https://doi.org/10.17221/83/2021-RAE

Engineering properties of the cashew nut in context of designing post-harvest handling and processing machinery

Arie Sudaryanto, Dadang Dayat Hidayat, Diang Sagita, Ashri Indriati, Ari Rahayuningtyas*

Research Center for Appropriate Technology, National Research and Innovation Agency, Subang, Indonesia

**Corresponding author: diang.sagita@gmail.com*

Citation: Sudaryanto A., Hidayat D.D., Sagita D., Indriati A., Rahayuningtyas A. (2022): Engineering properties of the cashew nut in context of designing post-harvest handling and processing machinery. Res. Agr. Eng., 68: 201–209.

Abstract: The determination of the engineering properties of the cashew nut is essential as the basis for the design and development of appropriate and optimum post-harvest handling and processing machinery. The present study was conducted to examine the physical, mechanical and colour properties of cashew nuts (n = 100) at a moisture content of 7.63% (wet basis) which were derived from Central Java, Indonesia. The main characteristics included the length, width, thickness, mass, volume, and density. The derivative properties consisted of the geometric diameter, arithmetic diameter, surface area, frontal surface area, transverse area, shape index, sphericity, bulk density, and porosity. The mechanical properties included the static friction, static and dynamic angle of repose, and compressive load (in four orientations). It was identified that the cashew nut from Central Java was dominant with a small-medium size with an average mass of 5.42 ± 0.99 g. This cashew nut was thicker, but shorter in length than the cashew nuts from India, Nigeria, and Ivory Coast. The results of the stepwise regression analysis determined that the volume had the most substantial relationship with the mass (R^2 = 0.949), the bulk density had the highest correlation with the mass (R^2 = 0.968), and the porosity showed a high correlation with the true density and mass (R^2 = 0.997). The highest friction, static angle of repose, and-dynamic angle of repose occurred on the surface plywood, and the lowest was on the stainless-steel surface. In the context of designing appropriate cashew nut cracking equipment, it was recommended to provide the impact parallel to the longitudinal axis orientation due to the minimum compressive load (reduce the power requirement). Furthermore, the cashew nut colour properties of the L^*, a^*, b^* coordinates were 35.988, 0.427, 1.718, respectively.

Keywords: angle of repose; appropriate technology; compressive load; physical properties

The cashew (*Anacardium occidentale* L.) is a plantation commodity that has an essential role in Indonesia and is the mainstay of its economy, such as in Sulawesi, Nusa Tenggara, Maluku, and Java. The Directorate General of Estates reported that, in 2018, cashew plantations in Indonesia reached 494 268 ha (Directorate General of Estates 2020). The cashew is the country's foreign exchange earner, a source of income for farmers, industrial raw materials, and a green crop for land conservation (Listyati and Sudjarmoko 2011). The cashew nut is also a significant plantation commodity as a vegetable protein source, both for direct consumption and a raw material for the food industry.

The post-harvest handling and processing stages of cashew nuts are crucial to produce a whole nut

Supported by the National Research and Innovation Agency, Indonesia, Project No. B-169/III/PR.03/5/2021.

https://doi.org/10.17221/83/2021-RAE

which is ready for further processing. This stage is still performed manually in Indonesia and uses simple technology, especially with the stripping steps of the cashew nutshells. The stripping stage of the shells is the most challenging and requires a great deal of labour, not only for cashew nuts, but for other kinds of nuts, such as walnuts and candlenuts also (Sutejo et al. 2021). Therefore, developing a technology package to handle and process cashew nuts with a high capacity is required.

In the context of designing optimised post-harvest handling and processing machinery of cashew nut shells, engineering properties, such as the physical and mechanical properties of the cashew nut shells, need to be studied. These engineering properties are essential because data and information related to the cashew's physical and mechanical characteristics, especially the variety from Gunung Kidul, Central Java, Indonesia, are not available. Previously published papers have investigated the physical properties of raw cashew nut shells (Balasubramanian 2001; Chaudhari et al. 2013), but different varieties come from Indonesia, especially in the Gunung Kidul region. The physical properties of biological materials are the shape and size, bulk density, porosity, mass of the seeds and friction against various surfaces (Balasubramanian 2001; Chaudhari et al. 2013). Many researchers have determined the engineering properties of several biological materials for different purposes, such as designing sowing or planting machinery (Jadhav et al. 2017, 2020), evaluating harvesting and threshing machinery (Srivastava et al. 1990; Mesquita and Hanna 1995), designing post-harvest machinery (Khoshtaghaza and Mehdizadeh 2006; Coşkuner and Karababa 2007) and investigating the effect of the moisture content on various properties (Gebreselassie 2012; Shelake et al. 2018).

The physical and mechanical properties were measured by referring to many standards and methods implemented in previous studies. This study aimed to examine the engineering properties of the cashew nut derived from Central Java, Indonesia in context to the design of typical machinery needed in the production process, such as post-harvest handling and processing machinery, drying, extraction, and other relevant processing operations.

