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Engineering properties of cashew apple and nut in relation to design of cashew apple and nut separator

K. Manjunatha[1]*, D. Balasubramanian[1], Ravindra Naik[2] and J.D. Adiga[1]

[1]*ICAR–Directorate of Cashew Research, Puttur, D.K., Karnataka. 574 202.* [2]*ICAR–Central Institute of Agriculture Engineering, Regional Centre, Coimbatore. Pin-641003. *E-mail: manjunatha.k@icar.gov.in*

Abstract

Cashew, an important tree nut crop, presents a challenge in separating the nut from the soft and fibrous cashew apple at maturity. Understanding the engineering properties of cashew apple and nut is necessary to design a machine for separating these two. The present study is aimed to determine the physical, mechanical and frictional properties of cashew apple and nut in six varieties *viz.*, Bhaskara, Nethra Ganga, Ullal-3, Vengurla-7, Vengurla-4 and Dhana. The cashew apple and nuts' arithmetic and geometric mean diameters were 44.58 to 52.11 mm, 43.41 to 51.41 mm and 24.96 to 28.81 mm, 23.89 to 28.11 mm, respectively. The sphericity of the cashew apple was found to be in the range of 0.76 to 0.89, whereas that of nut ranged between 0.71 and 0.80. Bulk density of cashew apple ranged from 495.15 to 581.50 kg m^{-3}, whereas that of nuts ranged from 451.66 to 531.47 kg m^{-3}. The static coefficient of friction of cashew apple and nuts varied on different surfaces. The mean values of the compression test in longitudinal and lateral directions were found to be in the range of 80.54 to 179.38 N and 90.92 to 139.40 N. The shearing force was found to be in the range of 20.36 to 53.08 N and 26.52 to 40.46 N in longitudinal and lateral directions, respectively. Statistically significant differences were observed in the physical properties of cashew apple and nuts among the varieties. These findings would be pertinent for designing the post-harvest machinery in cashew.

Key words: Cashew apple, raw cashew nut, physical characteristics and bulk density

Introduction

The cashew (*Anacardium occidentale* L.) is a tropical evergreen tree native to North-Eastern Brazil's semi-arid coastal zones. Cashew trees are now grown predominantly for nuts in over 30 countries in the tropics and subtropics. After almonds and walnuts, cashews were the world's third most popular tree nuts in terms of production (Anon., 2020). Over the last three decades, raw cashew nut (RCN) output has rapidly gained popularity on a global scale. Globally, RCN production has increased drastically from 0.7 million tonnes in 1990 to 3.9 million tonnes in 2018 (UNCTAD, 2021). India was the leading producer of RCN from 2014 to 2018, with an annual average output of 745,000 tonnes, followed by Côte d'Ivoire (675,000 tonnes) and Vietnam (296,000 tonnes) (UNCTAD, 2021).

The cashew apple (hypocarp) is the true fruit of the cashew tree, consisting of a nut attached to a swollen stalk. As a result, cashew has distinct whole fruit (nut and cashew apple). Due to its soft and fibrous nature at maturity, separating the nut from the cashew apple after collecting the fruits is difficult. Typically, the cashew apple and nut are separated manually by twisting the nut with fingers, which is inefficient, time consuming, and labor intensive. The mature cashew apple has a short shelf life of about 1-2 days before rotting due to its rapid senescing metabolism (Singh *et al.,* 2019). The softening of the cashew apple and its fibres attached to the nut make hand separation difficult. Furthermore, there has been a significant increase in labor shortages and labor costs as a result of rural-urban migration. As a result, mechanization of the separation process is required to meet the cashew industry's growing demand. In order to design or modify the equipment needed for various post-harvest processing and operations such as sorting, grading, sizing, peeling, cutting, juice extraction, drying, storage *etc.*, it is essential to have a comprehensive technical knowledge of the physical, mechanical, and frictional properties of the cashew apple and nut (Singh *et al.,* 2019). The design and optimization of machinery components for the abovementioned operations requires understanding the specific properties of fruits and nuts to attain desired performance levels.

