

Moisture-dependent engineering properties of black cardamom capsules and seeds

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Abstract: Engineering characteristics including dimensions, geometric mean diameter (GMD), bulk density (BD), true density (TD), sphericity (Sp), porosity (\emptyset), angle of repose (AP), static coefficient of friction (S_{CF}), hardness, and colour coordinates of the black cardamom capsules and seeds were evaluated as a function of different moisture contents (11% to 43% d.b.). The linearly increased trends were noticed for length, width, thickness, GMD, and AP from 25.60 to 27.63 mm, 13.41 to 15.79 mm, 9.32 to 11.32 mm, 14.73 to 16.82 mm, and 26° to 28° for capsules and 3.07 to 3.46 mm, 2.59 to 2.72 mm, 2.30 to 2.40 mm, 2.63 to 2.83 mm and 23° to 27° for seeds, respectively. As the moisture content increased from 11% to 43%, the BD and hardness declined from 286.98 to 260.60 kg m⁻³, 512.01 to 501.53 kg m⁻³, 21.31 to 4.08 N, and 5.50 to 3.52 N, while the TD and \emptyset increased from 853.33 to 899.22 kg m⁻³, 1523.33 to 1606 kg m⁻³, 66.36% to 71.02%, and 66.36% to 68.78%, respectively, for both the capsule and seeds. The color values (L^* , b^* , a^* , and ΔE) significantly ($p < 0.05$) varied from 26.81 to 19.78, 5.05 to 5.15, 5.37 to 5.22, and 1.41 to 0.49 for capsules and 25.46 to 19.78, 5.30 to 5.25, 8.49 to 5.89, and 3.94 to 4.54 for seeds, respectively. The different surface and moisture contents also significantly affect ($p < 0.05$) the S_{fc} of both the samples.

Keywords: large cardamom, physical dimensions, density, sphericity, hardness, color

Citation: Meetei, L. Y., and R. K. Raigar. 2026. Moisture-dependent engineering properties of black cardamom capsules and seeds. *Agricultural Engineering International: CIGR Journal*, 28(2): 251-259.

1 Introduction

Black cardamom (*Amomum subulatum* Roxb.) or large cardamom is a perennial bush of the ginger family (Zingiberaceae) with sheathed stems of ten to twelve feet in height. The plants are typically planted at an elevation of 700 to 1800 m above sea level with an annual rainfall of 2800 to 3300 mm to take advantage of the local mountain niche (Bisht et al., 2011). According to Hussain et al. (2018), the ripe fruit is trilobular, reddish brown, and has dark pink seed capsules with seeds. The more notorious varieties of

black cardamom in the state of Sikkim are Ramsey, Dzongu Golsey, Madhusay, Ramnag, Sawney, Varlangey, etc. Black cardamom is used as a spice mostly for flavoring in preparations of food, confectionery, beverages, and liquors. In addition to containing 2%–3% essential oils, it provides stomachic, diuretic, and cardiac stimulation. Furthermore, it can be used to treat throat and respiratory problems (Bisht et al., 2011).

Black cardamom of freshly harvested capsules contains about 70%–80% moisture, depending on the maturity level during harvested time of the capsules

Received date: 2025-03-08 **Accepted date:** 2026-02-16

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(Khan, 2023). The whole capsules are harvested, separated from the flower, and cleaned before further processing. For developing aroma, extending shelf life, and avoiding fungus infection, the moisture content is generally brought down below 10% immediately after harvesting. The design aspect of the machine used for primary processing and handling depends on various physical and engineering properties factors viz. density, size, shape and surface characteristic (Bajpai et al., 2020). The flow behavior mainly depends on frictional properties (angle of repose and coefficient of friction) of the grains and spice seeds from the storage structures (Silo and rectangular tank), conveying, and service hoppers. Therefore, frictional properties play a critical role in designing of the equipment (Bhushan and Raigar, 2020). Similarly, the physical properties were also influenced by different level of moisture content. Furthermore, these physical, and engineering properties help in the modeling of the absorption and desorption of the moisture content in seeds and capsules (Sánchez-Riaño et al., 2022).