MATERIAL AND METHODS

The study was conducted in the Research Center for Appropriate Technology, National Research and Innovation Agency, Subang – West Java. The sample of cashew nuts was procured from the Rejosari village (latitude 07°51'52"S, longitude 107°45'45"E, elevation 30 m a.s.l.), Semin sub-district, Gunung Kidul district, Central Java province. The measurements of the engineering properties including the physical and mechanical ones, as well as the colour were carried out at a sample moisture content of 6.73% wet basis (wb).

Determination of the physical properties. The measurement of the physical properties consisted of the length, width, thickness, mass, and volume. The length, width, and thickness were measured using digital vernier callipers with an accuracy of 0.01 mm. The randomly selected cashew nut samples (n = 100) were evaluated by the Mohsenin method (Mohsenin 1986) using Equations (1–8). This measurement method is used by many researchers (Abedi et al. 2019; Ahangarnezhad et al. 2019; Akbarnia and Rashvand 2019) to determine the geometric diameter, arithmetic diameter, surface area, frontal surface area, transverse area, coefficient of the contact surface, shape index, and sphericity. The shape of the cashew nut was observed visually and compared with the standard conditions given by the International Board for Plant Genetic Resources (Nayak et al. 2014). Figure 1 shows the positions of the length, width, and thickness of the cashew nut.

$$D_{gm} = \sqrt[3]{L \times W \times T} \quad (1)$$

$$D_{am} = \frac{L + W + T}{3} \quad (2)$$

$$A_s = \pi D_{gm}^2 \quad (3)$$

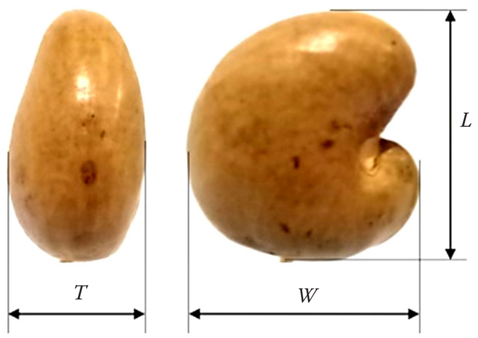

Figure 1. Position of the length (L), width (W), and thickness (T) of the cashew nut

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$$A_{fs} = \frac{\eth}{4} L \times W \quad (4)$$

$$A_t = \frac{\eth}{4} T \times W \quad (5)$$

$$C_{cs} = \frac{A_{fs} - A_t}{A_{fs}} \quad (6)$$

$$I_s = \frac{W}{\sqrt[2]{L \times T}} \quad (7)$$

$$\Phi = \frac{\sqrt[3]{L \times W \times T}}{L} \quad (8)$$

where: L – length (mm); W – width (mm); T – thickness (mm); D_{gm} – geometric diameter (mm); D_{am} – arithmetic diameter (mm); A_s – surface area (mm^2); A_{fs} – frontal surface area (mm^2); A_t – transverse area (mm^2); C_{cs} – coefficient of the contact surface; I_s – shape index; Φ – sphericity.

Generally, knowledge of the physical characteristics composed of the length, width, thickness, and porosity are essential parameters in designing specific machines and analysing the product's behaviour in handling materials. The dimension or size, such as the length, width and thickness, are important in the screening and the grading process and in evaluating the quality of the cashew nut. The surface area related to the length and width and thickness is essential for determining the terminal velocity, coefficient of drag, and Reynold's number. The frontal and transverse area is used to determine the coefficient of the contact surface, which is an important parameter in evaluating the contact surface between the cashew nut and the other surfaces, such as the milling machine surfaces. The shape of the cashew nut is one of the essential attributes that the consumer evaluates when buying it (Morimoto et al. 2000). It can also be used in grading, conveying and drying operations (Kays 1991).

For the properties of the mass and volume, the true density, bulk density, and porosity were determined by used ten nut samples selected randomly using Equations (9–11). The mass of the cashew nut was measured using an analytical balance with an accuracy of 0.0001 g, and the volume of a single nut (V) was measured using the water displacement method with an accuracy of 0.5 mL.

$$\rho_p = \frac{M}{V} \quad (9)$$

$$\rho_b = \frac{M_{V1000}}{V_{1000}} \quad (10)$$

$$\varepsilon = \frac{(\rho_p - \rho_b)}{\rho_p} \times 100\ \% \quad (11)$$

where: M – mass of a single nut (g); V – volume of a single nut (cm^3); ρ_p – true density (g·cm^{-3}); ρ_b – bulk density (g·cm^{-3}); ε – porosity; M_{V1000} – mass of 1 000 cm^3 of cashew nuts (g); V_{1000} – volume of the cashew nuts (1 000 cm^3).