The physical and chemical properties of fruits of different fruit and nut crops have been investigated in the past, revealing each having unique characteristics. For instance, mechanical properties of the sweet passion fruit (Linares *et al.,* 2013), engineering properties of peach fruits (Tabatabaekoloor, 2013), physical and mechanical properties of Pear fruits and seeds (Davies, 2018), chemical and physico-mechanical properties of pear cultivars (Ozturk *et al.,* 2009), engineering properties of tomato (Jahanbakhshi *et al.,* 2019), physio-chemical properties of cashew apple (Anand *et al.,* 2015; Msoka *et al.,* 2017), physical, chemical, textural, and thermal properties of cashew apple fruit (Singh *et al.,* 2019), physical, mechanical and chemical properties of plums (Altuntas and Yaldiz, 2016), physical properties of raw cashew nut (Balasubramanian, 2001), physical and mechanical properties of cashew nut and kernel (Plange *et al.,* 2012). A vast amount of scientific literature is available concerning the physical, mechanical, thermal, textural and biochemical aspects of fruit and nut crops.

Despite great socio-economic importance, the machinery for post-harvest handling of cashew fruits, especially for separation of nut from cashew apple is lacking due to limited understanding of the physical, mechanical and gravimetric properties of cashew apple and nuts as whole (Deenanath *et al.,* 2015). Previously, a few studies were conducted on physical-chemical properties of either cashew apple or nuts separately and not as whole fruit (Balasubramanian, 2001; Anand *et al.,* 2015; Msoka *et al.,* 2017; Singh *et al.,* 2019). A comprehensive study of the engineering properties of both nut and cashew apple is required to design efficient cashew fruit and nut separator. Keeping this in mind, the current study focuses on understanding the major physical, mechanical and frictional properties of the cashew apple and corresponding nuts towards designing and developing machinery pertinent to apple and nut separator. This fundamental data generated in this study is also useful for designing various post-harvest equipment related to cashew apple and nut.

Materials and methods

Raw materials: The mature, ripened and fresh cashew apples along with nuts of six different varieties, namely Bhaskara, Nethra Ganga, Ullal-3, Vengurla-7 (V-7), Vengurla-4 (V-4) and Dhana (Fig. 1) were harvested and collected from the fields of ICAR-Directorate of Cashew Research, Puttur, Karnataka, India (12.45°N latitude, 75.15°E longitude and 90 m above MSL). Three trees were selected randomly from each variety, and 100 samples were collected from each.

Determination of physical properties: The three axial dimensions *viz.*, length (L), width (W) and thickness (T) of cashew apple and corresponding nuts were measured using Mitutoyo digital vernier caliper with the accuracy of ±0.02 mm and repeatability of 0.01 mm. Then, the arithmetic mean diameter (Da); geometric mean diameter (Dg); equivalent diameter (De); aspect ratio (Ra); surface area (SA); and sphericity(ϕ) were determined at 100 fruit repetitions through the equations (1-6), respectively (Singh *et al.,* 2019; Jahanbakhshi *et al.,* 2019; Panda *et al.,* 2020; Ozturk *et al.,* 2009; Pradhan *et al.,* 2012; Balasubramanian, 2001). Also, the mass of the fruits and nuts was measured using an Essae DS-252 electronic weighing balance (Essae-Teraoka Pvt. Ltd. Karnataka, India) with an accuracy of 0.5 g and the true density was determined by the toluene displacement method.

$$D_a = \frac{(L + W + T)}{3} \qquad (1)$$

Fig. 1. The mature and fresh cashew apples along with nuts of six

$$D_g = (L + W + T)^{1/3} \qquad (2)$$

$$D_e = \left[\frac{L(W + T)^2}{4}\right]^{\frac{1}{3}} \qquad (3)$$

The shape of the cashew apple and nut was determined by calculating the sphericity and aspect ratio of the fruit.

$$AR = \frac{W}{L} \qquad (4)$$

$$\phi = \frac{(L \times W \times T)^{1/3}}{L} \qquad (5)$$

Where L, W, and T represent length, width, and thickness (mm), respectively.

The surface area of a cashew apple is similar to a conical-obovate; the nut resembles kidney shape and is given by the following:

$$SA = \pi\, (D_g)^2 \qquad (6)$$

Where, SA-surface area (mm^2).