Density (bulk and true) is used for the determination of feeding hopper capacity and the design of a suitable separation machine, while porosity is used to assess the behavior of kernel mass with airflow during drying and dehydration. Frictional properties (angle of repose and coefficient of friction) are widely used as the designing factors of grading equipment, seed containers, and storage structures (Ganjloo et al., 2018). Sadiku and Omogunsoye (2021) reported the effects of barley seeds' moisture levels (10% to 14% db) on bulk density, true density, porosity, angle of internal friction, and static coefficient of friction. A similar study with a different range of moisture content (13.15% to 45.82% d.b.) was conducted by Sologubik et al. (2013). Some physical properties of freshly harvested and dried large cardamom capsules were reported by Khura et al. (2013). The dried capsules and seeds of black cardamom absorbed or loose moisture content after drying, packaging, and storage due to atmospheric conditions, which influenced the design parameters.

Very few literature reports are available on the impact of moisture content on the physical, and engineering properties of black/large cardamom capsules and seeds (Gebreselassie, 2012; Khura et al., 2013). The studies were focused on the determination of limited physical and engineering properties. However, the engineering properties of black cardamom are greatly influenced by moisture content and scarce the information on these studies. Therefore, the present study was aimed at investigating the impact of moisture content on the engineering properties of black cardamom capsules and seeds, such as physical dimensions, sphericity, bulk and true density, porosity, angle of repose, static coefficient of friction, color and hardness.

2 Materials and methods

2.1 Sample preparation

A 20 kg of dried black cardamoms (*Sawney*) were bought from the farmers' market in the Gangtok District of Sikkim. Initially, capsule tails were cut manually; seeds were removed from the capsule shell by hand (force). The dried capsules and seeds were packed in separated pouches for further experiments. The initial moisture contents of black cardamom capsules and seeds were determined using a hot air oven at $105^{\circ}\text{C} \pm 1^{\circ}\text{C}$ for 24 h. The initial moisture contents for the mature seeds and capsules were $10.61\% \pm 0.003\%$ w.b. and $10.37\% \pm 0.0041\%$ w.b., respectively. The wet basis moisture content was converted into dry basis and based on the initial moisture content of capsules and seeds, five different levels of moisture [11%, 18%, 25%, 33%, and 43% (dry basis)] were chosen for this study for batch of 250 g and 1000 g of seeds and capsules, respectively. The different levels of moisture content were chosen based on the saturation level of black cardamom capsules and seeds. The required quantity of demineralized water was calculated by using Equation 1 for each desired moisture quantity of capsules and seeds. The calculated quantity of demineralized water was added to the samples accordingly (Bhushan and Raigar, 2020).

$$Q_c = \frac{Q_i(M_f - M_i)}{M_i + 100} \quad (1)$$

Where,

Q_i : black cardamom capsules/seeds weight (initial, kg);

M_i : black cardamom capsules/seeds moisture (initial, % d.b.), M_f is the desired moisture levels of the black cardamom capsules/seeds, % d.b.;

Q_c is the quantity of water to be added, kg.

Required amount of demineralized water was dispersed with a spraying bottle over the measured quantity of black cardamom capsules to get the different moisture of the samples. Furthermore, the moistened black cardamom capsules were kept inside low density polyethylene (LDPE) Zip lock pouches and stored in refrigeration condition ($4^\circ\text{C} \pm 1^\circ\text{C}$) for approximately 7 days to attain the uniform moisture content and inhibiting the growth of fungus, mold and bacteria's. Conditioning the samples led to the confirmation of different sets of moisture content of the samples.

