Table 2.** Colour parameters $a^*$, $b^*$, chroma and hue angle of fresh-cut papaya stored at 4 °C

| Cut-type | Day 0 | Day 2 | Day 4 | Day 7 | Day 10 |
|---|---|---|---|---|---|
| *a* value* | | | | | |
| Cube | 14.29 ± 1.50b | 15.06 ± 0.85ab | 15.83 ± 1.79ab | 13.96 ± 2.60a | 14.88 ± 1.89a |
| Parallelepiped | 13.80 ± 1.68b | 16.48 ± 2.33ab | 14.98 ± 1.19ab | 15.64 ± 2.36a | 13.50 ± 2.38a |
| Cylinder | 14.31 ± 1.43b | 12.90 ± 1.98b | 12.69 ± 2.37b | 9.92 ± 2.66b | 10.27 ± 2.49b |
| Sphere | 15.72 ± 3.30a | 17.71 ± 0.93a | 16.09 ± 4.20a | 14.48 ± 4.45a | 13.18 ± 3.82a |
| *b* value* | | | | | |
| Cube | 35.0 ± 2.30b | 41.38 ± 3.28ab | 39.04 ± 5.44b | 37.97 ± 5.72b | 42.52 ± 6.52a |
| Parallelepiped | 34.89 ± 4.93b | 38.45 ± 1.64bc | 37.64 ± 2.10b | 39.13 ± 2.49a | 37.67 ± 6.55ab |
| Cylinder | 37.57 ± 4.19b | 37.44 ± 5.40c | 38.00 ± 5.79b | 33.30 ± 5.16b | 33.90 ± 6.58b |
| Sphere | 44.21 ± 3.70a | 43.30 ± 1.59a | 42.82 ± 3.59a | 40.23 ± 6.06 a | 39.30 ± 5.89a |
| *Chroma* | | | | | |
| Cube | 37.83 ± 2.13b | 44.04 ± 3.24a | 42.15 ± 5.54ab | 40.46 ± 6.22b | 45.08 ± 6.51a |
| Parallelepiped | 36.04 ± 3.69b | 41.87 ± 2.03ab | 40.51 ± 2.33b | 42.16 ± 3.16a | 40.04 ± 6.86ab |
| Cylinder | 40.22 ± 4.23b | 39.61 ± 5.66b | 40.15 ± 5.57b | 34.77 ± 5.64b | 35.45 ± 6.84b |
| Sphere | 47.02 ± 3.76a | 46.77 ± 1.80a | 45.92 ± 3.52a | 42.95 ± 6.17a | 41.54 ± 6.36ab |
| *Hue angle (°)* | | | | | |
| Cube | 67.83 ± 2.69b | 70.03 ± 1.27a | 67.81 ± 1.97b | 69.90 ± 1.33b | 70.47 ± 2.68b |
| Parallelepiped | 67.07 ± 3.38ab | 66.94 ± 2.79b | 68.32 ± 0.92b | 68.31 ± 1.94b | 70.22 ± 1.82b |
| Cylinder | 69.14 ± 1.87ab | 71.02 ± 1.41a | 71.23 ± 4.23a | 73.67 ± 2.37a | 73.15 ± 2.75a |
| Sphere | 70.5 ± 3.94a | 67.83 ± 0.48b | 69.39 ± 5.27ab | 70.10 ± 5.65b | 71.76 ± 4.54ab |

For each parameter, values with different letters in the same column are significantly different ($P < 0.05$).

Rivera-Lopez *et al.*[7] reported initial hue angles of 53 ± 2.5°, lower than the $H$ values obtained in the present study. Their results showed that fresh-cut papaya cubes and slices retained their natural yellow/red colour during 18 days of storage.

Sphere-shaped papaya tended to show the highest $L^*$, $a^*$, $b^*$ and $C$ values. Compared with discolouration events in other crops, such as white blush in carrots and secondary browning in apples,[27] the results of the present colour evaluation of all papaya cut-types did not show severe browning. In terms of global appreciation the sensory panellists preferred sphere-shaped papaya on day 8 of storage (see Table 6). Heterogeneity of the whole papaya samples used during the study might have contributed to the variations in colour among samples. Lastly, the colour parameters of all cut-types did not change drastically, so colour was not a relevant factor in assessing the quality of fresh-cut papaya in the present study.