Determination of gravimetric parameters: The electronic balance was used to determine the thousand-unit mass (m_{1000}). To determine this parameter, 100 fruits and nuts were chosen at random, weighted and then multiplied by ten. The results represent the average of three repetitions.

True density (r_t) and volume were determined by the use of the toluene(C_7H_8) displacement method because of its low absorptivity (lower surface tension) to the sample. The sample was dropped from a certain height into a 1000 mL cylindrical container and the volume of displaced liquid from the container was taken as the volume of the sample and mass of the samples were also taken on the electronic weighing balance (Mohsenin, 1986).

$$\rho_t = \frac{m_f}{V_f} \qquad (7)$$

Where m_f is the mass of the sample in an open atmosphere and V_f is the volume of displaced toluene.

The bulk density (r_b) is computed as the ratio of the mass of the bulk samples to the volume of the container. It was determined by filling the rectangular-shaped box with samples, striking the top level and container weight was recorded (Rafiee *et al.,* 2007; Isa and Aderotoye, 2017).

$$\rho_b = \frac{m_f}{V_b} \qquad (8)$$

The porosity of fruit is defined as the ratio of inter-granular voids to the total space occupied by the fruit and it was calculated by the following equation as suggested by Panda *et al.* (2020).

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \qquad (9)$$

Where ε-porosity (%); ρ_b-bulk density (kgm^{-3}); and ρ_t-true density (kg m^{-3}).

Determination of frictional parameters: The static coefficient of friction of cashew apple and nuts varied on different base surfaces, *viz.*, stainless steel, aluminum sheet, galvanized sheet, mild steel, glass and plywood. The experiment was carried out using a friction device with a tilting platform, in which the samples were kept on the upper side of the friction material, which was gradually inclined up to a specific angle at which the samples started rolling. The angle was measured and the tangent of the friction angle gave the coefficient of static friction for the samples on the corresponding surfaces. The coefficient of friction was calculated from Equation 10 (Panda *et al.,* 2020; Mansouri *et al.,* 2017).

$$\mu = \tan \theta \quad (10)$$

Where, μ-coefficient of friction and θ-tilt angle (degree).

Determination of mechanical properties: To determine the mechanical properties of the cashew apple, the compression and shear tests were performed by means of a TA.HD. Plus Textural Analyzer. The equipment settings were as follows: the product distance was set at 15 mm and the pre-test, test speed and post-test speeds were kept at 1 mms^{-1}, 2 mms^{-1} and 10 mms^{-1}, respectively. For compression test a cylindrical probe with a diameter of 75 mm was used at a speed of 2 mm $s^{-1}$and for the shear test, a straight edge blade with a thickness of 1.4 mm and a blade angle of 30° was used at a testing speed of 2 mm s^{-1}. The Textural Analyzer was simultaneously connected to a computer and the force deformation curve was recorded in real time. All the tests were done at the fruit maturity stage, representing an average of three repetitions (Jahanbakhshi *et al.,* 2019; Singh *et al.,* 2019; Linares *et al.,* 2013; Li *et al.,* 2011).

Statistical analysis: Microsoft Office Excel 2019 was used to determine statistical indices such as maximum, minimum, mean and standard deviation values (SD) for physical, frictional and mechanical properties. All of the experiments were carried out in triplicate and the data for the various measured parameters are reported as mean ± SD except otherwise specified. Using R software, Duncan's multiple range test (DMRT) was carried out to determine critical values for comparison between means.

Results and discussion

The Cashew tree has a unique whole fruit consisting of nut (True fruit) borne attached to the cashew apple (hypocarp/false fruit). Each component, *i.e.*, nut and cashew apple, has different physical and biochemical properties. Separation of these two after the collection of fruits is difficult due to the soft and fibrous nature of matured apple. Mechanization for separation requires understanding the engineering properties of nut and cashew apple. Here, we describe the results of the evaluation of engineering properties of these and discuss their role in the mechanization of the separation as well as other post-harvest handling of the cashew fruits.