2.2 Engineering properties

2.2.1 Physical dimensions

A Vernier caliper (resolution: 0.01 mm, error: ± 0.02 mm and model: Mitutoyo, CD-8"ASX, Japan) was used to measure the length, width, and thickness of hundred capsules and seeds of Black cardamom at different moisture contents. The geometric mean diameter (GMD) and sphericity of capsules and seeds of Black cardamom were calculated for each moisture content experiments using Equation 2 and 3, respectively (Raigar and Mishra, 2015).

$$D_j = (LWT)^{\frac{1}{3}} \quad (2)$$

$$\varphi_l = \frac{D_j}{L} \quad (3)$$

Where,

D_j is the GMD (mm);

L is the length (mm);

B is the width (mm);

T is the thickness (mm);

φ_l is the sphericity of the samples.

2.2.2 Density

The bulk density of black cardamom capsules and

seeds at different moisture levels was determined by filling a 500 ml (volume) cylindrical container at a constant rate without any compaction and then weighing it. Then, bulk density was calculated using Equation 4 (Sakkaravarthy and Parameswaran, 2024).

$$\rho_{bc} = \frac{M_{bc}}{V_l} \quad (4)$$

Where,

ρ_{bc} , M_l and V_l are density (bulk) (kg m^{-3});

weight of black cardamom (kg);

sample occupied volume (m^3) of black cardamom, respectively.

True density was estimated through the volume computation process for both the samples. Due to the higher absorption of water by the sample, toluene was used instead as it absorbs in lesser extent. Firstly, a measuring cylinder was filled with toluene, and then the displaced volume of toluene was assessed by immersing a known weight of samples in toluene. The value of true density was computed by using Equation 5 (Bajpai et al., 2020).

$$\rho_{tl} = \frac{W_{bc}}{V_{bc}} \quad (5)$$

Where,

ρ_{tl} , M_l and V_{bc} are density (true) (kg m^{-3});

weight of black cardamom (kg);

sample occupied true volume (m^3) of black cardamom.

2.2.3 Porosity

Porosity was calculated from values of bulk density and true density of black cardamom capsules and seeds samples and determined by using Equation 6 and it is reported in % (Bajpai et al., 2020).

$$\eta_p = \left(1 - \frac{\rho_{bl}}{\rho_{tl}}\right) \times 100 \quad (6)$$

Where,

η_p is the calculated porosity of black cardamom samples (capsules and seeds);

ρ_{bl} is the bulk density and ρ_{tl} is the true density of black cardamom (kg m^{-3}).

2.2.4 Angle of repose (A_R)

A heap is created when black cardamom samples fall from a height of 30 cm on plane surface. The A_R of the samples was computed by using Equation 7

(Mishra et al., 2019).

$$\theta_l = \tan^{-1} \left[\frac{2H_{cl}}{D_{cl}} \right] \quad (7)$$

Where,

θ_a is the A_R of the black cardamom ($^\circ$);

H_{cl} is the height of the heap formed by the black cardamom (mm);

D_{cl} is the diameter base's heap (mm) of sample.

2.2.5 Static coefficient of friction (Scf)

The static coefficient of friction of black cardamom samples against three different surfaces, namely, plywood, mild steel, and aluminum sheet, was determined. Capsules filled in a square box were placed on a tilting top table. The static coefficient of friction was determined by using Equation 8 (Aviara et al., 2013).

$$\mu_{sc} = \tan \alpha \quad (8)$$

Where, μ_{sc} and α are the static coefficient of friction and tilt angle ($^\circ$) of the black cardamom samples, respectively.

2.2.6 Hardness

The hardness values of the black cardamom capsules and seeds were determined with the help of a texture analyzer (Stable Micro Systems, TA-HD, London, United Kingdom) at each moisture levels of samples (Bhushan and Raigar, 2020). During the experiments, post-test speed, pre-test speed, distance, and trigger force were 10 mm s^{-1} , 2 mm s^{-1} , 2 mm, and 50 N, respectively. The sample is forced by using a cylindrical probe of 25 mm diameter.

2.2.7 Color

The color parameters of black cardamom capsules and seeds were measured in L^* (lightness), a^* (redness), and b^* (yellowness) scales and total colour change (ΔE) with the help of a colorimeter (Model CR 410, Konica Minolta, Sensing Americas Inc., U.S.A.) (Raigar et al., 2020).