Determination of the mechanical properties. The mechanical properties measured in this study included the angle of repose, friction, skin strength, elasticity, and compression test. The angle of repose, referred to as the cone angle or slope angle, is critical for measuring and evaluating grain storage systems, including grain bins and outdoor piles. In storage applications, it is often used to determine the flow characteristics and tendency of flow problems in a powder and bulk grain products. The angle of repose is described as the angle between the slope of the pile and the horizontal plane when the pile is at rest (Mohsenin 1986). There are two types of angles of repose, static and dynamic. The static angle of repose is the angle measured from the horizontal plane at which the material is allowed to stay at a standstill and will begin to slide and roll on itself. The dynamic angle of repose is the angle between the stationary granular material and the horizontal direction after sliding (Mohsenin 1986). The static angle of repose is referred to as emptying or funnelling, while the dynamic angle of repose is also referred to as filling or piling. The dynamic angle of repose is generally more minor, by 3° to 10° than the static angle of repose (Mohsenin 1986). The dynamic angle of repose is the most common physical property used for material handling systems and bin designs. The discharge method, tilt method or injection method are usually used to measure the angle of repose (Gotoh et al. 1997). In this study, the static angle of repose was measured using an electrically inclined plane supported by a sensor; Figure 2 shows the apparatus for measuring the emptying angle of repose. The static angle of repose and static friction coefficients were determined on four surfaces, i.e., stainless steel, aluminium, acrylic and plywood. The static friction (μ) was calculated by using Equation (12) (Zareiforoush et al. 2010). This study measured the static angle of repose on 30 samples and the dynamic angle of repose on ten samples on each

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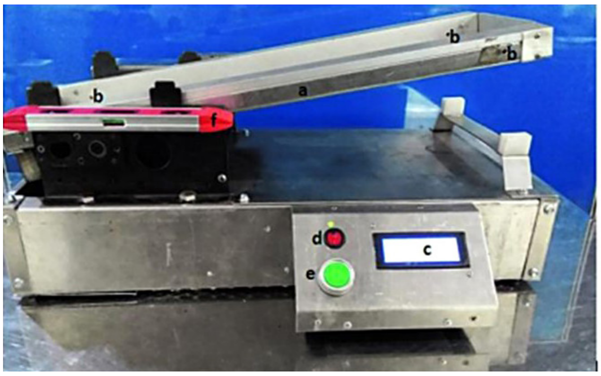
(A)



(B)

Figure 2. Angle of repose measuring instrument: the static angle of the repose measuring instrument (a – adjustable plane, b – motion sensor (4 pieces), c – display, d – on/off button, e – start button, f – water level) (A); the dynamic angle of repose measuring instrument (B)

surface. The static angle of repose was obtained by putting an individual sample on the plane of the instrument; by pushing the on/off switch, the device will raise and let the sample roll down. The static angle of repose was the angle when the sample begins to move downward. The amount of static angle of repose (θ_e) was automatically displayed by the instrument (Figure 2A).

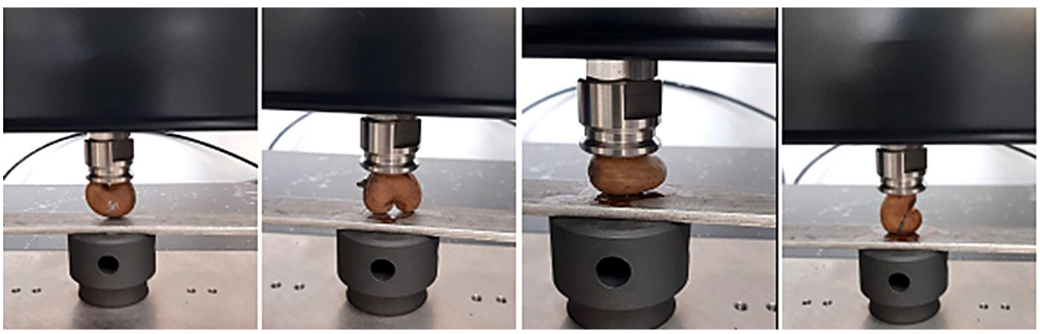
The dynamic angle of repose was determined by using a polyvinyl chloride (PVC) cylinder 100 mm in diameter and 100 mm in height, as shown in Figure 2B. The PVC cylinder was placed on four surfaces, i.e., stainless steel, aluminium, acrylic and plywood; the filled PVC was raised until it formed a cone. The mean of the pile diameter (D_p) and height of the pile (H_p) were recorded to calculate the dynamic angle of repose, which was then calculated using Equation (13) (Tarighi et al. 2011; Al-Hashemi and Al-Amoudi 2018).

$$\mu = \tan \theta_e \tag{12}$$

$$\theta_f = \tan^{-1}\left[\frac{2H_p}{D_p}\right] \tag{13}$$

where: μ – static friction; θ_e – static angle of repose (°); θ_f – dynamic angle of repose (°); H_p – height of the pile (mm); D_p – diameter of the pile (mm).

