

Physico-mechanical properties of sapota (*Achras sapota* L.)

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Abstract

Most of the sapota fruit processing methods employed is still traditional. It becomes imperative to characterize the fruits with a view to understand the properties that may affect the design of machines to handle their processing. Objectives of this study were to generate data for physical and mechanical properties of sapota fruit (cv. Kalipatti) in order to facilitate the design of some machines for its processing. The moisture content of sapota fruit was found to be 72 to 76% wb. The results showed that linear dimensions varied from 62.19 to 50.10 mm in length, 42.16 to 31.90 mm in width, and 41.42 to 27.40 mm in thickness. Average weight and volume of fruit were measured as 55.50 to 38.20 g and 587.7 to 408.3 cc, respectively. The bulk density, true density and porosity were 0.915 g/cc, 1.053 g/cc and 13.10%, respectively. The geometric mean diameter, sphericity and surface area were obtained as 41.81 mm³, 0.75, and 19715.81 mm², respectively. The average static coefficients of friction were measured as 0.20, 0.18, 0.12 and 0.15 on plywood, galvanized iron, glass and acrylic surfaces, respectively. The average peak cutting force, energy used for cutting, specific energy, ultimate cutting stress and deformation of fresh sapota was found to be 73.96 N, 228.42 N cm, 1.23 N/cm, 0.40 N/cm² and 3.18 cm, respectively. The average peak puncture force, energy used for puncture, specific energy, ultimate puncture stress and deformation of fresh sapota fruit was found to be 62.17 N, 25.50 N cm, 0.13 N/cm, 0.33 N/cm² and 0.42 cm, respectively.

Key words: Sapota fruit, dimensions, physical properties, post-harvest processing

Introduction

Design of machines and processes for harvesting, handling and storage of agricultural materials and for converting these materials into food and feed requires an understanding of their physical properties. Size and shape are most often used when describing grains, seeds, fruits and vegetables. Shape and physical dimensions are important in sorting and sizing of fruits, and determine how many fruits can be placed in shipping containers or plastic bags of a given size. Quality differences in fruits, vegetables, grains and seeds can often be detected by differences in density. When fruits and vegetables are transported hydraulically, the design fluid velocities are related to both density and shape. Volumes and surface areas of solids must be known for accurate modelling of heat and mass transfer during cooling and drying. Porosity, which is the percentage of air space in particulate solids, affects the resistance to air flow through bulk solids. Airflow resistance, in turn, affects the performance of systems designed for forced convection drying of bulk solids and aeration systems used to control the temperature of stored bulk solids. Knowledge of frictional properties is needed for design of handling equipment. Many researchers have conducted experiments to find the physical properties of various fruits and crops. Owolarafe and Shotonde (2004) determined some physical properties for okro fruit at a moisture content of 11.42% (wet basis). Akar and Aydin (2005) evaluated some physical properties of gumbo fruit varieties as functions of moisture content. Kashaninejad *et al.* (2006) determined some physical and aerodynamic properties of pistachio nut and its kernel as a function of moisture content in order to design processing equipment and facilities. Topuz *et al.* (2005) determined and compared several properties of four orange varieties. Also, Keramat Jahromi *et al.* (2007) obtained some physical properties of sapota.

The post-harvest mechanical properties data of fruits and vegetables are important in adoption and design of various handling, packaging, storage and transportation systems. The fruit compression tests simulate the condition of static loading that fruit can withstand in mechanical handling and storage. The most common practice to determine the fruit ripeness in field situation is pressing with ball of the thumb. Force deformation characteristics of fruits beyond the elastic limit may be important to simulate the destruction that occurs in bruising. Elastic modulus or Young's modulus is often used by engineers as an index of product firmness. Puncture tests are also measures of firmness of fruits and vegetables to estimate harvest maturity or post-harvest evaluation of firmness. Research has been carried out for several years to determine the resistance of fruits and vegetables to compression force. Witz (1954) reported resistance to bruising of potatoes to puncture by using a plunger. Studies on bruises to apples resulting from dropping and from application of pressure was reported by Gaston and Levin (1951). The objectives of this study were to determine physical properties of sapota (cv. Kalipatti) being the most preferred cultivar and physical properties data available is very limited. The development of the technologies will require knowledge of the properties of this fruit.

Materials and methods

For this study, the sapota fruit samples of Kalipatti cultivar were procured from the Department of Horticulture, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola by considering proper physiological maturity, uniformity, appearance and healthy fruits at random.