Physical parameters: The different physical and gravimetric properties of selected varieties of cashew apple and nut such as length, width, thickness, weight, arithmetic mean diameter, geometric mean diameter, equivalent mean diameter, aspect ratio, surface area, sphericity, bulk density, true density and porosity were analyzed and are presented in Table 1 and 2. The three principal dimensions like length, width and thickness are critical for designing cashew fruit and nut separator. The results showed that the average length, width and thickness of the freshly harvested cashew apple and nut ranged from 54.15±6.03 to 60.74±5.75 mm, 40.62±5.32 to 50.77±5.72 mm, 35.63±5.03 to 44.81±5.08 mm and 32.88±2.04 to 38.27±1.81 mm, 23.97±1.79 to 27.22±1.83 mm, and 16.83±1.04 to 23.93±1.41 mm, respectively. Fig. 2 (a&b) depicts a frequency distribution graph for the cashew apple and nut length, width and thickness. Thus, according to Fig. 2 (a&b), all three dimensions have the highest frequency at their respective fourth and fifth intervals. The graph's narrower and higher peaks indicated that the average values of all dimensions were skewed toward the normal distribution. Similarly, the average values of l (50.34mm), w (42.78 mm) and t (36.08mm) of the cashew apple fruit was reported by Singh *et al.* (2019). The mean values of l, w and t for raw cashew nuts were 31.00, 22.86 and 16.91 mm, respectively (Balasubramanian, 2001).

The cashew apple and nut average weights ranged from 41.32±12.81 to 72.20± 17.73 g and 7.14± 1.16 to 11.24±1.19 g, respectively. The average diameters of cashew apple and nut are useful to decide the aperture size of the fruit and nut separator sieve. The arithmetic mean diameter of the cashew apple varied between 44.58±5.22 to 52.1±4.77 mm. However, for nuts it varied from 24.96±1.39 to 28.81±1.11 mm. The geometric mean diameter of the cashew apples was determined to be 43.41±5.18 to 51.41±4.72 mm with Ullal-3 having the highest and V-4 having the lowest. However, for nuts, it varied between 23.89±1.28 to 28.11±1.13 with Nethra Ganga and Bhaskara variety having the highest and lowest values, respectively. The average equivalent diameter of the cashew fruit and nut were found to be in the range of 43.56±5.17 to 51.56±4.75 and 24.18±1.33 to 28.15±1.14 mm,

Table 1. Physical properties of cashew apple (Mean ± SD)

Physical Parameters	Bhaskara	Nethra Ganga	Ullal-3	V-7	V-4	Dhana
Length, mm	54.15^{b}±6.03	57.48^{ab}±4.92	60.74^{a}±5.75	55.44^{b}±5.56	57.50^{ab}±7.12	58.69^{ab}±5.74
Width, mm	43.16^{cd}±4.94	47.69^{ab}±4.02	50.77^{a}±5.72	49.10^{ab}±5.56	40.62^{d}±5.32	46.0^{bc}±4.10
Thickness, mm	39.70^{bc}±4.81	44.46^{a}±4.60	44.81^{a}±5.08	44.23^{ab}±4.25	35.63^{c}±5.03	41.96^{ab}±3.96
Weight, g	53.16^{cd}±16.39	69.33^{ab}±14.21	72.20^{a}±17.73	66.68^{abc}±17.29	41.32^{d}±12.81	55.82^{bcd}±13.91
Arithmetic mean diameter, mm	45.67^{bc}±4.84	49.88^{ab}±3.76	52.11^{a}±4.77	49.59^{ab}±4.53	44.58^{c}±5.22	48.88^{ab}±4.11
Geometric mean diameter, mm	45.05^{bc}±4.82	49.32^{ab}±3.74	51.41^{a}±4.72	49.12^{ab}±4.45	43.41^{c}±5.18	48.16^{ab}±4.06
Equivalent diameter, mm	45.13^{bc}±4.82	49.41^{ab}±3.74	51.56^{a}±4.75	49.23^{ab}±4.51	43.56^{c}±5.17	48.23^{ab}±4.05
Aspect ratio	0.79^{bc}±0.072	0.83^{bc}±0.065	0.84^{ab}±0.079	0.89^{a}±0.076	0.71^{d}±0.075	0.79^{c}±0.06
Sphericity	0.83^{b}±0.05	0.86^{ab}±0.05	0.85^{b}±0.05	0.89^{a}±0.05	0.76^{c}±0.05	0.82^{b}±0.04
Surface area, mm^2	6376.63^{bc} ±1397.67	7641.29^{ab} ±1153.35	8303.42^{a} ±1543.96	7580.95^{ab} ±1396.86	5920.33^{c} ±1424.95	7285.29^{ab} ±1238.80
Bulk density, kg m^{-3}	520.67^{abc}±10.88	581.50^{a}±7.0	495.15^{c}±10.96	575.67^{ab}±24.29	519.19^{bc}±17.83	527.99^{abc}±21.95
True density, kg m^{-3}	1047.78^{a}±84.0	1133.64^{a}±18.11	1024.28^{a}±59.42	1094.29^{a}±64.97	1127.43^{a}±48.24	1013.33^{a}±23.09
Porosity, %	50.10^{a}±4.01	48.69^{a}±1.42	51.58^{a}±2.11	47.34^{a}±1.87	53.85^{a}±3.51	47.90^{a}±1.42

Different letters indicate significant differences at $P < 0.05$ between treatments within the same factor.

Table 2. Physical properties of raw cashew nut (Mean ± SD)

Physical Parameters	Bhaskara	Nethra Ganga	Ullal-3	V-7	V-4	Dhana
Length, mm	33.75^{bc}±2.20	35.32^{b}±1.71	34.89^{b}±2.05	38.27^{a}±1.81	33.14^{c}±2.43	32.88^{c}±2.04
Width, mm	24.31^{b}±1.78	26.59^{a}±1.50	27.22^{a}±1.83	26.70^{a}±1.04	23.97^{b}±1.79	25.01^{b}±1.46
Thickness, mm	16.83^{e}±1.04	23.93^{a}±1.41	20.94^{bc}±1.69	21.46^{b}±1.36	18.76^{d}±1.64	19.97^{cd}±1.62
Weight, mm	7.14^{c}±1.16	10.86^{a}±1.34	10.21^{a}±1.37	11.24^{a}±1.19	7.67^{bc}±1.59	8.59^{b}±1.26
Arithmetic mean diameter, mm	24.96^{b}±1.39	28.61^{a}±1.16	27.68^{a}±1.50	28.81^{a}±1.11	25.29^{b}±1.69	25.95^{b}±1.42
Geometric mean diameter, mm	23.89^{c}±1.28	28.11^{a}±1.13	26.97^{a}±1.50	27.88^{a}±1.08	24.50^{bc}±1.63	25.32^{b}±1.38
Equivalent diameter. mm	24.18^{b}±1.33	28.15^{a}±1.14	27.15^{a}±1.49	28.0^{a}±1.07	24.64^{b}±1.63	25.43^{b}±1.39
Aspect ratio	0.72^{c}±0.037	0.75^{b}±0.038	0.78^{a}±0.032	0.69^{d}±0.028	0.72^{c}±0.041	0.76^{ab}±0.026
Sphericity	0.71^{d}±0.02	0.80^{a}±0.02	0.77^{b}±0.02	0.73^{c}±0.02	0.74^{c}±0.03	0.77^{b}±0.02
Surface area, mm^2	1799.21^{c}±193.57	2485.90^{a}±199.32	2293.36^{a}±248.41	2445.79^{a}±188.66	1895.38^{bc}±243.13	2019.23^{b}±219.44
Bulk density, kg m^{-3}	531.47^{a}±7.91	451.66^{b}±15.50	481.89^{b}±23.04	462.54^{b}±1.81	497.61^{ab}±12.08	495.80^{ab}±6.37
True density, kg m^{-3}	1108.60^{a}±16.24	1116.04^{a}±23.37	1228.06^{a}±49.01	1211.41^{a}±24.64	1177.41^{a}±67.56	1212.64^{a}±19.64
Porosity, %	52.05^{b}±0.85	59.50^{a}±2.14	60.75^{a}±1.55	61.81^{a}±0.68	57.62^{ab}±3.05	59.11^{a}±0.96

Different letters indicate significant differences at $P < 0.05$ between treatments within the same factor.

respectively. These average diameters help estimate the aperture size for designing separation equipment (Vivek *et al.,* 2018). The obtained results of the average diameters of cashew apples were found to be higher than tomato (Jahanbakhshi *et al.,* 2019) and pear fruit (Ozturk *et al.,* 2009; Davies, 2018) but less than apricot fruit (Ahmadi *et al.,* 2009).