## Texture

The firmness values of papaya cylinders were highest among all cut-types during 10 days of storage at 4 °C (Table 3). However, this may be due to the fact that the firmness of papaya cylinders was already highest at the beginning (day 0) of storage. Papaya spheres had the lowest firmness values on days 0 and 2, but after 4 days of storage they showed the same firmness as cubes and parallelepipeds, and their decrease in firmness was lowest after 10 days. The firmness of papaya spheres decreased significantly by 35%, cylinders by 41%, parallelepipeds by 48% and cubes by 58% after 10 days of storage.

The surface area/volume ($A/V$) ratio of a cube is 1.5–2 times higher than that of the corresponding sphere, resulting in greater firmness loss of cubes after 10 days of storage. Paull[13] reported that storage temperature may significantly influence fruit firmness and that firmness loss increases with storage time. According to Karakurt and Huber,[15] the firmness of fresh-cut papaya pieces (approximately 7 cm × 5 cm × 3 cm) decreased by about 36% after only 2 days and continued to decline steadily throughout storage at 5 °C. Similar trends were reported by Rivera-Lopez *et al.*,[7] who found that the firmness of papaya slices decreased significantly ($P \leq 0.05$) by 65% (from 9.8 to 3.2 N) while that of papaya cubes decreased by 57% (from 7.5 to 3.2 N) after 16 days of storage at 5 °C. Differences between the initial firmness values in the present study and those reported in the literature may have been due to the use of different cylindrical probes to evaluate firmness.

Watada and Qi[28] showed that water loss in fresh-cut fruits and vegetables is rapid owing to damaged

**Table 3.** Firmness, pH, titratable acidity, total soluble solids, moisture content and weight loss of fresh-cut papaya stored at 4 °C

| Cut-type | Day 0 | Day 2 | Day 4 | Day 7 | Day 10 |
|---|---|---|---|---|---|
| *Firmness (N)* | | | | | |
| Cube | 0.86 ± 0.06b | 0.70 ± 0.10b | 0.60 ± 0.07b | 0.51 ± 0.05b | 0.36 ± 0.08c |
| Parallelepiped | 0.82 ± 0.08b | 0.72 ± 0.08b | 0.59 ± 0.08b | 0.52 ± 0.07b | 0.43 ± 0.08b |
| Cylinder | 0.97 ± 0.08a | 0.89 ± 0.12a | 0.76 ± 0.09a | 0.64 ± 0.11a | 0.57 ± 0.11a |
| Sphere | 0.72 ± 0.06c | 0.63 ± 0.06c | 0.55 ± 0.08b | 0.52 ± 0.07b | 0.47 ± 0.08b |
| *pH* | | | | | |
| Cube | 5.44 ± 0.02c | 5.46 ± 0.01c | 5.52 ± 0.03c | 5.59 ± 0.02b | 5.72 ± 0.02a |
| Parallelepiped | 5.52 ± 0.02b | 5.54 ± 0.03b | 5.56 ± 0.03b | 5.56 ± 0.03b | 5.61 ± 0.01c |
| Cylinder | 5.55 ± 0.03b | 5.56 ± 0.02b | 5.58 ± 0.03b | 5.58 ± 0.02b | 5.67 ± 0.02b |
| Sphere | 5.61 ± 0.01a | 5.60 ± 0.02a | 5.64 ± 0.04a | 5.63 ± 0.02a | 5.68 ± 0.02b |
| *Titratable acidity (mg citric acid per 100 g fresh weight)* | | | | | |
| Cube | 84.74 ± 0.92a | 83.71 ± 1.24a | 82.64 ± 0.62a | 79.24 ± 0.99a | 74.38 ± 0.72b |
| Parallelepiped | 79.22 ± 0.50b | 78.63 ± 0.70b | 78.58 ± 0.68b | 78.30 ± 0.97a | 78.02 ± 0.58a |
| Cylinder | 79.82 ± 1.01b | 78.85 ± 0.97b | 78.12 ± 0.37b | 78.62 ± 0.77a | 77.74 ± 0.32a |
| Sphere | 76.81 ± 0.63c | 76.89 ± 0.87c | 75.54 ± 1.00c | 76.08 ± 0.72b | 75.57 ± 0.33b |
| *Total soluble solids (°Brix)* | | | | | |
| Cube | 13.1 ± 0.1b | 12.9 ± 0.3b | 13.8 ± 0.2a | 14.5 ± 0.1a | 13.7 ± 0.1a |
| Parallelepiped | 12.8 ± 0.2c | 13.1 ± 0.1ab | 12.2 ± 0.5c | 13.5 ± 0.1b | 13.6 ± 0.2a |
| Cylinder | 13.3 ± 0.1ab | 12.1 ± 0.2c | 13.7 ± 0.1a | 14.6 ± 0.2a | 12.9 ± 0.1b |
| Sphere | 13.5 ± 0.1a | 13.3 ± 0.3a | 13.2 ± 0.5b | 12.5 ± 0.1c | 12.9 ± 0.1b |
| *Moisture content (g kg$^{-1}$)* | | | | | |
| Cube | 858.5 ± 5.5a | 852.5 ± 5.3a | 847.0 ± 5.1ab | 842.5 ± 6.7b | 837.3 ± 5.9b |
| Parallelepiped | 853.3 ± 2.4a | 847.8 ± 2.7a | 843.6 ± 3.3b | 841.2 ± 2.7b | 837.5 ± 1.6b |
| Cylinder | 860.0 ± 7.3a | 855.6 ± 6.7a | 851.4 ± 7.1ab | 849.2 ± 7.9ab | 846.8 ± 7.1a |
| Sphere | 857.8 ± 4.5a | 855.4 ± 4.2a | 854.5 ± 4.0a | 852.0 ± 3.5a | 850.9 ± 5.3a |
| *Weight loss (%)* | | | | | |
| Cube | 0 | 2.05 ± 0.13b | 5.74 ± 0.02b | 7.92 ± 0.84ab | 11.21 ± 1.1a |
| Parallelepiped | 0 | 2.61 ± 0.20b | 5.10 ± 1.02b | 6.69 ± 0.16b | 9.69 ± 0.90a |
| Cylinder | 0 | 5.44 ± 1.82a | 7.99 ± 2.80a | 9.69 ± 2.21a | 10.83 ± 1.7a |
| Sphere | 0 | 3.20 ± 1.24b | 3.80 ± 0.80c | 5.23 ± 0.06c | 6.58 ± 0.43b |