A Tensilon RTG Universal Testing Machine (A&D Company, Ltd., Japan) was used to measure the compressive load until cashew nut samples were broken. The measurement was carried out 20 times for each orientation. The compressive test was applied in four positions as shown in Figure 3: perpendicular to the planes of the concave edges (A), perpendicular to the planes of the convex edges (B), perpendicular to the planes of the flanks (C), and parallel to the longitudinal axis (D). The skin strength, elasticity,



(A) (B) (C) (D)

Figure 3. Position of the cashew nut in relation to the loading direction: perpendicular to the planes of the concave edges (A), perpendicular to the planes of the convex edges (B), perpendicular to the planes of the flanks (C), and parallel to the longitudinal axis (D)

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and hardness are essential parameters in equipment design, such as the crusher, to determine the maximum force applied to a material.

Determination of the colour properties. The colour of the cashew nut samples was determined using an NH310 colorimeter (Shenzhen Threenh Technology Co., Ltd., China). The analysis method used the CIE (Commission Internationale de L'Eclairage) L^*, a^*, b^* and CIE L^*, c^*, h^* coordinates (Ruiz et al. 2012). Coordinate L^* represents the clarity, in which $L^* = 0$ is black, and $L^* = 100$ is white. Coordinate a^* denotes the shade of red and green, in which $a^* > 0$ indicates the red colour and $a^* < 0$ indicates the green colour. Coordinate b^* represents the tone of blue and yellow, in which $b^* > 0$ shows the intensity of yellow and $b^* < 0$ means the hue of blue.

Statistical analysis. The collected data were statistically analysed to assess the minimum, maximum, means, and standard deviation. The normality of data was tested using Kolmogorov Smirnov and Shapiro-Wilk tests. The correlation and the relationship among the properties were determined using Person's correlation and a stepwise regression analysis, respectively.

RESULT AND DISCUSSION

Physical properties. Table 1 shows the descriptive analysis results involve the minimum, maximum, mean, and standard deviation of physical properties, which were measured and calculated.

The Kolmogorov Smirnov and Shapiro-Wilk tests defined that the data collected were normally distributed ($P > 0.05$). Based on the Person's correlation analysis, the mass (M) correlated ($P < 0.05$) with the primary dimension of the length (L), width (W), thickness (T), and the derivative size of the geometric diameter (D_{gm}), arithmetic diameter (D_{am}), surface area (A_s), frontal surface area (A_{fs}), and transverse area (A_t). The results of stepwise regression analysis determined that volume had the most substantial relationship with the mass. The regression equation with the best fit of that relationship is as follows:

$$V = 1.038M + 0.019 \quad (R^2 = 0.949) \tag{14}$$

The bulk density correlated with the primary measurement of the mass. The porosity of the cashew nut sample has a high correlation with the true density and mass. The results of the stepwise regression analysis determined the best relationship of those correlations is as follows:

$$\rho_b = 0.001M - 0.014 \quad (R^2 = 0.968) \tag{15}$$

$$\varepsilon = 0.619\rho_b - 0.001M + 0.51 \quad (R^2 = 0.997) \tag{16}$$

Regarding the shape of the cashew nut sample, which was visually observed and compared to the Cashew Descriptors of the International Board for Plant Genetic Resources (Nayak et al. 2014), it was identified that the shape tended to have obliquely flattened similarities as shown in Figure 4. The cashew nut sample was intermediate (Nayak et al. 2014).

A further evaluation was carried out by comparing some of the cashew nut properties with cashew nuts originating from several countries as published by several researchers. Table 2 represents the physical properties of cashew nuts from India (Balasubramanian 2001), Nigeria (Kilanko et al. 2020), and Ivory Coast (Stéphane et al. 2020). It was revealed that the cashew nut from Central Java was dominant with a small-medium size, where the mass of the nut was 5.42 ± 0.99 g (the moisture content was 7.63% wb). This value was smaller than the cashew nut originated from Ivory Coast due to the difference

Table 1. Descriptive analysis of the engineering properties of the cashew nuts derived from Gunung Kidul, Central Java, Indonesia

Properties	Min	Max	Mean	SD
L (mm)	24.48	32.50	27.92	1.66
W (mm)	18.79	29.22	23.85	1.82
T (mm)	15.19	23.66	18.63	1.88
M (g)	3.05	8.32	5.42	0.99
D_{gm} (mm)	19.99	27.59	23.12	1.52
D_{am} (mm)	20.32	27.95	23.47	1.48
A_s (mm^2)	1 254.18	2 390.54	1 686.20	220.65
A_{fs} (mm^2)	376.13	745.48	524.14	64.19
A_t (mm^2)	248.98	507.38	350.26	54.82
C_{cs} (–)	0.17	0.47	0.33	0.06
I_s (–)	0.89	1.25	1.05	0.06
Φ (–)	0.74	0.93	0.83	0.04
V (cm^3)	4.00	7.50	5.73	1.20
ρ_p (g·cm^{-3})	0.89	1.09	0.96	0.05
ρ_b (g·cm^{-3})	0.57	0.61	0.59	0.01
ε (–)	0.32	0.45	0.38	0.04