2.3 Statistical analysis

Triplicate samples were analyzed using Microsoft Excel 2019 (Microsoft, USA) and reported as the mean \pm SD (standard deviation). A single-factor analysis of variance (ANOVA) was tested for all the experiments by using Origin Pro 8 trial software (OriginLab Corp.,

Northampton, USA) to check the significance level ($p \leq 0.05$) and reported coefficient of determination (R^2).

3 Results and discussion

3.1 Physical dimensions

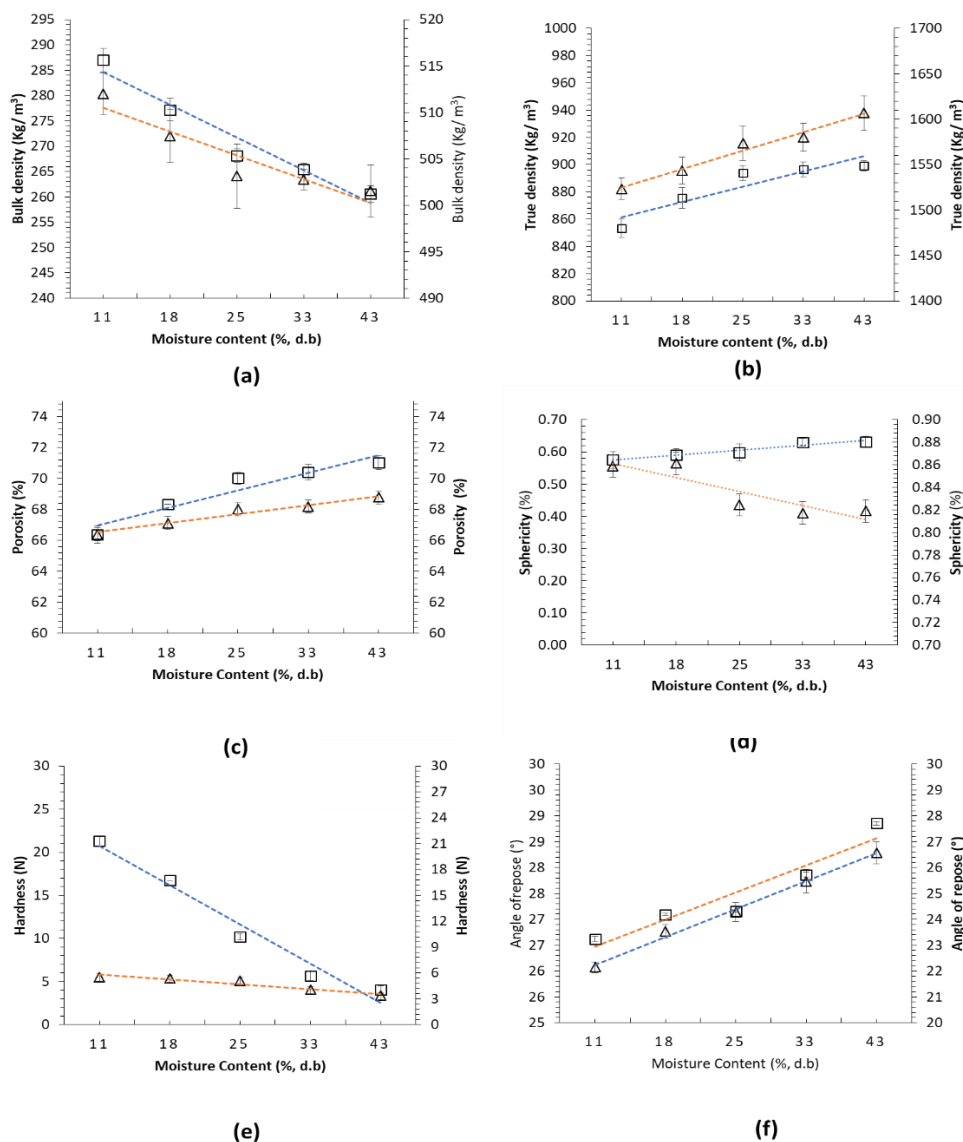
The physical dimensions of black cardamom capsules and their seeds were measured at various levels of moisture content (11% to 43% d.b.), viz., length, width, thickness, and geometric mean diameter, were found in range from 25.60 to 27.63 mm, 13.41 to 15.79 mm, 9.32 to 11.32 mm, and 14.73 to 16.82 mm for capsules and 3.07 to 3.46 mm, 2.59 to 2.72 mm, 2.30 to 2.40 mm, and 2.63 to 2.83 mm for seeds, respectively. The findings for the effect of increasing the different moisture levels on the physical dimensions of the capsule and seed are presented in Table 1. From Table 1, with varying moisture levels from 11% to 43% (db), a significant increase ($p < 0.05$) in all physical dimensions was observed. This was possibly because the moisture may have occupied the space between cells of the seed and resulted in the swelling of Black cardamoms. The mathematic relation between moisture contents and physical dimensions of capsules and seeds is given in Table 2. The higher R^2 shows the adequacy of the results. Similar results were provided by Altuntas and Demirtola (2007) in mung bean seeds and (Gebreselassie, 2012) in green cardamom seeds.