For each parameter, values with different letters in the same column are significantly different ($P < 0.05$).

and exposed cuticular and sub-epidermal layers and a lack of protective skin, leading to greater losses in firmness associated with factors such as temperature and storage time. The higher decrease in firmness of cube-shaped papaya compared with other cut-types may be attributable to its relatively high $A/V$ ratio, which resulted in high weight loss as well (Table 3).

### pH

Significant increases in pH value for all papaya cut-types were observed after 10 days of storage at 4 °C (Table 3). The lowest pH increase was 1.3% for spheres and the highest 5.2% for cubes.

Since organic acids (predominantly citric and malic acids in papaya) are the substrates of enzymatic reactions during respiration, an increase in pH is expected during storage.[29]

Papaya cubes presented the lowest pH among all cut-types on day 0, but subsequent storage equalised it to that of parallelepipeds and cylinders on day 7. However, after 10 days of storage the pH of cubes rose to the highest value (5.72). Meanwhile, similar pH values for parallelepipeds and cylinders were observed on days 0, 2, 4 and 7, lying between the pH values of cubes and spheres. This similarity in pH values may be attributable to their similar $A/V$ ratios (cylinder, 3.8 $cm^{-1}$; parallelepiped, 3.9 $cm^{-1}$). Low pH is preferred in fresh-cut fruits because it provides better protection against microbial growth. Although the pH differences among cut-types in the present study were not very large, they were significant.

Papaya cv. Solo fruits commercialised in four establishments located in Brasilia-Distrito Federal were found to have pH values varying from 5.20 to 5.71, with higher values being observed in August and September.[30] The approximate pH of papaya has been reported as 5.2–6.0.[31] The initial pH in the present study was around 5.5.

However, Chauhan *et al.*[20] reported lower pH values of 4.5–5.0 for papaya pretreated by mild acidification with citric acid. Their study showed that the pH value decreased significantly ($P < 0.05$) from the original pH 5.7–5.8 of cut papaya during 60 days of storage at 6 ± 1 °C.