Moisture content: The moisture content of fresh sapota fruit was determined by using the method as proposed by Association

of official analytical chemist (1984). The averages of three replications were recorded as the moisture content. The moisture content of the sample was calculated using following equation:

$$MC(\%) = \frac{W_1 - W_2}{W_1} \times 100 \quad 1$$

where, W_1 and W_2 are mass of original sample and after drying samples in g.

Dimensions: The maximum tri-axial dimensions length (L), width (B) and thickness (T) of sapota fruit were measured from 10 randomly selected average size fruit using vernier caliper (Mitutoyo Made in Japan) having least count of 0.02 mm.

Size and sphericity : The size and sphericity of sapota fruit was determined by using following formulae.

$$S = (L \times B \times T)^{1/3} \quad 2$$

$$\text{Sphericity } (\Phi) = (LBT)^{1/3} / L \quad 3$$

Where, S is the size of sapota fruit (mm), L, B and T are length, width and thickness of fruit in mm, respectively.

Fruit weight: For determination of fruit weight 25 sapota fruits were randomly selected according to average size and then weighed using an electronic precision balance with accuracy of 0.005 g and their average weights were recorded as fruit weight.

Fruit volume and surface area: The volume was calculated by considering the geometry of the object similar to the geometrical shape. Knowing the values of length, width and thickness. The volume of the sapota fruit was calculated by considering the geometry as to be oblate spheroid by using following formula (Mohsenin, 1986).

$$V = \frac{4}{3}(\pi a^2 b) \quad 4$$

$$S = 2\pi a^2 + \pi(b^2/e) * \ln(1+e)/(1-e) \quad 5$$

Where, V is volume of sapota fruit (mm^3), S is surface area (mm^2) and e is eccentricity

$$e = \left[1 - \left(\frac{b}{a} \right)^2 \right]^{1/2}$$

Coefficient of friction: The coefficients of static friction were obtained with respect to three different surfaces, namely, galvanized iron, plywood and glass surfaces, by using an inclined plane apparatus as described by Dutta *et al.* (1988).

$$\mu = \tan \theta \quad 6$$

where, μ = Coefficient of friction, θ = Inclined angle ($^\circ$)

Bulk density: The bulk density of sapota fruit was determined by using following formula as suggested by Mohasnin (1986).

$$\rho_b = W/V \quad 7$$

where, ρ_b = bulk density (g/cc), W = weight of fruit (g) and V = volume of cylindrical container (cc).

True density: The true density of sapota fruit was determined by using toluene displacement method. Weight of single sapota fruit was taken with electronic precision balance with least count 0.005 g and fruit was immersed carefully into measuring cylinder partially filled with toluene. The volume of toluene displaced by the fruit was noted down. The true density was calculated by using following Eqn.

$$\rho_t = W/V_{td} \quad 8$$

where, ρ_t = true density, g/cc, V_{td} = volume of cylindrical container (cc).

Porosity: The porosity (ρ) was calculated from bulk and true densities using the relationship (Mohsenin, 1980, Fathollahzadeh *et al.*, 2009) as follows:

$$\rho = \frac{\rho_b}{\rho_t} \times 100 \quad 9$$

pH and total soluble solid: The pH and total soluble solid of sapota pulp was measured by using digital pH meter and refractometer.

Mechanical properties

Fruit cutting test: Blade set knife of the Texture Analyzer was attached to probe carrier. The cutter speed of 2 mm/s was used with 5 kg load cell. The load against depth of cut was recorded continuously. Sample data generated by a fruit cutting test. The average values of ten fruits were considered for determination of mechanical properties (Javead *et al.*, 2012). The peak cutting force were taken as the maximum peak force applied while fruit cutting respectively. The total fruit cutting energy was considered as the total area under the force-deformation curve. From these results the ultimate cutting stress and specific energy were calculated from the cut sectional areas as:

$$\tau_u = \frac{F_{sp}}{A} \quad 10$$

$$E_{ts} = \frac{E}{A} \quad 11$$

where, τ_u is the ultimate cutting stress (N/cm^2), F_{sp} is the peak cutting force, N and A is cut sectional area in the sample, cm^2

Puncture resistance: For measurement of puncture resistance, the Texture Analyzer was fitted with a 5 mm cylindrical probe to the probe carrier. Sapota was placed upon a flat plate. The test was carried out at the probe speed of 1 mm/s. The maximum force required to make the puncture on the fruit surface was taken from the force-deformation curve. The puncture resistance was measured with 10 fruits (replications) and average values are reported.