3.2 Geometric dimension (Sphericity)

The sphericity values were obtained from 0.53 to 0.63 for black cardamom capsules and 0.85 to 0.82 for cardamom seeds at various range of moisture content, from 11% to 43% (d.b.). Figure 1d addressed the declining trend in the sphericity of black cardamom seeds, while the sphericity of capsules increased. The decline in sphericity was particularly due to the greater expansion in liner dimension (length) compared to the breadth and thickness of the seed. However, an insignificant decrease ($p > 0.05$) in the sphericity of seeds was obtained at the given moisture ranges. We also show the fit to the relationship between the sphericity and moisture content for seeds and capsules, as illustrated in Table 2. A similar finding was reported

by Gebreselassie (2012) and Singh and Meghwal

(2020).



(a)bulk density, (b) true density, (c) Porosity, (d) sphericity, (e) hardness and (f) Angle of repose of large cardamom capsules (□) and seeds (Δ).

Figure 1 Effect of different moisture content on the engineering properties

Note: The primary and secondary axis for capsule and seeds, respectively

Table 1 Effect of moisture content on length, breadth, thickness and geometric mean diameter of large cardamom capsule and seeds.

	Moisture content (%d.b.)	Length (L) (mm)	Width (W) (mm)	Thickness (T) (mm)	Geometric mean diameter (GMD) (mm)
Capsule	11	25.33±0.306 ^a	13.40±0.100 ^a	9.10±0.215 ^a	14.56±0.138 ^a
	18	25.86±0.115 ^b	13.82±0.112 ^b	9.80±0.045 ^b	15.19±0.072 ^b
	25	26.42±0.131 ^c	14.94±0.085 ^c	10.75±0.081 ^c	16.19±0.090 ^c
	33	27.74±0.040 ^d	15.74±0.050 ^d	11.14±0.115 ^d	16.94±0.499 ^d
	43	27.98±0.104 ^d	15.95±0.040 ^c	11.38±0.104 ^c	17.18±0.073 ^c
Seed	11	3.07±0.070 ^a	2.51±0.070 ^a	2.31±0.036 ^a	2.63±0.030 ^a
	18	3.24±0.040 ^b	2.63±0.015 ^b	2.38±0.030 ^b	2.73±0.018 ^b
	25	3.48±0.104 ^c	2.70±0.011 ^c	2.45±0.035 ^c	2.84±0.036 ^c
	33	3.48±0.63 ^c	2.78±0.026 ^c	2.47±0.030 ^c	2.87±0.473 ^c
	43	3.55±0.050 ^c	2.78±0.028 ^c	2.49±0.015 ^c	2.88±0.016 ^c

Note: Values are mean ± SD, n = 3. Different letters in rows/columns indicate significant differences (Duncan, p < 0.05).