### Titratable acidity

Significant decreases in titratable acidity (TA) were observed for all papaya cut-types during 10 days of storage at 4 °C. However, higher TA values are preferred during storage because they correlate with low pH values, thereby preventing the early growth of micro-organisms in fresh-cut fruits.

In agreement with the pH results (Table 3), it was observed that the TA of papaya cubes decreased significantly by 12% after 10 days (Table 3). Parallelepipeds showed the lowest decrease in TA (1.5%) during the same time, followed by spheres (1.6%). Cubes presented the highest TA values on days 0, 2 and 4, while spheres showed the lowest values on days 0, 2, 4 and 7.

The decrease in TA observed was in agreement with the results of Teixeira *et al.*,[8] who reported that 'Formosa' papaya chunks (2.5 cm × 5.0 cm) showed higher TA reduction at 6 and 9 °C than at 3 °C.

The acid content of papaya is very low and comes from almost equal amounts of citric and malic acids,[32] the concentrations of which are known to decrease during ripening.[33]

Published TA values for papaya are within the range found in this study. Hernandez *et al.*[34] reported a ripe papaya TA value of 72 ± 8 mg citric acid per 100 g fruit. The papaya used in their study was harvested at the mature green stage and allowed to ripen at 18 °C, with a total soluble solids content of 12.1 ± 1.1 °Brix, which is very similar to the values obtained in the present study. Meanwhile, Fernandes *et al.*[35] reported a fresh papaya TA value of 15 ± 1 mg citric acid per 100 g fruit.

### Total soluble solids

Significant differences in total soluble solids (TSS) were observed on day 0 among papaya cut-types, with parallelepipeds showing the lowest and spheres the highest TSS value (Table 3). Papaya cubes were found to have the highest TSS values on days 4, 7 and 10, while no specific trend was observed regarding which cut-type had the lowest TSS value after 10 days of storage at 4 °C.

TSS values remained approximately constant throughout storage, but with significant differences among cut-types. The results of the present study are somewhat in contrast with those of Rivera-Lopez *et al.*,[7] who found that 3/4 ripe papaya with an initial TSS of 9.5 °Brix showed decreases in TSS in cubes and slices after 18 days of storage at 5, 10 and 20 °C. They explained this finding on the assumption that sugars are the first substrates used during respiration.

### Moisture content

No significant differences in moisture content were observed among papaya cut-types during the first 2 days of storage at 4 °C (Table 3). Papaya cubes showed the highest (2.5%) and spheres the lowest (0.8%) decrease in moisture content after 10 days of storage.

Spheres and cylinders had the highest moisture contents on days 4 and 7, while parallelepipeds and cubes had the lowest moisture contents on days 4, 7 and 10.

According to Fernandes *et al.*,[35] the average initial moisture content of fresh papaya before osmotic dehydration was 878.3 g $kg^{-1}$, while Hernandez *et al.*[34] reported a moisture content of ripened papaya of 900 ± 30 g $kg^{-1}$. These values are very close to those obtained in the present study. Although the reduction of moisture content to a certain level is one of the main tasks in food preservation,[36] moisture retention in fresh-cut fruits is desirable for the preservation of fresh-like quality.

## Weight loss

Papaya cubes showed the highest (11%) and spheres the lowest (7%) weight loss after 10 days of storage at 4 °C (Table 3).

Higher weight loss in cubes would require more force to puncture fresh-cut papaya. The higher decrease in weight of papaya cubes may be attributed to their higher $A/V$ ratio ($4.3\,\text{cm}^{-1}$) compared with other cut-types.

Fresh-cut produce has a large surface area without any skin and thus has the potential to lose a substantial amount of weight, particularly at higher temperatures where the vapour pressure deficit is large.[37]

Weight loss results for spheres were in agreement with firmness results only on day 2: lower weight losses in spheres corresponded to lower decreases in firmness. Higher weight losses in cubes resulted in higher decreases in firmness on days 7 and 10.

Paull[13] reported that in many fresh commodity storage studies the deterioration of quality attributes such as appearance and texture was ascribed to water loss.

## L-Ascorbic acid content

No significant differences in L-AA content on a fresh weight basis among papaya cut-types were observed on day 1 of storage at 4 °C (Table 4).