Fruit aspect ratio and sphericity values aid in determining fruit shape and flowability characteristics. The cashew apple aspect ratio ranged from 0.71±0.075 to 0.89±0.076. In the case of nuts, it ranged from 0.69±0.028 to 0.78±0.032. The sphericity of the cashew apple was found to be in the range of 0.76±0.05 to 0.89±0.05 resembled a conical-obovate, whereas the nut resembled a kidney shape having sphericity value ranged between 0.71±0.02 to 0.80±0.02. The high sphericity values indicate that the fruit tends to roll rather than slide on specific surface (Vivek *et al.,* 2018). The sphericity values aid in the design of separators and the sizing of equipment, whereas the aspects ratio indicates how oblong the fruit is (Singh *et al.,* 2019). The surface area of the cashew apple and nut was determined as a function of the linear dimensions. It was observed that, Ullal-3 having the highest surface area value (8303.42±1543.96 mm^2) while V-4 has the lowest value of 5920.33±1424.95 mm^2. However, the surface area of nuts varied from 1799.21±193.57 to 2485.90±199.32 mm^2. The surface area obtained for the cashew apple was found to be smaller than that of the pear fruit (Ozturk *et al.,* 2009).

Table 3. Frequency distribution of cashew apple and raw cashew nut

	Raw cashew nut							Raw cashew nut					
Range	Length						Range	Length					
	Bhaskara	Nethra Ganga	Ullal-3	V-7	V-4	Dhana		Bhaskara	Nethra Ganga	Ullal-3	V-7	V-4	Dhana
40-45	5	0	0	2	1	0	24-27	0	0	1	0	4	0
45-50	23	6	2	15	14	8	27-30	4	0	2	0	4	8
50-55	30	27	14	29	28	19	30-33	35	7	15	2	33	43
55-60	23	35	35	34	23	33	33-36	42	59	48	7	51	45
60-65	12	24	26	14	18	26	36-39	16	32	32	53	8	3
65-70	6	7	14	5	11	9	39-42	3	2	2	36	0	0
70-75	1	1	7	1	3	4	42-45	0	0	0	2	0	1
75-80	0	0	2	0	2	1	24-27	0	0	1	0	4	0
	Width							Width					
20-25	0	0	0	0	0	0	20-22.5	12	1	3	0	20	4
25-30	1	0	0	0	17	0	22.5-25	62	10	13	5	53	47
30-35	22	0	2	0	37	7	25-27.5	22	66	34	76	26	44
35-40	38	20	7	10	29	38	27.5-30	3	22	44	19	1	5
40-45	24	42	22	36	17	40	30-32.5	0	0	6	0	0	0
45-50	12	33	39	34	0	12	32.5-35	1	0	0	0	0	0
50-55	3	3	20	17	0	3	35-37.5	0	1	0	0	0	0
55-60	0	2	10	3	0	0	20-22.5	12	1	3	0	20	4
	Thicknes							Thickness					
20-25	0	0	0	0	3	0	11-13.5	1	0	1	0	1	0
25-30	2	0	0	0	15	0	13.5-16	23	0	0	0	9	0
30-35	17	3	3	1	27	6	16-18.5	71	0	6	1	26	17
35-40	38	14	18	19	35	23	18.5-21	5	2	40	34	57	64
40-45	29	33	31	40	18	47	21-23.5	0	36	51	60	7	18
45-50	9	45	27	25	2	21	23.5-26	0	54	2	4	0	1
50-55	5	3	17	12	0	3	26-28.5	0	8	0	1	0	0
55-60		1	4		0	0	11-13.5	1	0		0	1	