Table 2 Empirical linear relationship between moisture content and properties and ANOVA results of black cardamom capsules and seeds

Properties	Capsule					Seeds				
	Regression equation	R ²	SS	Fca	%cv	Regression equation	R ²	SS	Fca	%cv
Sizes										
L (mm)	0.122x+24.12	0.76	2435.77	14.23	1.45	0.023x+2.822	0.85	18.57	25.20	1.36
W (mm)	0.13x+11.94	0.90	4880.59	38.75	1.39	0.006x+2.535	0.96	3.249	102.86	1.59
T (mm)	0.123x+8.01	0.89	115.16	34.77	2.65	0.004x+2.257	0.93	0.787	54.65	2.63
GMD (mm)	0.118x+13.63	0.79	56.23	16.31	3.55	0.011x+2.521	0.88	5.52	32.22	3.56
Sphericity	0.015x + 0.5603	0.93	59.85	18.69	4.30	-0.0124x + 0.8734	0.80	5.35	35.66	1.56
Bulk density (kg m ⁻³)	-1.20x+295.18	0.89	105.55	34.59	2.30	-0.43x+514	0.83	4.66	21.22	2.69
True density (kg m ⁻³)	1.95x+844.32	0.75	39.40	13.29	1.35	4.06x+1483.25	0.97	18.87	173.20	1.22
Porosity	0.21x+65.18	0.89	83.31	35.92		0.14x+65.10	0.91	79.63	46.55	2.11
Hardness (N)	-8216x+27.60	0.91	12.40	46.51	1.39	-0.12x+7.18	0.93	1.39	58.92	2.26
Angle of repose (°)	0.10x + 25.14	0.98	502.14	251.93	1.99	0.19x + 21.10	0.89	363.97	35.36	1.02

Note: X: moisture content, R²: correlation of coefficient, SS: sum of square, Fca: calculated F value and % Cv: coefficient of variation

3.3 Density

The different levels of moisture content on the bulk density of black cardamom capsules and seeds are reported in Figure 1a. Figure 1a shows that for black cardamom capsules and seeds, the bulk density was found to decrease with increasing moisture level from 11% to 43% db. The significant decline in bulk density was due to a higher increase in bulk volume corresponding to capsule mass. A previous study showed that bulk density mostly decreased with increasing moisture levels (Gebreselassie, 2012; Singh and Meghwal, 2020). According to Table 2, black cardamom seeds and capsules have negative linear equations for their bulk densities. The bulk density was found in the range of 286.98 to 260.55 kg m⁻³ for capsules, while it decreased significantly from 512.01 to 501.53 kg m⁻³ for seeds due to its increased moisture level from 11% to 43% (d.b.).

The results obtained for true density of black cardamom capsules and seeds with varying moisture content are reported in Figure 1b. The true density values were obtained from 853.33 to 899.22 kg m⁻³ and 1523.33 to 1606 kg m⁻³ for capsules and seeds, respectively. It was observed that true density increased with increased in the moisture level from 11% to 43% (d.b.) for both capsules and seeds. Table 2 represents the linear relationships for the true densities of capsules and seeds.

3.4 Porosity

The calculated porosity (%) of the capsules and seed increased linearly which was significant ($p < 0.05$) from 66.36% to 71.02% and 66.38% to 68.78%, respectively, with varying moisture content in Figure 1c. It has been found that porosity increased almost simultaneously for black cardamom capsules and seeds at raise the moisture content from 11% to 43% (d.b.). This reading could be the changes due to more quantity of water absorbed by capsules and seeds and resulted to enhance in volume. As the moisture content increases, the seeds and capsules become saturated with moisture content. A linear equations relationship developed between porosity and moisture content of black cardamom (capsule and seeds) samples, which is given in Table 2. From Table 2, the R² values are calculated as 0.89 and 0.91 for capsules and seeds, respectively. A similar pattern was also observed in jamun seeds by Bajpai et al. (2020).