L-AA contents in the present study were slightly lower than those reported by Rivera-Lopez *et al.*[7] for 3/4 ripe papaya cubes and slices, which contained 65.47 mg L-AA per 100 g fresh weight at the beginning of storage. However, Wall[38] reported that 1/8 ripe Hawaiian papaya cultivars contained 45–55 mg L-AA per 100 g fresh weight. The L-AA contents of fresh-cut papaya found in the present study were much lower than (less than half) those reported by Hernandez *et al.*[34] for mature green papaya ripened at 18 °C (154 ± 17 mg L-AA per 100 g fresh weight).

L-AA contents were also calculated on a dry weight basis, because weight losses were very different among samples and therefore L-AA content on a fresh weight basis did not reflect the real content of L-AA. No significant differences in L-AA content on a dry weight basis were noted among different papaya cut-types on day 1 of storage at 4 °C (Table 4). It was only on day 3 that significant differences in L-AA contents of papaya cubes *versus* cylinders and spheres were observed. These differences were not so obvious on a fresh weight basis.

The L-AA content of papaya cubes on a dry weight basis decreased by 14%, parallelepipeds by 20%, spheres by 21% and cylinders by 26% after 10 days of storage.

Alhough the total surface area of papaya cubes ($11.8\,\text{cm}^2$) was not very different from that of cylinders ($12.0\,\text{cm}^2$), the decrease in L-AA content of papaya cylinders was almost double that of cubes after 10 days of storage. Higher losses might be expected in papaya cubes, since their $A/V$ ratio ($4.3\,\text{cm}^{-1}$) is somewhat higher than that of cylinders ($3.8\,\text{cm}^{-1}$).

Differences in L-AA content between fresh and dry weight bases can be attributed to the moisture content evolution of fresh-cut samples during storage. There was no defined correlation between the decrease in L-AA content and each cut-type surface area or $A/V$ ratio for all geometries, though cylinders and parallelepipeds had similar $A/V$ ratios. Artés-Hernández *et al.*[39] reported that wedges, slices and 1/2 slices of fresh-cut lemon products ('Lisbon') were preserved for a 10 day shelf-life period, with good retention of vitamin C, when kept at 0–5 °C and protected from water loss by proper packaging with high relative humidity during distribution. In the present study, cube-shaped fresh-cut papaya tended to retain higher L-AA content than other cut-types during the 10 day shelf-life period at 4 °C.

## Microbiological analysis

### Total count of micro-organisms

On day 1 of storage at 4 °C, there were significant differences in total counts of micro-organisms on papaya cubes and parallelepipeds compared with those on papaya cylinders and spheres (Table 5). However, there were no differences in total count among all cut-types on day 10 of storage. Total counts on papaya spheres were relatively low up to day 8 but increased during the last 2 days of storage. This might be attributed to the fact that the $A/V$ ratio of papaya spheres ($1.9–2.9\,\text{cm}^{-1}$) is the lowest among all cut-types. Total counts of micro-organisms on

**Table 4.** L-Ascorbic acid (L-AA) content of fresh-cut papaya stored at 4 °C

| Cut-type | Day 1 | Day 3 | Day 6 | Day 9 |
|---|---|---|---|---|
| *mg L-AA per 100 g fresh weight* | | | | |
| Cube | 56.73 ± 2.23a | 60.24 ± 0.50a | 58.34 ± 3.93a | 55.13 ± 8.51a |
| Parallelepiped | 51.72 ± 1.26a | 56.62 ± 3.17ab | 54.02 ± 2.34ab | 48.32 ± 1.10b |
| Cylinder | 53.48 ± 1.81a | 57.32 ± 2.26ab | 48.56 ± 7.82b | 43.82 ± 6.76b |
| Sphere | 52.19 ± 2.19a | 51.75 ± 1.27b | 49.90 ± 4.18b | 48.29 ± 2.96b |
| *mg L-AA per 100 g dry weight* | | | | |
| Cube | 396.3 ± 16a | 380.8 ± 3a | 360.1 ± 24a | 341.2 ± 48a |
| Parallelepiped | 381.2 ± 9a | 376.9 ± 21ab | 350.4 ± 15ab | 305.8 ± 7a |
| Cylinder | 391.9 ± 13a | 368.7 ± 7b | 324.2 ± 52b | 289.5 ± 45b |
| Sphere | 387.5 ± 16a | 356.9 ± 9b | 330.6 ± 28a | 307.7 ± 19a |

For each content, values with different letters in the same column are significantly different ($P < 0.05$).