Results and discussion

The moisture content of sapota fruit samples was found to be in the range of 72-76 % wet basis.

Fruit size: The size of sapota fruit was determined from the measurement of its length, width and thickness. The length, width and thickness of sapota have been presented in Table 1 and found to vary in the ranges from 50.10 to 62.19, 31.90 to 42.16 and 27.40 to 41.42 mm, respectively. The mean values of fruit in terms of length, width and thickness were found to be 55.93, 37.18 and 35.35 mm, respectively. The shape of sapota fruit may be classified as Eleptical as per classification given by Mohsenin (1980).

Fruit volume: The average value of length, width and thickness also further decides the size which is taken as the apparent volume of sapota fruit. The volume of the sapota fruit was determined using mathematical expression as described in equation 3, 4 and the result obtained in Table 1. The fruit volume was found to

Table 1. Variation in length, width, thickness and volume of sapota

Particulars	Length (mm)	Width (mm)	Thickness (mm)	Volume (cc)	Fruit weight (g)	Pulp recovery (%)
Average	55.93	37.18	35.35	486.3	47.25	80.28
Range	50.10 to 62.19	31.90 to 42.16	27.40 to 41.42	408.3 to 587.7	38.20 to 55.50	73.85 to 84.45
SD	3.43	2.91	3.61	51.75	4.814	2.462

vary from 408.3 to 587.7 cc. The average volume of sapota was found to be 486.3 cc.

Geometric mean diameter, surface area and sphericity: The geometric mean diameter, sphericity and surface area varied from 37.77 to 45.84 mm, 0.61 to 0.84, and 15762 to 24288 mm², while mean values were 41.81 mm, 0.75, and 19715 mm², respectively.

Fruit weight: The weight of corresponding 25 fruits was recorded with the help of top pan balance (least count 0.01 g). The maximum weight of the sapota fruit was recorded to be 55.50 g, whereas, minimum was 38.20 g with their standard deviation of 4.81. The average weight of the fruit was 47.25 g (Table 1).

Pulp recovery: The weight of fruit pulp was measured after removing the skin; with the help of top pan balance (least count 0.01 g). The pulp weight per fruit was found to vary in 28.21 to 46.87 range with average value of 38.040 g and standard deviation of 4.930 9 (Table 1). It was also observed during the experiment that the sapota fruits having higher weight, had recorded better pulp recovery. The maximum pulp recovery of the sapota fruit was recorded to be 84.45 percent, whereas, minimum was 73.85 percent with the standard deviation of 2.462 (Table 1).

The average pulp recovery from the fruit was 80.28 percent. It was observed during the experiment that the sapota fruit having higher fruit weight recorded higher pulp weight, and better pulp recovery.

During experimentation it was observed that, fruit weight and its volume had some relationship. Hence, volume could be taken as a parameter for the estimation of fruit weight. The relationship between volume and weight of fruit is shown in Fig. 1 (a). Taking volume as a function of sapota fruit weight, the following 2nd degree polynomial equation was developed.

$$Y = 0.3182x^2 - 19.684x + 698.81 \quad (R^2 = 0.93) \quad 12$$

where, Y = fruit volume, cc; x = fruit weight, g and the constants of the equation are

As sapota fruit pulp recovery is also a function of sapota fruit weight, fruit weight can be taken as a parameter for the estimation of pulp recovery. The relationship between fruit weight and pulp recovery is shown in Fig. 1 (b). Taking pulp recovery as a function of the fruit weight, following 2nd degree polynomial equation was developed.

$$Y = -0.0105x^2 + 1.4576x + 35.085 \quad (R^2 = 0.85) \quad 13$$

where, Y = Pulp recovery, %; x = fruit weight, g and the constants of the equation are

Sapota fruit pulp recovery can also be related with fruit volume. Hence, volume can be taken as a parameter for the estimation of pulp recovery. The relationship between volume and pulp recovery is shown in Fig. 1 (c). Taking sapota fruit pulp recovery as a function of the volume, following 2nd degree polynomial equation was developed.