3.5 Hardness

The hardness was significantly ($p < 0.05$) decreased from 21.31 to 4.08 N for black cardamom capsules and 5.50 to 3.52 N for black cardamom seeds, as the level of moisture increased from 11% to 43% (d.b.). Initially, experiments showed a higher value of hardness for capsules and seeds. This might be due to the lower availability of water in the seed and capsule. Furthermore, upon increasing the moisture content from 11% to 43% (d.b.), there were significant decreases in hardness [Figure 1(e)]. A lower value of

hardness was noticed at higher moisture contents of 43%. This showed that the cardamom capsule and seed were sensitive to moisture content, which might help to loosen the bond between carbohydrate and protein in the capsule wall and seeds of black cardamom by increasing the moisture content. This results in a

decrease in hardness due to the higher moisture content. A similar observation was reported in green cardamom seeds by Balakrishnan et al. (2011). A negative correlation was obtained between the moisture content and hardness of the seeds and capsule, as shown in Table 2.

Table 3 Effect of different moisture content on static coefficient of friction of large cardamom capsule and seeds.

Moisture content (d.b)	Plywood (PW)		Mild steel (MS)		Aluminium (AL)	
	Capsule	Seeds	Capsule	Seeds	Capsule	Seeds
11	0.50±0.07 ^a	0.57±0.02 ^a	0.47±0.04 ^a	0.57±0.02 ^a	0.34±0.01 ^a	0.54±0.04 ^a
18	0.59±0.03 ^b	0.65±0.04 ^b	0.54±0.08 ^{ab}	0.67±0.02 ^b	0.41±0.02 ^b	0.55±0.04 ^a
25	0.62±0.05 ^c	0.66±0.03 ^a	0.61±0.02 ^c	0.68±0.02 ^b	0.55±0.03 ^c	0.66±0.01 ^b
33	0.68±0.02 ^b	0.67±0.02 ^b	0.69±0.02 ^c	0.67±0.03 ^b	0.57±0.08 ^{cd}	0.67±0.01 ^b
43	0.75±0.03 ^c	0.76±0.01 ^c	0.67±0.03 ^c	0.69±0.01 ^b	0.58±0.02 ^c	0.68±0.01 ^b

Note: Values are mean ± SD, n = 3. Different letters in rows/columns indicate significant differences (Duncan, p < 0.05).

Table 4 Colour values of the capsule and seeds at different moisture contents of black cardamom capsules and seeds

Moisture content (d.b)	L* (lightness)		b* (Yellowness)		a* (Redness)		Total colour change (ΔE)	
	Capsule	seeds	Capsule	seeds	Capsule	seeds	Capsule	seeds
11	26.81±0.011 ^c	25.46±1.862 ^c	6.28±0.700 ^b	8.49±1.005 ^c	5.04±0.255 ^b	5.30±0.426 ^b	0	0
18	26.74±0.086 ^c	21.36±0.336 ^b	5.63±0.526 ^{ab}	6.94±0.222 ^b	5.80±0.668 ^b	5.27±0.057 ^b	2.43	4.54
25	26.41±0.230 ^c	20.22±0.213 ^{ab}	5.27±0.070 ^a	6.17±0.181 ^{ab}	5.93±0.005 ^{ab}	5.12±0.124 ^b	1.41	3.94
33	25.78±0.252 ^b	19.33±0.208 ^a	5.23±0.243 ^a	5.79±0.208 ^a	5.42±0.089 ^a	4.790±0.080 ^a	0.527	3.58
43	25.37±0.329 ^a	19.78±0.239 ^{ab}	4.89±0.420 ^a	5.88±0.189 ^a	5.14±0.100 ^a	5.25±0.091 ^{ab}	0.49	3.65

Note: Values are mean ± SD, n = 3. Different letters in rows/columns indicate significant differences (Duncan, p < 0.05).

3.6 Angle of repose (AR)

The AR of the Black cardamom capsule and seed varied from 26.08° to 27.14° and 23.23° to 29.71°, respectively, as the moisture content increased from 11% to 43% d.b. This implied that AR for capsules and seeds increased as the moisture content increased (Figure 1(f)). The increase in the AR was attributed to two primary reasons: first moisture absorption causes the seeds to expand in size; second, increased surface moisture surface enhance cohesiveness and friction within cardamom surface, resulted to more stable. Similarly, increasing trends with increasing moisture content for the AP were also observed by Bajpai et al. (2020) for Jamun seeds, Sanket Sawant et al. (2022) for black cumin seeds, Igbozulike and Amamgbo (2019) for pumpkin seeds, and Kruszelnicka et al. (2022) for maize kernels.

3.7 Static coefficient of friction (S_{CF})

The S_{CF} was evaluated on different surfaces, viz., for plywood (PW), mild steel (MS), and aluminum

(AL). For capsules, the static coefficient of friction ranged from 0.47 – 0.67, 0.33 – 0.58, and 0.49 – 0.75 for PW, MS, and AL, respectively. However, the static coefficient of friction ranged from 0.57 to 0.76 for plywood, 0.57 – 0.68 for mild steel, and 0.53 – 0.68 for aluminum for Black cardamom seeds (Table 3). It is mainly due to the moisture that covers the outside of the seed and increases the force of adhesion between the seed and the surfaces used for evaluation that these trends occur. A higher static friction coefficient on wood was obtained at a higher moisture content of 43%. This might be attributed to the fact that the wooden surface has more roughness and created a more friction compared to mild steel and aluminum. Similar studies were reported for sesame seeds (Yilmaz et al., 2012).

3.8 Color

The effect of different moisture contents on color parameters, i.e., lightness (L*), redness (a*), yellowness (b*), and total color change of black

cardamom capsules and seeds, is presented in Table 4. L^* value significantly decreased from 26.81 to 26.37 for the whole capsule and 25.46 to 19.78 for the cardamom seeds, from 11% to 43% (d.b.) moisture content. The redness to greenness value (a^*) was found to range from 5.37 to 5.22 and 8.49 to 5.89 for black cardamom capsules and seeds, respectively. Similarly, b^* values were observed to range from 5.05 to 5.15 and 5.30 to 5.25, respectively, for black cardamom over the moisture range from 11% to 43% (d.b.). It could be concluded that the lightness and redness of capsules and seeds were reduced with higher moisture content. The total color change also decreases with increasing moisture content (Table 4). For identifying the quality of cardamom during storage, L^* , a^* , and b^* color values are used.

4 Conclusion

Moisture content is the critical parameter that affects the engineering properties of dried spices and herbs and significantly contributes to an improvement in design of food processing machines and equipment. The moisture content is also an important process parameter that directly affects the engineering properties, viz., length, width, thickness, GMD, surface area (Sp), bulk density (BD), true density (TD), porosity, apparent porosity (AP), static coefficient of friction (S_{CF}), hardness, and color values of dried spices. The length, width, and thickness; sphericity, true density, porosity, and angle of repose were significantly enhanced with an increase in levels of moisture content of capsules and seeds of black cardamom, while bulk density followed a reverse trend in the same range of moisture content from 11% to 43% (d.b.). The hardness of samples was noticed to decline from 21.31 to 4.08 N and 5.50 to 3.52 N for black cardamom capsules and seeds, respectively, as the moisture content increased. The SCF values were also observed to increase over the surfaces, namely, plywood (0.47–0.67, 0.57–0.68), mild steel (0.33–0.58, 0.57–0.68), and aluminum (0.49–0.75, 0.53–0.68), for capsules and seeds of black cardamom as the moisture content increased from 11% to 43% d.b. The L^* , a^* ,

b^* , and ΔE were significantly ($P < 0.05$) influenced within the moisture content range. As a result of these measurements, equipment designers, storage facilities, and applications involving black cardamom will benefit.

Acknowledgment

The authors are thankful to Prof. P.P. Dabral, former Dean, College of Agricultural Engineering and Post-Harvest Technology, CAU-Imphal, Ranipool, Sikkim, India, for providing the necessary facility for conducting the research.

Funding

NIL

Conflict of Interest

The authors have no conflicts of interest to declare for this manuscript.

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