**Table 5.** Counts of total micro-organisms, yeasts and moulds, faecal coliforms and lactic acid bacteria on fresh-cut papaya stored at 4 °C

| Cut-type | Day 1 | Day 3 | Day 8 | Day 10 |
|---|---|---|---|---|
| *Total micro-organisms (CFU g$^{-1}$)* | | | | |
| Cube | <30 × 10a | <30 × 10a | <30 × 10a | <30 × 10a |
| Parallelepiped | <30 × 10a | <30 × 10a | <30 × 10a | <30 × 10a |
| Cylinder | <1.0 × 10b | <30 × 10a | <30 × 10a | <30 × 10a |
| Sphere | <1.0 × 10b | <1.0 × 10b | <1.0 × 10b | <30 × 10a |
| *Yeasts and moulds (CFU g$^{-1}$)* | | | | |
| Cube | <1.0 × 10a | 1.0 × 10a | 1.0 × 10a | 2.0 × 10a |
| Parallelepiped | <1.0 × 10a | <1.0 × 10b | 1.0 × 10a | 2.0 × 10a |
| Cylinder | <1.0 × 10a | <1.0 × 10b | 1.0 × 10a | 2.0 × 10a |
| Sphere | <1.0 × 10a | <1.0 × 10b | <1.0 × 10b | <1.0 × 10b |
| *Faecal coliforms (CFU g$^{-1}$)* | | | | |
| Cube | <1.0 × 10a | <1.0 × 10a | <1.0 × 10a | <15 × 10a |
| Parallelepiped | <1.0 × 10a | <1.0 × 10a | <1.0 × 10a | <15 × 10a |
| Cylinder | <1.0 × 10a | <1.0 × 10a | <1.0 × 10a | <15 × 10a |
| Sphere | <1.0 × 10a | <1.0 × 10a | <1.0 × 10a | <15 × 10a |
| *Lactic acid bacteria (CFU g$^{-1}$)* | | | | |
| Cube | <1.0 × 10a | <1.0 × 10a | <1.0 × 10a | <1.0 × 10a |
| Parallelepiped | <1.0 × 10a | <1.0 × 10a | <1.0 × 10a | <1.0 × 10a |
| Cylinder | <1.0 × 10a | <1.0 × 10a | <1.0 × 10a | <1.0 × 10a |
| Sphere | <1.0 × 10a | <1.0 × 10a | <1.0 × 10a | <1.0 × 10a |

For each parameter, values with different letters in the same column are significantly different ($P < 0.05$).

papaya cubes studied by O'Connor-Shaw *et al.*[4] were $(2.6-3.3) \times 10^4$ CFU g$^{-1}$ on day 4 of storage. Jacxsens *et al.*[40] reported that the critical limit of total counts of micro-organisms for vegetables is $10^8$ CFU g$^{-1}$, which is higher than the levels found in the present study.

### Yeasts and moulds

Significant increases in counts of yeasts and moulds were observed on papaya cubes, parallelepipeds and cylinders from day 1 to day 10 of storage at 4 °C (Table 5). However, there was no effect of papaya cut-type on day 1. Sphere-shaped fresh-cut papaya showed the lowest counts among all cut-types, as no occurrence of yeasts and moulds was observed, in agreement with the results for total counts of micro-organisms on days 1, 3 and 8.

All counts were lower than the critical limit for yeasts ($10^5$ CFU g$^{-1}$)[41] on all days of storage. Chauhan *et al.*[20] reported that pretreated papaya slices stored under various modified atmosphere packaging conditions showed zero counts of yeasts and moulds.

### Faecal coliforms

No significant differences in faecal coliform count were observed among cut-types during 10 days of storage at 4 °C (Table 5). Although O'Connor-Shaw *et al.*[4] stated that coliforms are part of the normal microflora of fruits found in the soil, the results of the present study did not reflect this, as careful sample preparation and disinfection were performed. On day 10 of storage, relatively higher counts of faecal coliforms were registered, though still acceptable.[41]

O'Connor-Shaw *et al.*[4] reported Enterobacteriaceae counts of $(1.2-1.6) \times 10^6$ CFU g$^{-1}$ on minimally processed papaya on day 4 of storage at 4 °C, as the authors did not sanitise the fruit prior to processing, though good manufacturing practices were followed. Meanwhile, Chauhan *et al.*[20] found that papaya slices pretreated with antimicrobial additives such as sorbate and benzoate and packed in modified atmosphere registered zero coliform counts up to 60 days.