$$Y = -6E-05x^2 + 0.1009x + 45.513 \quad (R^2 = 0.78) \quad 14$$

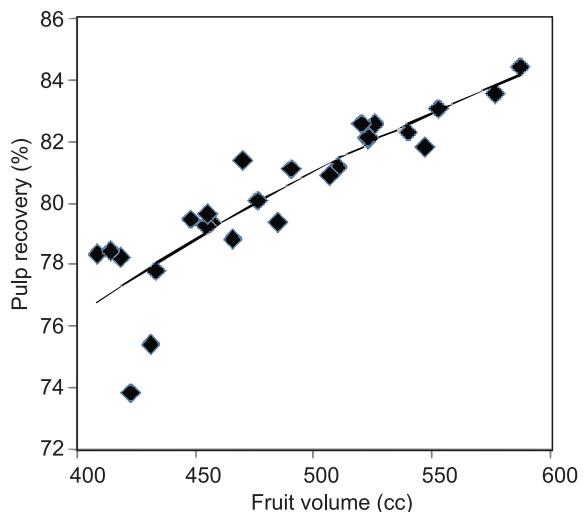
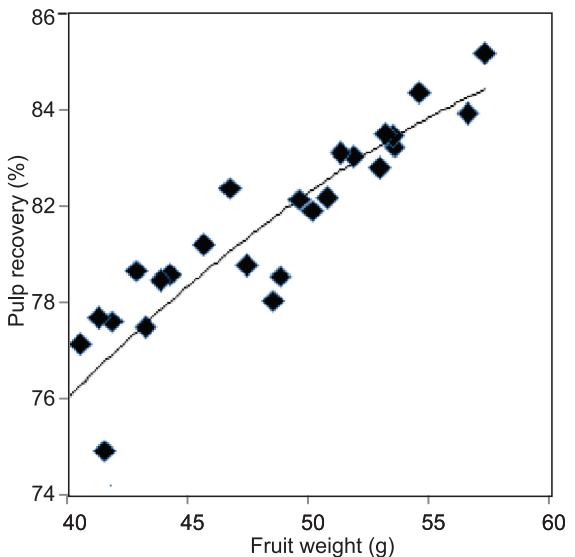
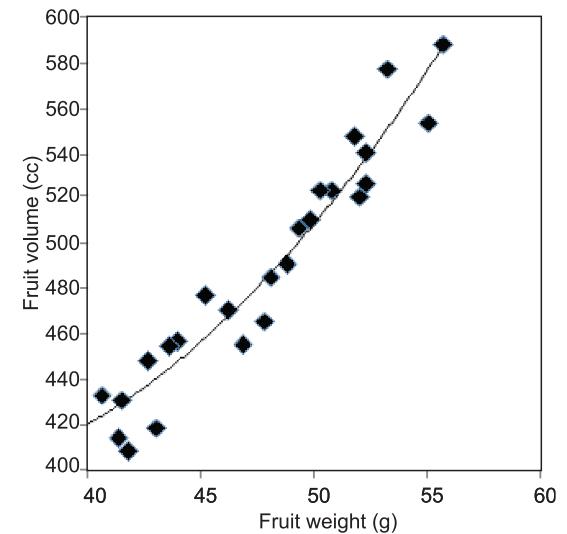


Fig. 1. Relationship between fruit volume and fruit weight, pulp recovery and fruit weight and pulp recovery and fruit volume

Table 2. Peak cutting force, energy used for cutting, specific energy and ultimate cutting stress of fresh sapota

Particulars	Peak cutting force (N)	Deformation (cm)	Energy used for cutting (N cm)	Ultimate Stress (N/cm ²)	Specific energy (N/cm)
Average	73.96	3.18	228.42	0.40	1.23
Range	50.79 to 94.90	2.80 to 3.80	192.99 to 265.73	0.24 to 0.50	0.93 to 1.39
SD	18.74	0.48	29.71	0.12	0.21

Table 3. Peak puncture force, energy used for puncture, specific energy and ultimate puncture stress of fresh sapota

Particulars	Peak cutting force (N)	Deformation (cm)	Energy used for cutting (N cm)	Ultimate Stress (N/cm ²)	Specific energy (N/cm)
Average	62.17	0.42	25.50	0.33	0.13
Range	48.18 to 84.47	0.18 to 0.61	15.07 to 45.14	0.23 to 0.49	0.05 to 0.08
SD	12.36	0.14	9.35	0.08	0.05