L – length; W – width; T – thickness; M – mass of a single nut; D_{gm} – geometric diameter; D_{am} – arithmetic diameter; A_s – surface area; A_{fs} – frontal surface area; A_t – transverse area; C_{cs} – coefficient of the contact surface; I_s – shape index; Φ – sphericity; V – volume of a single nut; ρ_p – true density; ρ_b – bulk density; ε – porosity; SD – standard deviation

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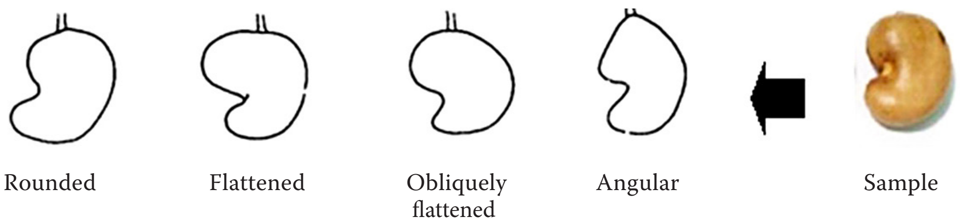

Figure 4. Cashew nut shape comparison

in the moisture content, where the moisture content of cashew from Ivory Coast was 12.48–12.81% (wb). The mass of cashew nut after the data were calculated by using the same moisture content showed a relatively similar value in the range of 6.19–6.24 g. For the dimensions, it was shown that the length, width, and thickness of the cashew nut from Central Java was thicker, but shorter, in length than the cashew nut from India, Nigeria (except the large size), and Ivory Coast. Based on this information, it was essential to develop equipment for handling cashew nuts with typical specifications or with an adjustable specification that could accommodate all the cashew nut sizes. The other properties that were not available in the previous research were measured and calculated in this research to complete the information related to the engineering properties of the cashew nut as mentioned in Table 1. The coefficient of contact surface (C_{cs}) and shape index (I_s) were among several parameters that were not available in the previous papers. C_{cs} is an important parameter needed to evaluate the contact surface between the cashew nut and the surfaces (Saif 2008), such as those in the transport, handling, and loading-unloading process. The maximum, minimum, and average C_{cs} of the cashew nuts were 0.17, 0.47, and 0.33, respectively. Regarding the shape index, it is used to evaluate the shape of the cashew nut that is considered as oval when the shape index > 1.5 or spherical for a shape index ≤ 1.5 (Saif 2008; Wondimkun et al. 2019). The maximum, minimum, and average shape indices of the cashew nuts were 0.89, 1.25, and 1.05, respec-

Table 2. Some physical properties of the cashew nuts from different countries

Properties	India (Balasubramanian 2001)			Nigeria (Kilanko et al. 2020)			Ivory Coast (Stéphane et al. 2020)		
	large	medium	small	large	medium	small	Bondoukou	Dabakala	Mankono
L (mm)	36.89	31.87	27.97	34.78	31.08	29.13	28.5	29.73	29.34
W (mm)	24.68	23.27	21.73	26.26	23.7	22.18	23.21	23.37	23.33
T (mm)	17.62	17.3	16.16	18.15	17.17	16.22	16.74	16.48	16.72
M (g)	7.21	6.45	4.9	7.47	5.68	4.8	6.19	6.21	6.24
D_{gm} (mm)		22.78		25.46	23.27	21.86	22.48	22.51	22.48
D_{am} (mm)	N/A	N/A	N/A	N/A	N/A	N/A	23.12	23.19	23.13
A_s (mm^2)	N/A	N/A	N/A	N/A	N/A	N/A	1 600.87	1 600.15	1 600.09
A_{fs} (mm^2)	N/A	N/A	N/A	N/A	N/A	N/A	540.08	548.07	541.48
A_t (mm^2)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
C_{cs} (–)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I_s (–)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Φ (–)		0.74		0.73	0.75	0.75	0.76	0.76	0.77
V (cm^3)	N/A	N/A	N/A	N/A	N/A	N/A	6.098	6.067	6.089
ρ_p (g·cm^{-3})		1.212		1.022	1.08	1.06	N/A	N/A	N/A
ρ_b (g·cm^{-3})		0.614		0.55	0.55	0.56	N/A	N/A	N/A
ε (%)		49.317		45.87	49.28	47.36	N/A	N/A	N/A

L – length; W – width; T – thickness; M – mass of a single nut; D_{gm} – geometric diameter; D_{am} – arithmetic diameter; A_s – surface area; A_{fs} – frontal surface area; A_t – transverse area; C_{cs} – coefficient of the contact surface; I_s – shape index; Φ – sphericity; V – volume of a single nut; ρ_p – true density; ρ_b – bulk density; ε – porosity; N/A – not available

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tively. According to the definition by Saif (2008), the shape of the cashew nuts from Central Java was found to have a spherical shape.