### Lactic acid bacteria

Papaya cut-type had no effect on the growth of lactic acid bacteria, since zero counts were recorded for all cut-types during 10 days of storage at 4 °C (Table 5). These results agree with the claim by Brackett[42] that the low pH of most fruits restricts the microflora to acid-tolerant micro-organisms such as fungi and lactic acid bacteria. O'Connor-Shaw *et al.*[4] recorded lactic acid bacteria counts of $(1.8-3.1) \times 10^3$ CFU g$^{-1}$ on papaya cubes after 4 days of storage at 4 °C. According to Jacxsens *et al.*,[40] the critical limit for lactic acid bacteria on vegetables is $10^7$ CFU g$^{-1}$, which is again very high compared with the results of the present study.

Minimally processed products with high pH (>4.6) are considered to be highly perishable when they are not subjected to preservative processes that delay undesirable biological and biochemical changes.[43] The results of the microbiological evaluation in the present study, however, indicate that storage at 4 °C, associated with disinfection of whole papaya (pH ≈ 5.5), can extend the shelf-life of all cut-types studied to 10 days. In relation to this, Teixeira *et al.*[8] reported that fresh-cut 'Formosa' papaya chunks, hygienically prepared during processing, also showed low microbial counts ($10^3$ CFU g$^{-1}$) after storage at 9 °C for 7 days.

## Sensory evaluation

Most studies on fresh-cut fruits have been concerned with market quality determined objectively and subjectively by colour, sensory and texture measurements as well as by microbiological assays.[44] The present study included the first microbiological analysis of fresh-cut papaya stored at 4 °C for up to 10 days. Since the results were satisfactory (i.e. counts well below acceptable limits), sensory evaluation was carried out on days 8 and 10 of storage.

Sensory studies have been extensively carried out to evaluate the influence of processing and storage conditions on the quality perception of fresh-cut fruits by either trained or untrained judges.[45] Consumers judge the quality of fresh-cut fruits and vegetables on the basis of appearance and freshness at the time of purchase. Sphere-shaped papaya received the highest score for global appreciation on day 8 (Table 6).

The sensory results indicated that the edible shelf-life of all papaya cut-types was 10 days at 4 °C if the limit of acceptability was set at 3.0. Quality scores ranged between 3.3 and 4.1. There were no significant differences among papaya cut-types in terms of global appreciation, general appearance, odour and flavour on day 10. However, on that day, papaya parallelepipeds were regarded by panellists as having the most acceptable texture, while spheres received the lowest score. These results are not in agreement with the firmness results, as papaya cylinders were found to be most firm and cubes least firm on day 10 (Table 3). Differences in sensory panellists' evaluation could be attributed to the use of different batches of whole papaya. Ergun *et al*.[46] reported that ripe papaya slices treated with 1-methylcyclopropene and stored at 5 °C had an edible shelf-life of 6 days as compared with only 2–3 days for control samples.

Papaya cv. Maradol cubes and slices stored at 5 °C showed good overall quality (score of 4 = good) until day 10 of storage.[7] However, O'Connor-Shaw *et al*.[4] evaluated the shelf-life of papaya cubes stored at 4 °C and reported that it was limited to only 2 days owing to unacceptable appearance and bitter flavour.

In addition to maintaining the appearance of produce, low-temperature storage has the benefit of protecting quality attributes such as texture, nutrition, aroma and flavour.[13] The results of physicochemical, microbiological and sensory analyses performed on the different papaya cut-types in the present study indicated an acceptable minimally processed product during storage at 4 °C for up to 10 days. Sphere-shaped papaya showed reduced weight loss, lower increase in pH, higher titratable acidity, higher firmness and acceptable microbial and sensory results, making it the best cut-type until day 10 of storage at 4 °C, while cube-shaped papaya was the least acceptable. However, laboratory studies may vary considerably from commercial handling and thereby affect shelf-life. Thus quality improvement at all levels of produce handling and recognition that each step or procedure is significant can have a great impact on the minimal processing of fruits and vegetables.