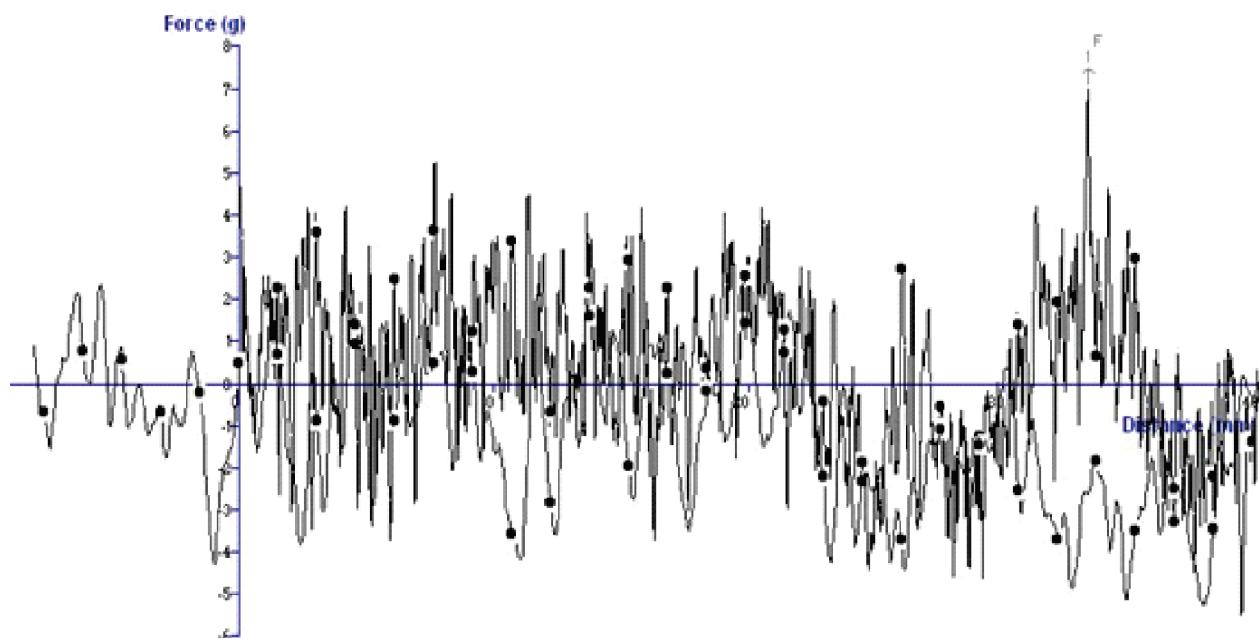


Fig. 2. Sample copy of graph of deformation vs cutting force

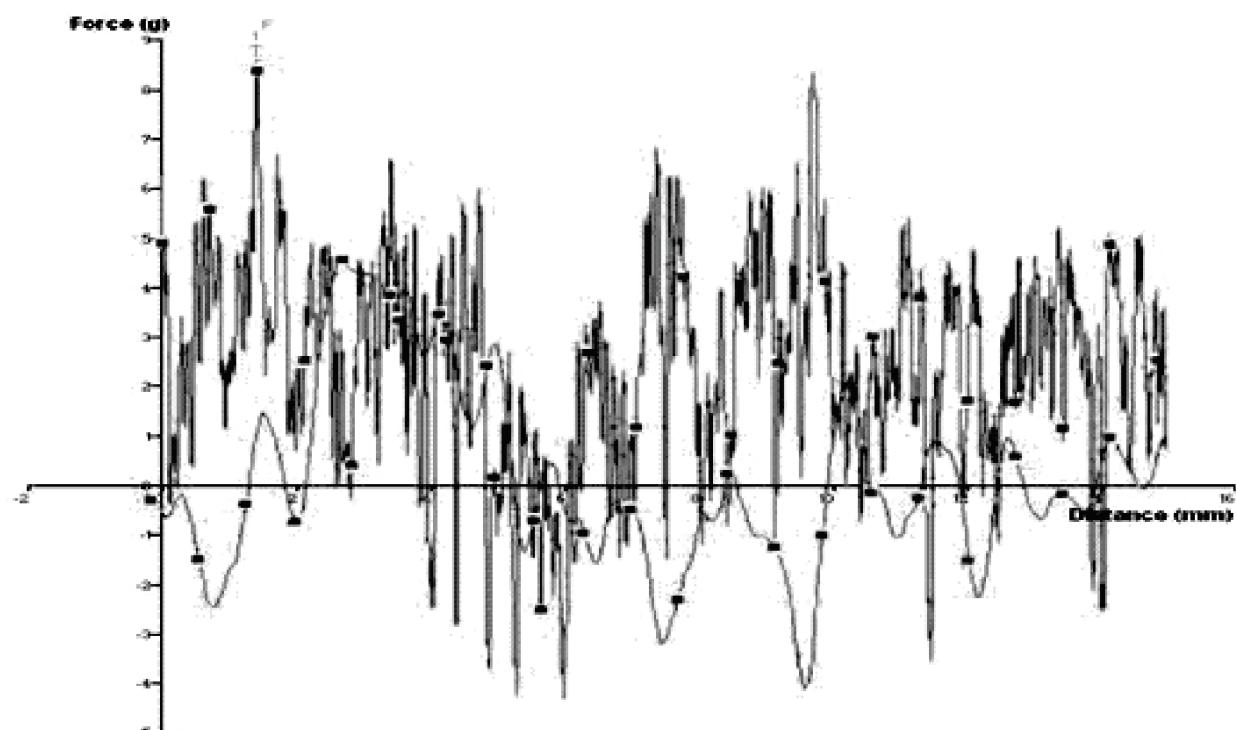


Fig. 3. Sample copy of graph of deformation vs puncture force.

where, Y = pulp recovery (%); x = fruit volume (cc)

From above equation (12, 13 and 14) it is observed that, sapota fruit weight can be taken as criteria for assessing pulp recovery than volume.

Bulk, true density and porosity: Whole fruit bulk density and true density was measured and found to be between 0.891 to 0.912 g/cc and 1.013 to 1.055 g/cc with average values of 0.915 and 1.053 g/cc, respectively. The porosity was found to be between 12.82 to 13.62% with average values of 13.10%

Coefficient of friction: Mean coefficient of static friction on plywood, galvanized iron, glass and acrylic surfaces was found to be 0.20, 0.18, 0.12 and 0.15, respectively. The static coefficient of friction on galvanized iron was higher than that on glass and lower than that of plywood surface. This is due to the frictional properties between the fruits and surface materials. These properties may be useful in the separation process and the transportation of the fruits. Similar results were reported by Patil *et al.* (2012) on mucuna bean and Shirkole *et al.* (2011) on soybean.

pH and total soluble solid: The average value of pH was found in the range of 5.2 to 5.7 and TSS was found in the range of 17 to 22 °B.

Mechanical properties