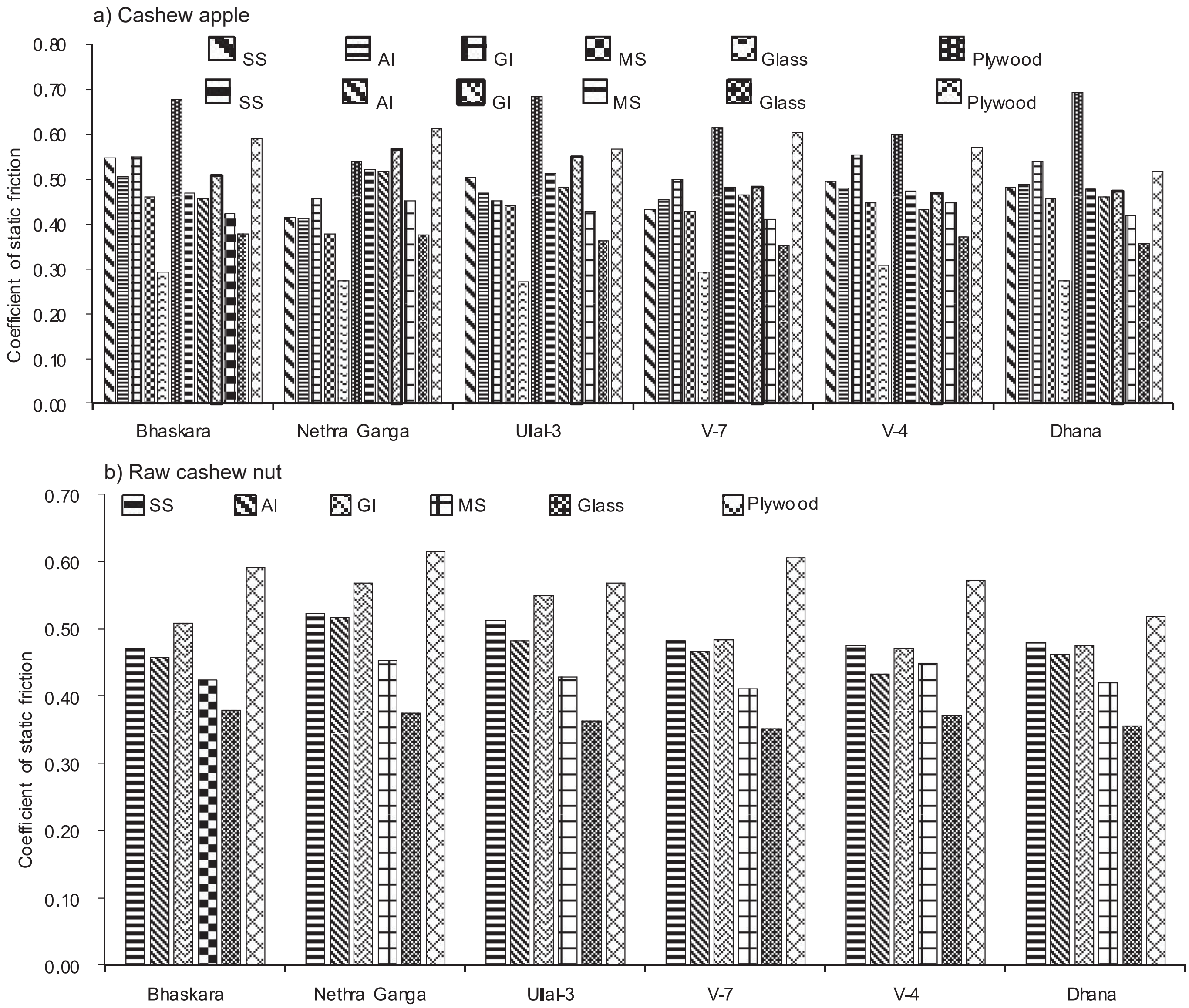

Fig. 3. Coefficient of static friction of cashew apple and nut .

The statistical analysis revealed that the physical characteristics factors were significant (P0.01) at the 1% significance level. The mean comparison of data using Duncan's test also revealed that the parameters considered under physical characteristics were significantly different among the six varieties.

Gravimetric parameters: The bulk density of cashew apple was found to be maximum for Nethra Ganga (581.50±7.0 kg m^{-3}) and minimum for Ullal-3 variety (495.15±10.96kg m^{-3}). The bulk density of cashew apple was higher than the pear fruits (Ozturk *et al.,* 2009; Davies, 2018). The true density of the cashew apple ranged from 1013.33±23.09 to 1133.64±18.11 kg $m^{-3,}$ whereas corresponding values of bulk density and true density of nuts ranged from 451.66±15.50 to 531.47± 7.91 kg m^{-3} and 1108.60±16.24 to 1228.06±49.01 kg m^{-3} respectively. The porosity of cashew apple was observed to vary between 47.34±1.87 to 53.85±3.51 percent, while the values for nut varied between52.05±0.85 to 61.81±0.68 %, respectively. The porosity results obtained for cashew apple were lower than the pear fruits (Ozturk *et al.,* 2009).

