Physical properties of large cardamom cultivated in north eastern Himalayan region of Sikkim, India

T. K. Khura[1*], J. Debbarma[2], R. Chandra[2], S. N. Yadav[2],
N. S. Chauhan[2], S. K. Rautaray[2]

(1. *Division of Agricultural Engineering, Indian Agricultural Research Institute, Pusa, New Delhi 110 012, India*;
2. *Department of Farm Power & Machinery, College of Agricultural Engineering & Post Harvest Technology, Central Agricultural University, Gangtok, Sikkim 737 135, India*)

Abstract: The large cardamom is one of the most important spice crops grown in Himalayan region of Sikkim, India. The capsules of the harvested large cardamom are dried before consumption. The paper presents the physical properties of freshly harvested and dried large cardamom capsules. The geometrical mean diameter, sphericity, bulk density and mean values of angle of repose of the freshly harvested large cardamom capsules were observed to be 18.53±1.73 mm, 0.76, 332.21±14.24 kg m^{-3} and 28.74±4.04°, respectively. Whereas for dried large cardamom capsules the values were found to be 11.113±0.92 mm, 0.56, 393.109±9.622 kg m^{-3} and 29.84±2.93°, respectively. The peak static coefficient of friction of freshly harvested large cardamom over mild steel, plywood and plastic film surfaces were 0.386, 0.463 and 0.359, respectively. However, for dried large cardamom capsules, the observed values were 0.436, 0.394 and 0.155, respectively.

Keywords: large cardamom, spice crop, physical properties

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1 Introduction

Large cardamom (*AmomumsubulatumRoxb.*) is an important spice crop cultivated in sub-Himalayan region of North Eastern India, especially in Sikkim (Sharma et al., 2009). It is a perennial herb that belongs to the family Zingiberaceae under order seitaminae (Rao et al., 1993). India is the largest producer of large cardamom in the world with annual production of 4,000 tons, followed by Nepal and Bhutan. More than 85% of the production within India is from Sikkim only (Mande et al., 1999). The large cardamom has great demand in international markets of Pakistan, Bangladesh and Arabian countries. It is used as a flavoring agent in curry, confectionery, hot or sweet pickles and in beverages. It is also credited with curative properties in Ayurvedic and Unani systems of medicine (Singh and Singh, 1996). The plant of large cardamom consists of subterranean rhizomes and several leafy aerial shoot/tillers. It is grown in cold humid condition under shade of trees at an altitude between 800–2,000 m above mean sea level with an average annual precipitation of 3,000–3,500 mm spread over about 200 days and the temperature ranging between 6°C in December–January to 30°C in June–July. The matured large cardamom capsules are collected from the field throughout the day in gunny bags (old or discarded sackcloth packaging bags) or in bamboo baskets (Kishore and Rastogi, 1987). The physical and mechanical properties data of fruits and vegetables are important in adoption and design of various handling equipment involved in, i.e. harvesting,

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*** Corresponding author: T. K. