Original Research Artile

Textural and Physicochemical Properties of ‘Cricket Ball’ Sapota (Manilkara Achras): Post-Harvest Evaluation for Quality Assessment

Abstract

Sapota (Manilkara achras), particularly the ‘Cricket Ball’ cultivar, is a tropical fruit valued for its sweetness and nutritional profile but suffers from rapid post-harvest deterioration. This study investigated the physical, textural, and physicochemical properties of freshly harvested fruits to better understand quality changes during storage. Fifty fruits were evaluated for physical attributes, including average length (49.37 mm), width (47.00 mm), thickness (45.98 mm), mass (62.68 g), and sphericity (0.96), with bulk density of 444.29 kg/m^3, true density of 925.60 kg/m^3, and porosity of 52%. Mechanical testing indicated progressive softening, with puncture force declining from 5.69 N on day 0 to 3.03 N by day 4, and compression force reducing from 64.98 N to 32.30 N. Shear stress force similarly decreased from 25.42 N to 7.68 N, accompanied by higher coefficients of variation, indicating greater textural heterogeneity. Physiological loss in weight (PLW) increased substantially, while spoilage advanced from edible condition to senescence by day 4. Biochemical analysis revealed rising avarage pH (4.90 to 6.74), declining ascorbic acid (5.25 to 3.65 mg/100 g) and titratable acidity (0.28% to 0.23%), and consistent increases in total sugars (45.44% to 52.50%), reducing sugars (8.40% to 11.84%), and non-reducing sugars (33.68% to 39.45%). The pulp-to-peel ratio increased over storage, indicating relative deterioration, whereas the pulp-to-seed ratio ranges from 18.31 to 17.83. These integrated physicochemical and mechanical changes highlight accelerated ripening, structural degradation, and nutritional losses within four days, providing critical insights for optimizing harvest maturity, storage, and processing strategies for sapota fruits.

Keywords: Cricket Ball Sapota, Texture Analysis, Physicochemical Properties, Post-harvest Storage, Quality Assessment

1 Introduction

Sapota (Manilkara achras) fruit, like many climacteric fruits, experiences a cascade of biochemical transformations during the ripening process, leading to perceptible modifications in color, texture, and flavor, signifying underlying compositional changes (Desai et al., 2017). These postharvest changes in sapota, particularly in widely cultivated cultivars such as ’Kalipatti’ and ’Cricket Ball’, can significantly impact their marketability and consumer acceptance. Understanding these changes is crucial for

optimizing postharvest handling and storage practices to extend shelf life and maintain fruit quality. The deterioration of fruits such as sapota, characterized by alterations in quality, visual appeal, edibility, availability, and overall freshness, can be attributed to a combination of mechanical, physiological, biochemical, chemical, microbiological, and other biological factors that initiate a decline in fruit integrity (Shankar et al., 2024). The limited shelf life of sapota and its propensity for rapid deterioration often result in seasonal gluts, highlighting the need for effective preservation methods (Bons et al., 2020).

Texture is the important factor of fruits and vegetables quality. Texture analyzer is about the character of force with food texture, the result is sensitive and objective (Liu & Li, 2010).The textural attributes of sapota, particularly the softening of the pulp, are critical determinants of consumer preference and overall eating quality, which can be affected by storage conditions (Sapper & Chiralt, 2018). The assessment of textural properties, such as firmness and crispiness, is crucial in evaluating fruit quality during storage (Streif et al., 2009). Textural deterioration during storage can be attributed to enzymatic degradation of cell wall components, leading to a loss of turgor and structural integrity. Recent studies have examined the physicochemical and textural properties of sapota fruits. Sapodilla (Manilkara zapota) and white sapote (Casimiroa edulis) were found to have high moisture content, ranging from 78.72% to 79.7% . Both fruits exhibited significant antioxidant activity, with sapodilla showing 88.01% and white sapote 86.32%. The fruits are rich in phenolic compounds and flavonoids (Abdraboh & Arfa, 2024; Abdul Latif et al., 2023). Edible coatings, such as Aloe vera gel, can help maintain fruit quality and extend shelf life (Padmaja et al., 2015).

The sapota cultivars 'Kalipatti' and 'Cricket Ball' are widely cultivated in India due to their desirable characteristics. 'Kalipatti' fruits are slightly larger and heavier than 'Cricket Ball', but the latter has higher total soluble solids and overall acceptability in jam production. Cricket Ball sapota is a significant variety cultivated in India, known for its physical attributes and processing suitability. It has an average weight of 51.63g and dimensions of 41.7mm x 46.2mm x 46.3mm (Bons & Rehal, 2019).

Sapota fruits undergo significant biochemical changes during ripening. Studies have shown that total soluble solids, total sugars, and reducing sugars increase in both peel and pulp, while acidity decreases (Bala et al., 2017). The principal carbohydrates identified are sucrose, glucose, and fructose, with cultivar-specific variations in composition (Selvaraj & Pal, 1984). Sapota exhibits a climacteric respiration pattern, reaching eating ripeness nine days after harvest, associated with increased pectinesterase activity, decreased firmness, increased sugar content, and reduced phenols (Reyes et al., 2005).Chemical analyses across studies determined moisture (72-79%), total soluble solids (19-21%), pH (5.7), acidity (0.14-0.40%) (Abdraboh & Arfa, 2024).

Given the significance of textural and physicochemical properties in determining the quality, shelf life, and processing suitability of sapota, it is essential to assess these parameters systematically. The material and methodology section of current study focuses on evaluating the textural (firmness, compression, puncture, strain, and shear resistance) and physicochemical (TSS, acidity, ascorbic acid, moisture loss, sugar content, pH, and spoilage) properties of the 'Cricket Ball' variety during storage. These insights aim to provide a foundational understanding that can inform harvesting, postharvest handling, processing, and quality control strategies for sapota. Result and discussions section analyse the data and discusses the useful insights.

2 Materials and Methods

Cricket Ball sapota fruits were sourced from a commercial orchard in Gujarat, ensuring uniform maturity and absence of visible defects. Fifty mature 'Cricket Ball' sapota fruits were selected for further analysis. All fruits were cleaned thoroughly with distilled water to remove any surface contaminants and were equilibrated to ambient room temperature prior to testing. Three fruits per treatment were randomly selected for each textural and physicochemical test to maintain statistical robustness.

2.1 Measurement of Physical Properties

Physical properties of food are characteristics that can be observed or measured without changing the food's chemical composition. A total of 50 freshly harvested sapota fruits were selected for the analysis of their physical properties.

2.1.1 Physical Dimensions and mass

The length (L), width (B), and thickness (T) of each fruit were measured as shown in Figure 1a using a digital vernier caliper (Make: Themisto Model: TH-M61) with a least count of 0.1 mm. Measurements were taken along the three principal axes. The mass of each fruit was measured individually using an electronic balance as shown in Figure 1b with an accuracy of 0.01 g and statistical averaging was performed. The shape of the fruits was assessed visually and compared against a standard shape chart as shown in Figure 1c.

(a) Size (b) Weight (c) Shape (d) True Density

Figure 1: (a) (b) (c) and (d) measurement of physical properties

2.1.2 Geometric Mean Diameter

The Geometric Mean Diameter (GMD) of fruits is a measurement used to characterize the size and shape of irregularly shaped objects like fruits. The geometric mean diameter (D_g) was determined using:

$$D_g = (L \times B \times T)^{1/3} \tag{2.1}$$

2.1.3 Sphericity

Sphericity, a measure of how spherical a fruit is, is important for sorting and sizing. It is calculated by comparing the fruit's actual surface area to that of a sphere with the same volume. Sphericity (ϕ) was calculated using:

$$\phi = \frac{(L \times B \times T)^{1/3}}{L} \tag{2.2}$$

2.1.4 Bulk Density, True Density and Porosity

Bulk density of fruits was measured by determining the ratio of the mass of the fruits *W* to the total volume *V* they occupy, including voids and spaces. it was measured by filling a container with the

Figure 2: Textural analysis

fruits and measure the volume occupied by the fruits, including any gaps or voids between them. Bulk density (ρ_b) was calculated using:

$$\rho_b = \frac{W}{V} \tag{2.3}$$

True density is useful to understand the inherent density of a material, independent of its packing arrangement. The method used as per (Mohsenin, 2020). True density (ρ_t) was calculated by:

$$\rho_t = \frac{W}{V_{displaced}} \tag{2.4}$$

Porosity is defined as the percentage of void volume within a test sample at a given moisture content. It is determined by calculating the ratio of the difference between true density and bulk density to the true density, and expressing the result as a percentage using the following equation. Porosity (P) was calculated using:

$$P = 1 - \frac{\rho_b}{\rho_t} \tag{2.5}$$

2.1.5 Coefficient of Friction

The coefficient of static friction for fruit was measured using an inclined plane method. The static coefficient of friction is the force needed to initiate movement, while the dynamic coefficient of friction is the force required to maintain movement. The coefficient of static friction (μ) was measured between piled sapota fruits will be estimated on plywood using a tilting platform method:

$$\mu = \tan\theta \tag{2.6}$$

2.2 Determination of Textural Properties

In this study, textural properties such as puncture force, compressive strength, and shear strength were determined using a texture analyzer (Make: Stable Micro System, Model: TA.HD plus) as shown in figure 2. Standard test protocols were followed to evaluate the mechanical behavior of food samples under controlled conditions. These measurements provided quantitative data essential for assessing product quality and consumer acceptability.

2.2.1 Puncture Test

To further assess fruit firmness and resistance to skin penetration, a puncture test was conducted using a texture analyzer equipped with a cylindrical probe. Fruits were positioned horizontally on a stable platform, and the probe was lowered vertically at a controlled penetration rate (standardized at 5 mm/s) until a preset depth of 10 mm was reached. The peak force (in Newtons, N) required for puncturing was recorded. Tests were repeated across all three replicates, and the average puncture force was computed. This method simulates mechanical damage during handling and helps assess shelf-life potential (Rahman & Al-Farsi, 2005).

2.2.2 Compression Test

Compression strength was evaluated using a textural analyzer equipped with flat compression plates. Each fruit was placed centrally between the plates, and force was applied gradually from both sides at a crosshead speed of 10 mm/min until visible deformation or rupture occurred. The peak compression force (in N) was recorded for each sample. This test provides insight into structural stability under storage and transport conditions (Karaj & Müller, 2010).

2.2.3 Shear Force Test

Shear resistance was determined using a blade-type probe in a texture analyzer. Sapota fruits were sliced into uniform segments (10 mm thick) and placed on the test platform. The blade was driven vertically through the fruit at a consistent rate (e.g., 2 mm/s), and the maximum force required to shear the slice was recorded. Shear force measurements reflect internal cohesiveness and cell wall integrity, which are important for both fresh consumption and processing applications (Al-Hinai et al., 2013).

Each of the above textural properties was measured in triplicate, and the results were expressed as mean ± standard deviation. Statistical consistency was ensured by calculating the coefficient of variation (CV%) for each parameter:

3 Determination of Physicochemical Properties

The physicochemical characteristics of Cricket Ball sapota were systematically evaluated over a defined storage period, and stored at ambient condition to monitor changes in fruit quality parameters. These included physiological weight loss, spoilage, pH, titratable acidity, sugar content, and ascorbic acid content. Each parameter was measured in triplicate and reported as mean ± standard deviation. All analytical procedures were carried out under controlled laboratory conditions.

3.1 Physiological Loss in Weight (PLW)

Physiological loss in weight was calculated by recording the initial weight of each fruit before storage and comparing it with the weight on subsequent observation days. The percentage loss in weight was used as an indicator of moisture loss and transpiration effects. The PLW was computed using the following equation:

$$\text{PLW } (\%) = \left(\frac{W_1 - W_2}{W_1} \right) \times 100 \tag{3.1}$$

- W_1: Initial weight of the fruit
- W_2: Final weight of the fruit

This parameter is crucial for evaluating postharvest water loss, which directly affects freshness and (Ranganna, 1986).

3.2 Spoilage percentage (%)

The number of fruits showing decay symptoms, rotted and with mouldy odour were noted periodically and calculated as spoilage percentage on the basis of total number of fruits treated.

3.3 Total soluble solids (°Brix)

Total soluble solids of the pulp were recorded using a refractometer (make:ATAGO, Model: RX-7000α).The average of three fruits was computed and recorded.

3.4 Titrable acidity (%)

The method described by Ranganna (1979) was adopted for estimation of the titrable acidity of fruits. Ten grams of homogenized pulp were transferred into a 100 ml volumetric flask and diluted to volume with distilled water. The resulting suspension was thoroughly mixed and filtered using Whatman No. 1 filter paper. The clear filtrate was then used for titration. A 5 ml aliquot of the filtrate was titrated against standard sodium hydroxide solution using phenolphthalein as an indicator. The titratable acidity was calculated as the percentage of malic acid equivalent using the following formula:

$$\text{Titratable Acidity (\%)} = \frac{V \times N \times EW \times 100}{W} \tag{3.2}$$

where V is the volume of NaOH used (mL), N is the normality of NaOH, EW is the equivalent weight of the predominant acid (e.g., 67.045 for malic acid), and W is the weight of the sample (g).

3.5 Ascorbic acid content (mg/100g pulp)

The titrimetric method described by (Ranganna, 1986) was followed for the estimation of ascorbic acid. Ten grams of homogenized pulp were transferred into a 100 ml volumetric flask, and the volume was made up using 4% oxalic acid solution. The mixture was allowed to stand for 30 minutes and then filtered through Whatman No. 1 filter paper.

Prior to titration, the dye solution 2,6-dichlorophenol indophenol was standardized by titrating it against a standard ascorbic acid solution to determine the dye factor.

A 5 ml aliquot of the filtrate was titrated with the standardized dye solution using a burette. Titration was continued until a light pink color persisted for approximately 15 seconds.

The ascorbic acid content in the sample was then calculated using the following formula.

$$\text{Ascorbic acid content} = \frac{T \times DF \times V}{A \times S} \times 100 \tag{3.3}$$

where T is the titrate, DF is the dye factor, V is the volume made up, A is the aliquot of extract taken for estimation, and S is the weight or volume of the sample taken for estimation.

3.6 Total sugars (%)

The filtrate obtained from the estimation of reducing sugars was used for the determination of total sugar. A 25 ml aliquot of the filtrate was taken and one fifth of its volume (5 ml) of hydrochloric acid (1:1) was added. The mixture was allowed to undergo inversion overnight at room temperature.

The following day, the solution was neutralized with 40% sodium hydroxide using phenolphthalein as an indicator, and the final volume was made up to 100 mL. This solution was then filtered through Whatman No. 1 filter paper and titrated against boiling Fehling's mixture as described earlier.

The percentage of total sugars was calculated using the following formula:

$$TS = \frac{GE}{T} \times \frac{V_t}{W} \times \frac{V_i}{A} \times 100 \tag{3.4}$$

where TS is the total sugar (%), GE is the glucose equivalent (0.05), T is the titre value (mL), V_t is the total volume made up (mL), W is the weight of pulp taken (g), V_i is the volume made up after inversion (mL), and A is the aliquot taken for inversion (mL).

3.6.1 Reducing sugar (%)

The titrimetric method of Lane and Eynon, as described by (Ranganna, 1986), was employed for the estimation of reducing sugars.

Invert sugar or reducing sugars reduce copper from Fehling's solution to form red, insoluble cuprous oxide. The sugar content in the sample is determined by measuring the volume of the unknown sugar solution required to completely reduce a known volume of Fehling's solution. Prior to analysis, Fehling's solution A and B (5 ml each) were standardized using standard glucose to obtain the glucose equivalent factor.

A 25 g portion of homogenized pulp was taken in a 250 ml volumetric flask, to which 2 ml of 45% basic lead acetate solution was added for clarification. After 10 minutes, the solution was deleaded by adding an excess of potassium oxalate crystals, and the volume was made up with distilled water. The solution was filtered through Whatman No. 1 filter paper. The filtrate was placed in a burette and titrated against boiling Fehling's mixture (5 ml Fehling's solution A and 5 ml Fehling's solution B) until a blue colour appeared. One millilitre of 1% methylene blue indicator was then added, and titration was continued until the solution attained a brick-red colour. The titre value at this point was recorded, and the percentage of reducing sugar was calculated using the following formula:

$$\%R_s = \frac{GE}{T} \times \frac{V_t}{W_p} \times 100 \tag{3.5}$$

where $\%R_s$ is the percentage of reducing sugar in the sample, GE is the glucose equivalent factor (g) with a value of 0.05 g, T is the titre value (mL) obtained from titration, V_t is the total volume of solution made up (mL), and W_p is the weight of pulp taken for analysis (g).

3.6.2 Non-reducing sugar (%)

The percentage of non-reducing sugars was determined by multiplying the difference between the total sugars and the reducing sugars by a factor of 0.95. The results were expressed as a percentage.

$$NR = (T - R) \times 0.95 \tag{3.6}$$

where NR is the non-reducing sugar (%), T is the total invert sugar (%), R is the reducing sugar (%), and 0.95 is the conversion factor.

4 Results and Discussion

This section presents the experimental findings obtained during the study and provides a comprehensive discussion of the observed results. The analysis focuses on interpreting key trends, variations, and their scientific implications.

4.1 Physical Dimensions and Mass

The average length, width, and thickness were 49.43 mm, 47.07 mm, and 46.03 mm, respectively, with standard deviations of 2.91 mm, 2.95 mm, and 2.85 mm. The average mass was 62.92 g with a standard deviation of 9.01 g. Sphericity values ranged from 0.90 to 1.00, with an average of 0.96 (SD = 0.02). The geometric mean diameter averaged at 47.46 mm (SD = 2.43 mm). The coefficient of friction ranged from 0.46 to 0.61, averaging at 0.54 (SD = 0.04) as shown in Table 1.

Table 1: Physical properties of fruit

Sr. No.	Length	Width	Thickness	Weight	Sphericity	GMD	Coefficient of Friction
1	53.2	51.7	50.3	85	0.97	51.72	0.53
2	53.9	52.9	41.8	59	0.91	49.21	0.59
3	50.4	47.4	46.4	84	0.95	48.04	0.54
4	45.1	42.1	44.5	69	0.97	43.88	0.51
5	46.8	44.9	46.0	62	0.98	45.89	0.49
6	52.0	50.4	44.5	71	0.94	48.86	0.47
7	50.6	50.3	46.7	54	0.97	49.17	0.53
8	54.4	50.6	43.2	72	0.90	49.18	0.56
9	54.7	51.8	53.8	62	0.98	53.42	0.54
10	52.9	49.6	46.2	64	0.94	49.49	0.58
11	55.2	51.5	46.8	78	0.92	51.05	0.52
12	55.3	51.4	53.3	67	0.96	53.31	0.51
13	52.0	49.9	44.8	68	0.94	48.80	0.56
14	49.4	48.3	44.3	65	0.96	47.28	0.58
15	53.5	46.7	47.3	60	0.92	49.07	0.54
16	47.5	45.6	44.9	78	0.97	45.99	0.46
17	51.0	47.9	45.5	53	0.94	48.08	0.49
18	50.5	48.2	46.6	50	0.96	48.41	0.51
19	52.2	48.8	47.0	60	0.94	49.29	0.59
20	47.7	46.2	46.7	62	0.98	46.86	0.51
21	47.1	44.0	50.0	60	1.00	46.97	0.58
22	44.0	42.0	45.0	54	0.99	43.65	0.52
23	48.6	45.9	50.6	89	0.99	48.33	0.57
24	48.1	47.3	44.4	65	0.97	46.57	0.56
25	49.4	44.4	46.6	72	0.95	46.76	0.53
26	54.2	52.7	55.1	72	1.00	53.99	0.57
27	49.9	47.8	44.3	58	0.95	47.28	0.59
28	48.5	46.8	44.4	61	0.96	46.54	0.61
29	48.1	44.8	46.6	53	0.97	46.48	0.59
30	46.5	45.4	42.0	68	0.96	44.59	0.58
31	49.1	48.5	42.1	60	0.95	46.46	0.53
32	47.6	45.1	44.7	71	0.96	45.78	0.54
33	49.0	48.5	48.7	63	0.99	48.73	0.60
34	53.1	50.7	46.6	62	0.94	50.06	0.54
35	48.3	44.7	43.3	59	0.94	45.39	0.53
36	46.2	44.8	45.0	57	0.98	45.33	0.58
37	48.8	48.7	42.8	57	0.96	46.68	0.51

Sr. No.	Length	Width	Thickness	Weight	Sphericity	GMD	Friction
38	48.7	47.8	47.9	66	0.99	48.13	0.58
39	49.6	46.7	46.6	56	0.96	47.61	0.51
40	49.1	48.1	45.1	53	0.97	47.40	0.52
41	48.6	42.7	45.5	58	0.94	45.54	0.57
42	45.5	44.9	45.4	56	0.99	45.27	0.49
43	46.6	46.1	46.0	55	0.99	46.23	0.52
44	47.6	42.0	42.6	59	0.92	44.00	0.56
45	45.8	41.9	41.9	50	0.94	43.16	0.52
46	46.7	46.5	45.7	57	0.99	46.30	0.58
47	46.1	43.6	44.9	67	0.97	44.86	0.57
48	47.6	44.6	46.3	52	0.97	46.15	0.53
49	46.8	45.7	45.2	55	0.97	45.89	0.56
50	47.9	44.6	45.8	58	0.96	46.07	0.55

Detailed property distributions and their correlations are illustrated in Figure 3.This distributions highlight the variability observed across all measured physical parameters. The correlation analysis further demonstrates the interdependence between key attributes.

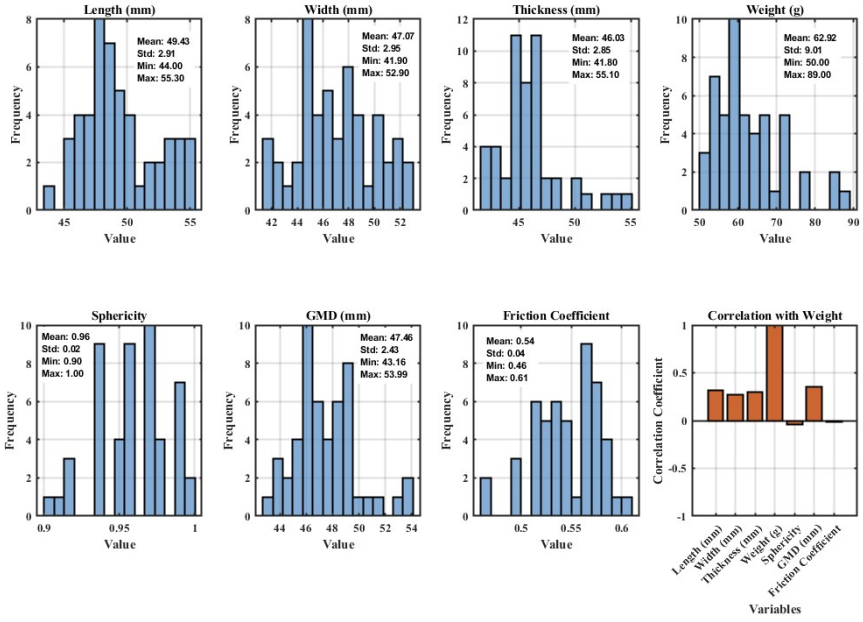

Figure 3: Detailed Property Distributions and Correlations

The fruits showed uniform dimensions (length, width, thickness, GMD 43–54 mm) with moderate weight variation (50–89 g). Strong correlations among dimensions and GMD confirm its reliability as a size indicator, while weight was moderately linked to dimensions as shown in Figure 4. The correlation matrix heatmap shows strong positive relationships among the dimensional properties of sapota fruits, indicating consistent growth patterns.

Length and width (r = 0.87) are highly correlated, suggesting that larger fruits tend to be proportionally broader, while thickness and geometric mean diameter (r = 0.72) also show a strong association. Weight exhibits moderate correlations with length and GMD, implying that heavier fruits are generally larger. In contrast, sphericity shows negative correlations with length (r = –0.49) and width (r = –0.22), indicating that elongated fruits tend to be less spherical. The friction coefficient shows negligible correlation with other parameters, suggesting that surface texture is largely independent of fruit size or shape. As shown in 3D scatter plot, the data points show a clustered distribution, indicating that most fruits have relatively similar size characteristics, with moderate variation in weight ranging from approximately 50 to 85 g. A gradual increase in weight is observed with increasing fruit dimensions, suggesting a positive correlation between fruit size and mass. However, the spread of points also indicates that some fruits with comparable dimensions differ in weight, likely due to variations in internal density or moisture content.Overall, fruits are dimensionally consistent, with GMD suitable for grading and sorting.

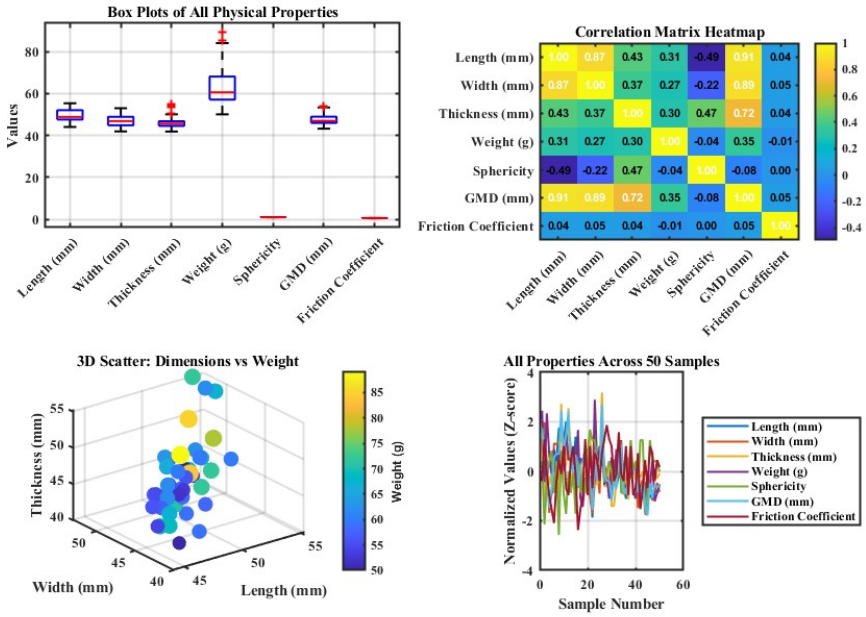

Figure 4: Comprehensive Analysis of Fruit Physical Properties

4.2 Bulk Density, Porosity, and True Density

The bulk density, porosity, and true density of the samples were found to be 444.29 kg/m^3, 0.52 (52%), and 925.60 kg/m^3, respectively, as presented in Table 2.

Table 2: Bulk Density, Porosity, and True Density of Samples

Sr. No.	Bulk Density (kg/m^3)	Porosity	True Density (kg/m^3)
1	442.70	0.49	926.38
2	444.87	0.54	924.69
3	445.29	0.53	925.71
Average	444.29	0.52	925.60
SD	1.39	0.03	0.85

4.3 Textural Properties

The puncture test showed a clear decline in peak force from 5.69 N on day 0 to 3.03 N on day 4, indicating progressive softening of the samples. Compression test results followed a similar trend, with peak force decreasing from 64.98 N to 32.30 N over the same period. Shear force measurements also reduced significantly from 25.42 N to 7.68 N as presented in Table 3. Coefficient of variation values generally increased with storage time, suggesting greater variability in texture as the samples aged.

Table 3: Puncture, Compression, and Shear Force Test Results

Day	Sample No.	Puncture Test		Compression Test		Shear Force	
		Peak force (N)	Avg $\pm$ SD (CV%)	Peak force (N)	Avg $\pm$ SD (CV%)	Peak force (N)	Avg $\pm$ SD (CV%)
00	1	5.65		65.14		23.68	
00	2	5.47	5.69 $\pm$ 0.24 (4.35)	62.36	64.98 $\pm$ 2.55 (3.92)	27.88	25.42 $\pm$ 2.19 (8.62)
00	3	5.96		67.45		24.69	
02	1	4.21		53.58		12.75	
02	2	4.65	4.29 $\pm$ 0.33 (7.63)	50.39	51.97 $\pm$ 1.60 (3.08)	15.36	13.88 $\pm$ 1.34 (9.65)
02	3	4.01		51.95		13.52	
04	1	3.25		35.65		7.98	
04	2	2.18	3.03 $\pm$ 0.76 (25.08)	31.65	32.30 $\pm$ 3.08 (9.54)	6.58	7.68 $\pm$ 0.98 (12.76)
04	3	3.65		29.59		8.47	

4.4 Physicochemical Properties

The physiological loss in weight (PLW) of sapota fruits increased progressively with storage duration. On day 0, PLW averaged 83.03 g (CV = 1.00%), while by day 4 it had declined to 65.90 g (CV = 9.00%), indicating substantial weight reduction due to moisture loss and metabolic activity. The coefficient of variation (CV) increased over time, suggesting greater reduction in weight loss among samples at later stages as shown in Table 4.

Spoilage status transitioned from ”edible” at day 0 and day 2 to advanced ripening by day 4, corresponding with increased enzymatic activity and softening. pH values exhibited a notable rise from an initial 4.89 (CV = 3.00%) to 6.59 (CV = 2.00%) by day 4, indicating progressive alkalization due to degradation of organic acids and accumulation of soluble metabolites during ripening and senescence. Standard deviation and CV values for pH were higher on day 2, reflecting variability in ripening rate among individual fruits.

The temporal variations in the physicochemical properties of the samples throughout the storage period are depicted in Figure 5.

Table 4: Physiological loss in weight (PLW), spoilage, and pH values over time

Day	Sample No.	PLW (g)			Spoilage	pH		
		Weight	SD	CV		pH value	SD	CV
00	1	83.02				4.89		
	2	82.62	1.46	0.01	Edible	4.95	0.03	0.03
	3	85.34				4.88		
02	1	74.68				5.09		
	2	74.21	1.48	0.01	Edible	5.45	0.18	0.03
	3	76.99				5.26		
04	1	65.90				6.59		
	2	65.47	0.59	0.90	Edible	6.78	0.13	0.02
	3	66.89				6.86		

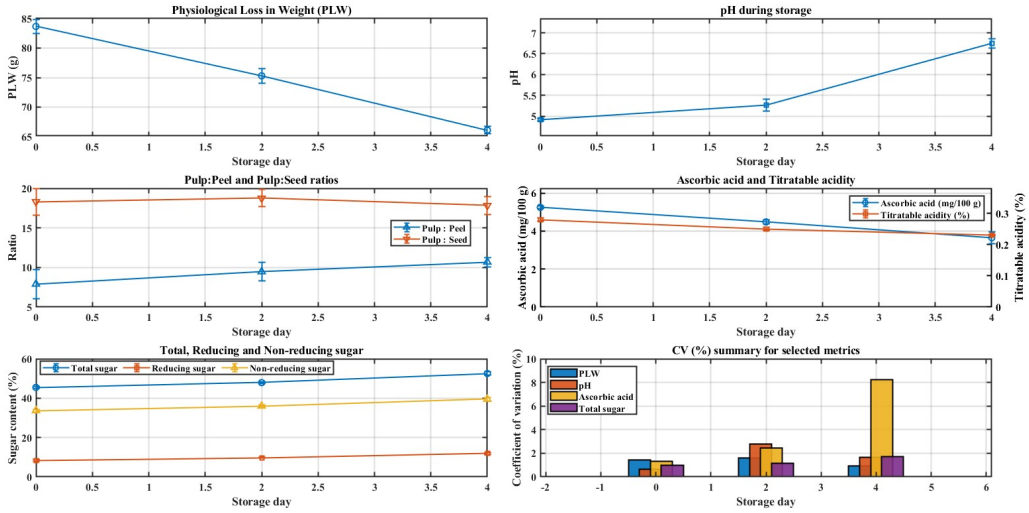

Figure 5: Storage study: Physicochemical changes

The pulp-to-peel ratio of sapota samples exhibited a progressive increasing during the storage period, indicating changes in fruit composition and potential quality deterioration over time. As shown in Table 5, on Day 0, the pulp-to-peel ratio was lowest, averaging approximately 8.04, with total fruit weight ranging from 92.52 g to 96.31 g and pulp weight constituting over 88.93% of the total weight. By Day 2, the pulp-to-peel ratio increased to approximately 9.47, accompanied by a reduction in both total and pulp weights. On Day 4, a further increase in ratio to approximately 10.75 was recorded, reflecting the smallest pulp weight and increased relative contribution of the peel. The standard deviation (SD) and coefficient of variation (CV) values for each storage day suggest the ratio increases is that the peel weight decreases faster relative to the pulp weight between measurements. In other words, over time, the proportion of the sample's weight made up by the pulp is increasing,

while the proportion made up by the peel is decreasing. This could be due to differences in moisture content or compositional changes in the two parts during the storage period.

Table 5: Pulp to peel ratio

Day	Sample no.	Total weight	Pulp weight	Peel weight	SD	CV	Pulp to peel ratio
00	1	92.52	81.98	10.54			
	2	92.35	82.46	9.89	0.28	0.03	8.04
	3	96.31	85.62	10.68			
02	1	84.76	76.36	8.40			
	2	85.34	77.14	8.20	0.41	0.04	9.47
	3	87.47	79.45	8.01			
04	1	76.90	70.11	6.79			
	2	78.33	72.32	6.01	1.12	0.10	10.75
	3	77.71	70.58	7.12			

The pulp to seed ratio (PSR) of sapota samples was assessed over three time points (Day 0, Day 2, Day 4) using three replicates per day. On Day 0, the mean PSR value is 18.39 as shown in Table 6. By Day 2, the PSR slightly increase to 19.20, suggesting minor changes in seed to pulp balance, possibly due to moisture migration or early ripening processes. On Day 4, the PSR declined to 18.17, indicating that the pulp proportion was relatively stable during the short storage period.

The standard deviation (SD) and coefficient of variation (CV) values across days were low (SD: 1.57–3.25; CV: 0.08–0.19), reflecting minimal variability among replicates and indicating consistent fruit morphology within the sampled batch. The stable PSR suggests that short-term storage under the studied conditions did not cause significant loss of pulp mass relative to seed weight.

Table 6: Pulp to seed ratio

Day	Sample no.	Total weight	Pulp weight	Seed weight	SD	CV	Pulp to seed ratio
00	1	92.52	81.98	4.86			
	2	92.35	82.46	4.12	1.57	0.08	18.39
	3	96.31	85.62	4.68			
02	1	84.76	76.36	3.96			
	2	85.34	77.14	4.98	3.67	0.19	19.20
	3	87.47	79.45	3.48			
04	1	76.90	70.11	4.53			
	2	78.33	72.32	4.19	3.25	0.17	18.17
	3	77.71	70.58	3.24			

The ascorbic acid content of sapota fruits showed a consistent decline during storage, decreasing from an initial average of 5.25 mg/100 g at day 0 to 4.48 mg/100 g by day 2, and further to 3.65 mg/100 g by day 4. The coefficient of variation (CV) increased from 0.01 to 0.10 over the storage period, indicating higher variability among samples as degradation progressed as shown in Table 7.

Titratable acidity also exhibited a gradual reduction, with mean values decreasing from 0.28 at day 0 to 0.25 at day 2 and 0.23 at day 4. Variability in acidity remained low throughout storage, with CV values under 0.02, reflecting relative uniformity among replicates despite

the decline.

Table 7: Ascorbic acid and Titratable acidity during storage

Day	Sample no.	Ascorbic acid				Titratable acidity			
		Value	Average	SD	CV	Value	Average	SD	CV
00	1	5.16				0.28			
	2	5.35	5.25	0.09	0.01	0.29	0.28	0.005	0.02
	3	5.25				0.28			
02	1	4.64				0.25			
	2	4.35	4.48	0.14	0.03	0.25	0.25	0.005	0.02
	3	4.47				0.26			
04	1	3.97				0.24			
	2	3.74	3.65	0.36	0.10	0.23	0.23	0.005	0.02
	3	3.25				0.23			

The total sugar, reducing sugar, and non-reducing sugar contents of sapota fruits showed a progressive increase during storage from day 0 to day 4. At day 0, the average total sugar content was 45.44% with a coefficient of variation (CV) of 1.0%, which increased to 47.88% on day 2 (CV = 1.0%) and reached 52.50% by day 4 (CV = 2.0%). Reducing sugars increased more sharply, from 8.40% (CV = 6%) at day 0 to 9.73% (CV = 1.59%) on day 2 and further to 11.84% (CV = 5%) on day 4. Similarly, non-reducing sugar content rose from 33.68% (CV = 2.0%) initially to 36.00% (CV = 1.0%) on day 2 and 39.45% (CV = 2.0%) on day 4 as shown in Table 8. The steady rise in all sugar fractions suggests ongoing carbohydrate metabolism during ripening, with starch and complex sugars being hydrolyzed into simpler forms. The increase in reducing sugar content was proportionally higher compared to non-reducing sugars, particularly after day 2, indicating active enzymatic conversion.

Table 8: Total sugar, Reducing sugar, and Non-reducing sugar during storage

Day	Sample no.	Total sugar				Reducing sugar				Non-reducing sugar			
		Value	Average	SD	CV	Value	Average	SD	CV	Value	Average	SD	CV
00	1	45.01				8.96				34.29			
	2	45.24	45.44	0.56	0.01	8.44	8.40	0.57	0.06	33.98	33.68	0.79	0.02
	3	46.08				7.82				32.78			
02	1	47.20				9.52				35.81			
	2	47.89	47.88	0.68	0.01	9.78	9.73	0.19	0.01	35.45	36.00	0.67	0.01
	3	48.56				9.89				36.75			
04	1	52.84				11.08				39.63			
	2	53.42	52.50	1.12	0.02	11.98	11.84	0.70	0.05	40.24	39.45	0.89	0.02
	3	51.25				12.47				38.48			

5 CONCLUSIONS

The complete analysis of the textural and physicochemical attributes of sapota provides an elaborate understanding of the quality factors of this tropical fruit. Attributes like total

sugar, titratable acidity, ascorbic acid content, pulp-to-peel ratio, physiological loss in weight, and mechanical characteristics determined by compression and puncture tests altogether render a strong characterization model. Physical characterization indicated that the samples had a geometry close to spherical (average sphericity 0.96) with uniform size distribution, average bulk density (444.29 kg/m^3), and high porosity (52%). Mechanical tests showed gradual softening through storage, as evidenced by pronounced decreases in puncture force (5.69 N to 3.03 N), compression force (64.98 N to 32.30 N), and shear force (25.42 N to 7.68 N) within four days. Higher coefficients of variation further indicated that the textural heterogeneity increased with storage time. Together, these results bring out the loss in firmness and homogeneity of the samples during post-harvest storage. Fruits of sapota showed incremental post-harvest loss of quality during storage, as evidenced by rising physiological loss in weight (PLW) along with noteworthy biochemical and compositional modifications. Weight loss was largely due to water loss and metabolic respiration, whereas simultaneous pH increases and ascorbic acid and titratable acidity losses indicated organic acid breakdown and loss of vitamin C. Pulp-to-peel ratio increases, reflecting relative deterioration, while pulp-to-seed ratio (PSR) stayed almost constant, indicating minimal short-term changes in fruit morphology. Softening of texture, as indicated by reducing puncture and compression forces, was in line with enzymatic action and breakdown of cell walls. Carbohydrate metabolism was reflected in a continuous increase in total, reducing, and non-reducing sugars, with a increase in reducing sugars on and after Day 2, which accounted for starch hydrolysis and sucrose inversion. Combined, these physicochemical and mechanical changes support accelerated ripening and senescence development within four days of storage, resulting in structural integrity loss, nutritional worth, and shelf-life stability.

Author Contributions

All authors contributed in different capacities to this work. This paper is derived from the departmental work supervised by the first and second authors. They all read and approved the final version of the paper.

Conflicts of Interest

The author declares no conflict of interest. / All authors declare no conflict of interest.

Ethical Review and Approval

No approval from the Board of Ethics is required.

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