Frictional parameters: Static coefficient of friction of cashew apple and nuts varied on different base surfaces *viz.*, SS, GI, MS, Al, glass and plywood. The static coefficient of friction value for cashew apple was found to be highest for plywood and lowest in case of glass for all the selected varieties (Fig. 3a). The values obtained for the plywood were 0.541 to 0.695 and for glass 0.272 to 0.310. A similar trend was observed for raw cashew nuts (Fig. 3b). Because of its smooth and polished surface, the glass had the least friction. Understanding the coefficient of friction is a key factor in designing the fruit and nut separation module, conveyor and hopper of the fruit and nut separator machine. Due to the elliptical nature, all surfaces have high rolling resistance (Singh *et al.,* 2019).

Mechanical parameters: Texture profile analysis (TPA), as depicted in Fig. 4, was used to determine the mechanical properties of cashew apple, such as compression and shear tests. The mean values of the measured properties in the compression test (maximum force required to crush the cashew apple) in both longitudinal and lateral directions were found to be in the range of 80.54±12.46 to 179.38±14.51 N and 90.92±7.26 to 139.40±1.09 N. The mean values of the measured properties in the shearing test (maximum force required to shear the cashew apple) in both longitudinal and lateral directions were found to be in the range of 20.36±1.88 to 53.08±8.07 N and 26.52±4.50 to 40.46±9.53N. The average cutting force obtained for the cashew apple was

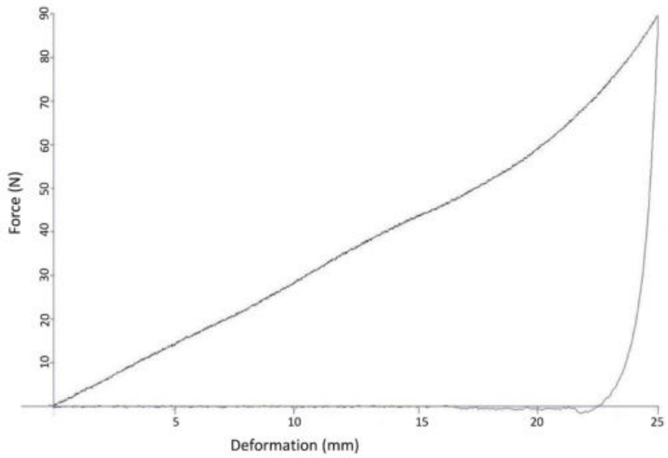

Fig. 4. Force/deformation curve for a cashew apple specimen under compression test

lower than for the sapota fruit (Gupta *et al.,* 2015). The typical force/deformation curve for a cashew apple specimen under compression test and shearing test is shown in Fig. 4.

Aside from the importance of studying physical, mechanical and frictional characteristics for designing the cashew fruit and nut separator, these properties are used to develop the machinery and equipment used during harvest and post-harvest operations. It was found that the mean axial dimensions varied widely among the varieties, with large standard deviations and also the frequency distribution graph of the axial dimensions indicated that all three dimensions have the highest frequency at their respective fourth and fifth intervals. The cashew apple shape resembled to be a conical-obovate whereas the nut resembled as kidney shape. Static coefficient of friction of cashew apple and nuts varied on different base surfaces.

In examining mechanical properties, the mean values of the measured properties in the compression test in both longitudinal and lateral directions were found to be in the range of 80.54±12.46 to 179.38±14.51 N and 90.92±7.26 to 139.40±1.09 N. Whereas, in the shearing test it was found to be in the range of 20.36±1.88 to 53.08±8.07 N and 26.52±4.50 to 40.46±9.53N in both longitudinal and lateral directions. This fundamental data is also useful for designing and developing various post-harvest equipment related to cashew apple and nut.

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