To identify the magnitude level of the sphericity of an object, the sphericity value was calculated. In terms of sphericity, it was found that cashews from Central Java, Indonesia showed a higher sphericity value (0.83) than the cashews from India, Nigeria, and Ivory Coastwith a value of 0.73–0.76. The higher the sphericity value (close to 1), the closer the shape is to a sphere, resulting in a higher tendency to roll about any of the three axes (Niveditha et al. 2013). Furthermore, with this nearly spherical shape, as a result, the porosity of cashew nut from Central Java was smaller than the porosity of the nuts from India and Nigeria, while the data from Ivory Coast were not available.

Mechanical properties. Table 3 shows the mechanical properties of the cashew nuts, which consisted of the static angle of repose, dynamic angle of repose and static friction in four surface materials.

As shown in Table 3, the static and dynamic angle of repose had a similar pattern. The highest average static and dynamic angle of repose occurred in the surface of plywood, and the lowest of occurred in the surface of stainless steel. The value of the static angle of repose on a specific surface was relatively higher than that of the dynamic one. This result is under the study of the earlier work done by other researchers (Mohsenin 1986). The static friction, principally, is the tangential function of the bulk static angle of repose. The static friction correlated proportionally with the emptying angle of repose, the higher static friction, and the higher the static angle of repose. Another study regarding static friction was reported by Gharibzahedi et al. (2010) on pine nuts. They found that the highest static friction was on a plywood surface, followed by a galvanised iron sheet, glass, and the least for stainless steel. Abedi et al. (2019) also found that the static friction coefficient of potatoes on a wood surface was the highest, followed by rubber, glass, and an aluminium sheet, and the lowest occurred on a galvanised iron sheet. This parameter is essential in designing the hopper design, especially a cashew peeling machine. The design of a hopper made from stainless steel requires a smaller cone slope so that for the same hopper volume, the height of the stainless-steel cone hopper can be designed lower.

The results of compressive load measured by using a Universal Testing Machine (UTM) in four orientations are shown in Table 4. The minimum hardness was parallel to the longitudinal axis (orientation D). Regarding this mechanical property, it is a very important parameter in the development of an optimal mechanical peeler or cracking equipment, especially with the selection of an electric motor. Designs which do not take these parameters into account may not be optimal, i.e., may have inadequate power or maybe over-designed, i.e., too much power, which results in wasting money. This issue needs to be avoided so that the design of the tool/machine is fit and proper in terms of its function and price. To be even more optimal, it is also necessary to consider the cashew orientation during the peeling process, in which the cutting knife needs to be forced into cutting in the direction of orientation (D) so that the design of the cashew shell peeler uses the least engine power.

Table 3. Static and dynamic angle of repose had a similar pattern

Properties	Materials	Min	Max	Mean	SD
θ_e (°)	stainless steel	20.15	35.52	27.89	3.68
	acrylic	18.23	41.68	28.39	6.30
	aluminium	24.63	46.41	34.30	4.82
	plywood	25.91	64.88	34.85	6.74
θ_f (°)	stainless steel	16.94	21.75	19.46	1.73
	acrylic	12.84	25.07	19.60	3.87
	aluminium	15.35	23.30	19.65	2.82
	plywood	15.95	23.32	20.15	2.29
μ (–)	stainless steel	0.54	0.68	0.59	0.05
	acrylic	0.56	0.75	0.65	0.06
	aluminium	0.55	0.71	0.65	0.05
	plywood	0.73	0.78	0.76	0.01

θ_e – static angle of repose; θ_f – dynamic angle of repose; μ – static friction; SD – standard deviation

Table 4. Compressive load of the cashew nuts in four orientations (in N)

Orientation	Min	Max	Mean	SD
A	527.05	960.56	642.00	96.73
B	408.56	1066.40	706.71	153.52
C	282.22	1324.70	540.14	279.33
D	251.19	718.97	390.50	106.11

A – perpendicular to the planes of the concave edges; B – perpendicular to the planes of the convex edges; C – perpendicular to the planes of the flanks; D – parallel to the longitudinal axis; SD – standard deviation

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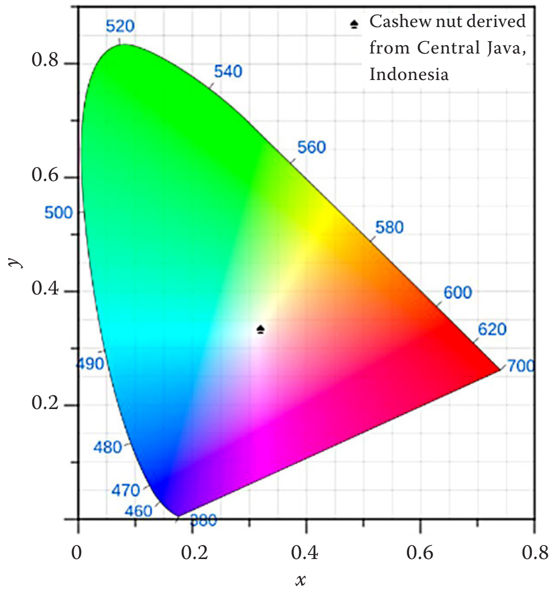