## Conclusions

The effect of different cut-types (cube, parallelepiped, cylinder and sphere) on the quality of papaya cv. Sunrise Solo was determined. The results of physicochemical, microbiological and sensory analyses performed on the different papaya cut-types indicated an acceptable minimally processed product during storage at 4 °C for up to 10 days.

Colour values did not differ significantly among cut-types, though papaya spheres (1.55 cm radius) tended to show higher $L^*$, $a^*$ and $b^*$ values and relatively low decreases in $C$ value compared with other cut-types throughout the storage period.

Papaya spheres showed the lowest losses of texture and weight during 10 days of storage at 4 °C, while cubes (1.4 cm side) presented the highest losses. Papaya cubes also exhibited the highest pH increase after 10 days. Papaya spheres and parallelepipeds showed low TA values, while TSS contents did not show a consistent trend, remaining approximately constant.

**Table 6.** Sensory evaluation of fresh-cut papaya on days 8 and 10 of storage at 4 °C

| Cut-type | Global appreciation | General appearance | Odour | Texture | Flavour |
|---|---|---|---|---|---|
| *Day 8* | | | | | |
| Control (fresh-cut cube) | 3.7 ± 0.6ab | 3.4 ± 0.6b | 3.6 ± 0.9a | 3.6 ± 0.6b | 3.7 ± 0.8a |
| Cube | 3.8 ± 0.5ab | 3.8 ± 0.4a | 3.5 ± 0.5a | 4.1 ± 0.4a | 4.1 ± 0.4a |
| Parallelepiped | 3.6 ± 0.9ab | 3.5 ± 0.7ab | 3.6 ± 0.5a | 3.7 ± 0.6ab | 3.7 ± 0.5a |
| Cylinder | 3.3 ± 0.9b | 3.6 ± 0.7ab | 3.5 ± 0.5a | 3.9 ± 0.5ab | 3.7 ± 0.6a |
| Sphere | 3.9 ± 0.6a | 3.8 ± 0.8ab | 3.6 ± 0.5a | 4.1 ± 0.4a | 3.7 ± 0.5a |
| *Day 10* | | | | | |
| Control (fresh-cut cube) | 3.9 ± 0.7a | 3.8 ± 0.7a | 3.7 ± 0.7a | 3.6 ± 0.8ab | 4.0 ± 0.6a |
| Cube | 3.6 ± 0.6a | 3.9 ± 0.5a | 3.3 ± 0.5a | 3.7 ± 0.6ab | 3.8 ± 0.6a |
| Parallelepiped | 3.9 ± 0.5a | 3.9 ± 0.6a | 3.6 ± 0.5a | 3.9 ± 0.7a | 4.0 ± 0.7a |
| Cylinder | 3.8 ± 0.7a | 3.9 ± 0.6a | 3.6 ± 0.6a | 3.6 ± 0.6ab | 3.8 ± 0.6a |
| Sphere | 3.8 ± 0.5a | 3.9 ± 0.7a | 3.4 ± 0.5a | 3.4 ± 0.5b | 3.9 ± 0.6a |

For each day, values with different letters in the same column are significantly different ($P < 0.05$).

Differences in L-AA content between fresh and dry weight bases could be attributed to the different moisture contents of samples during storage. Cube-shaped fresh-cut papaya retained the highest L-AA content among all cut-types throughout the 10 day shelf-life period.

The results of microbiological evaluation indicated that sphere-shaped fresh-cut papaya exhibited the lowest counts among all cut-types, as no occurrence of yeasts and moulds was observed. Although papaya parallelepipeds (length 2 cm, width 1.4 cm, height 1.4 cm) were considered by the panellists to have the best texture in sensory evaluation, spheres received the highest score for global appreciation on day 8 of storage.

The microbiological evaluation results indicated that disinfection of whole papaya associated with storage at 4 °C allowed a shelf-life of 10 days for all cut-types studied.

It is important to note that laboratory studies may vary consideably from commercial handling and thereby affect shelf-life. Thus quality improvement at all levels of produce handling and recognition that each step or procedure is significant can have a great impact on the minimal processing of fruits and vegetables.

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