Fruit cutting test: Peak cutting force, energy used for cutting, specific energy and ultimate cutting stress of fresh sapota are presented in Table 2. The average peak cutting force, energy used for cutting, specific energy, ultimate cutting stress and deformation of fresh sapota was found to be 73.96 N, 228.42 N cm, 1.23 N/cm, 0.40 N/cm² and 3.18 cm, respectively. The actual sample graph of deformation verses fruit cutting force was plotted in Fig. 2. The trend of how much cutting force is required to cut the fresh sapota was obtained from Fig. 2.

Puncture resistance: Peak puncture force, energy used for puncture, specific energy and ultimate puncture stress of fresh sapota are presented in Table 3. The average peak puncture force, energy used for puncture, specific energy, ultimate puncture stress and deformation of fresh sapota was found to be 62.17 N, 25.50 N cm, 0.13 N/cm, 0.33 N/cm² and 0.42 cm, respectively. The force required to puncture the fresh sapota is shown in Fig. 3.

The physical properties such as geometric mean diameter, sphericity and surface area were obtained as 41.81 mm³, 0.75, and 19715.81 mm², respectively. The bulk density, true density

and porosity of fresh sapota were 0.915 g/cc 1.053 g/cc and 13.10%, respectively. The average peak cutting force, energy used for cutting, specific energy, ultimate cutting stress and deformation of fresh sapota was found to be 73.96 N, 228.42 N cm, 1.23 N/cm, 0.40 N/cm² and 3.18 cm, respectively is to be used for designing sapota peeler. The average peak puncture force, energy used for puncture, specific energy, ultimate puncture stress and deformation of fresh sapota fruit was found to be 62.17 N, 25.50 N cm, 0.13 N/cm, 0.33 N/cm² and 0.42 cm. The physical and mechanical properties are useful for designing processing equipments for sapota fruit.

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