Figure 5. Colour coordinates of the cashew nuts derived from Central Java, Indonesia

Colour. The colour properties of cashew nuts have not been elucidated upon in previously published papers so that this is additional information related to the engineering properties of cashew nut. The measurement results of the colour determined the average *L**, *a**, *b**, *c**, and *h** coordinates of the colour was 35.988 ± 0.002, 0.427 ± 0.013, 1.718 ± 0.016, 1.770 ± 0.017 and 0.001 ± 0.000, respectively. For illustration, the *L*, a*, b** coordinates were converted to the CIE 1931 colour space diagram using the software developed by Hasabeldaim (2021) which is based on two-axes as shown in Figure 5. It was shown that the cashew nut colour was plotted in the white region (did not contain any pigment colour). The colour is an essential parameter that can be used for the development of separating equipment (separation from broken material and unnecessary material), sorting good commodities and several related equipment based on the colour.

CONCLUSION

The following conclusions can be drawn about the physical and mechanical properties of cashew nuts derived from Gunung Kidul district, Central Java province, Indonesia at an average moisture content of 6.73% wet basis. The properties of the length, width, thickness, mass, volume, true density, bulk density, and porosity were 27.92 ± 1.66 mm, 23.85 ± 1.82 mm, 18.63 ± 1.88 mm, 5.42 ± 0.99 g, 5.73 ± 1.20 cm^3, 0.96 $g{\cdot}cm^{-3}$, 0.59 $g{\cdot}cm^{-3}$, and 0.38 ± 0.04, respectively. The cashew nuts of a small-medium size from Central Java were dominant. These cashew nuts were thicker, but shorter in length than the cashew nuts from India, Nigeria, and Ivory Coast. It is essential to develop equipment for handling cashew nuts with typical specifications or with an adjustable specification that can accommodate all sizes of cashew nuts. Furthermore, the highest friction, static and dynamic angle of repose was 0.76 ± 0.02, 34.85 ± 6.74, and 20.15 ± 2.29, which occurred on the plywood surface. The value of the dynamic angle of repose was less than that of the static angle of repose. The average compressive load at the orientation position (A) perpendicular to the planes of the concave edges, (B) perpendicular to the planes of the convex edges, (C) perpendicular to the planes of the flanks, and (D) parallel to the longitudinal axis were 642.00 N, 706.71 N, 540.14 N and 390.50 N, respectively. In context of designing appropriate cashew nut cracking equipment, it was recommended to provide the impact parallel to the longitudinal axis orientation due to the minimum compressive load (reduce the power requirement). The *L**, *a**, *b** colour coordinates of the sample were 35.988, 0427, 1.718, respectively.

Acknowledgement: We would like to express our appreciation to the Research Center for Appropriate Technology, the National Research and Innovation Agency, who supported this study. We would like to offer our appreciation to all those who offered us the possibility to complete this study. We also would like to thank Teguh Santoso, Dadang Gandara, and Iman Rusim for their help in carrying out this study.

REFERENCES

Abedi G., Abdollahpour S., Bakhtiari M.R. (2019): The physical and mechanical properties of potato (*Solanum tuberosum* L.) tubers as related to the automatic separation from clods and stones. Research in Agricultural Engineering, 65: 77–84.

Ahangarnezhad N., Najafi G., Jahanbakhshi A. (2019): Determination of the physical and mechanical properties of a potato (the Agria variety) in order to mechanise the harvesting and post-harvesting operations. Research in Agricultural Engineering, 65: 33–39.

Akbarnia A., Rashvand M. (2019): An evaluation of the physical, dynamic and aerodynamic properties of olives. Research in Agricultural Engineering, 65: 48–55.

Al-Hashemi H.M.B., Al-Amoudi O.S.B. (2018): A review on the angle of repose of granular materials. Powder Technology, 330: 397–417.

Balasubramanian D. (2001): Physical properties of raw cashew nut. Journal of Agricultural Engineering Research, 78: 291–297.

Chaudhari A.P., Thakor N.J., Sonawane S.P., Sawant A.A. (2013): Physical properties of cashew nut shells. International Journal of Agricultural Engineering, 6: 254–260.

Coşkuner Y., Karababa E. (2007): Some physical properties of flaxseed (*Linum usitatissimum* L.). Journal of Food Engineering, 78: 1067–1073.

Directorate General of Estates (2020): Tree Crop Estate Statistics of Indonesia. Jakarta, Secretariate of Directorate General of Estates.

Gebreselassie T.R. (2012): Moisture dependent physical properties of cardamom (*Elettaria cardamomum* M.) seed. Agricultural Engineering International: CIGR Journal, 14: 108–115.

Gharibzahedi S.M.T., Etemad V., Mirarab-Razi J., Fos'hat M. (2010): Study on some engineering attributes of pine nut (*Pinus pinea*) to the design of processing equipment. Research in Agricultural Engineering, 56: 99–106.

Gotoh K., Masuda H., Higashitani K. (1997): Powder Technology Handbook. Bosa Roca, Taylor and Francis, Inc.

Hasabeldaim E.H.H. (2021): CIE Chromacity Diagram 1931. Available at https://sciapps.sci-sim.com/CIE1931.html (accessed Nov 16, 2021).

Jadhav M., Mohnot P., Shelake P. (2017): Investigation of engineering properties of vegetable seeds required for the design of pneumatic seeder. International Journal of Current Microbiology and Applied Sciences, 6: 1163–1171.

Jadhav M., Din M., Nandede B., Kumar M. (2020): Engineering properties of paddy and wheat seeds in context to design of pneumatic metering devices. Journal of the Institution of Engineers (India): Series A, 101: 281–292.

Kays S.J. (1991): Postharvest Physiology and Handling of Perishable Plant Products. New York, Springer.

Khoshtaghaza M., Mehdizadeh R. (2006): Aerodynamic properties of wheat kernel and straw materials. Agricultural Engineering International: CIGR Journal, 8: 1–10.

Kilanko O., Ojolo S.J., Leramo R.O., Ilori T.A., Oyedepo S.O., Babalola P.O., Fayomi O.S., Onwordi P.N., Ufot E., Ekwere A. (2020): Dataset on physical properties of raw and roasted cashew nuts. Data in Brief, 33: 106514.

Listyati D., Sudjarmoko B. (2011): Economic value added of cashew processing in Indonesia. Jurnal Tanaman Industri dan Penyegar, 2: 231–238.

Mesquita C., Hanna M. (1995): Physical and mechanical properties of soybean crops. Transactions of the ASAE, 38: 1655–1658.

Mohsenin N. (1986): Physical Properties of Plant and Animal Materials: Structure, Physical Characteristics, and Mechanical Properties. 2nd Ed., New York, Gordon and Breach.

Morimoto T., Takeuchi T., Miyata H., Hashimoto Y. (2000): Pattern recognition of fruit shape based on the concept of chaos and neural networks. Computers and Electronics in Agriculture, 26: 171–186.

Nayak M., Mohana G., Bhat P., Saroj P., Swamy K., Bhat M. (2014): Catalogue of Minimum Descriptors of Cashew Germplasm Accessions. Karnataka, ICAR: Directorate of Cashew Research.

Niveditha V., Sridhar K., Balasubramanian D. (2013): Physical and mechanical properties of seeds and kernels of Canavalia of coastal sand dunes. International Food Research Journal, 20: 1547–1554.

Ruiz F.J., Agell N., Angulo C., Sánchez M. (2012): A qualitative learning system for human sensory abilities in adjustment tasks. In: 26th Int. Workshop on Qualitative Reasoning, California, July 16–18, 2012: 1–7.

Saif A.E.-E.O. (2008): Determination of engineering and chemical properties of some Yemeni coffee. In: the 15th Annual Conference of the Misr Society of Agricultural Engineering, Cairo, March 12–13, 2008: 497–512.

Shelake P., Yadav S., Jadhav M., Dabhi M. (2018): Effect of moisture content on physical and mechanical properties of turmeric (*Curcuma longa*) rhizome. Current Journal of Applied Science and Technology, 30: 1–7.

Srivastava A.K., Mahoney W.T., West N.L. (1990): The effect of crop properties on combine performance. Transactions of the ASAE, 33: 63–72.

Stéphane K.Y., Halbin K.J., Charlemagne N. (2020): Comparative study of physical properties of cashew nuts from three main production areas in Côte d'Ivoire. Agricultural Sciences, 11: 1232–1249.

Sutejo A., Sagita D., Suherdiman G.P.I. (2021): Effect of heating pre-treatments and cracking methods on the whole candlenut kernel yield. Journal of The Institution of Engineers (India): Series A, 102: 973–980.

Tarighi J., Mahmoudi A., Alavi N. (2011): Some mechanical and physical properties of corn seed (Var. DCC 370). African Journal of Agricultural Research, 6: 3691–3699.

Wondimkun Y.W., Emire S.A., Esho T.B. (2019): Assessment of physical properties and sensory qualities of Ethiopian specialty washed green coffee beans. Annals. Food Science and Technology, 20: 865–876.

Zareiforoush H., Komarizadeh M.H., Alizadeh M.R. (2010): Mechanical properties of paddy grains under quasi-static compressive loading. New York Science Journal, 3: 40–46.

Received: November 18, 2021
Accepted: March 15, 2022
Published online: November 21, 2022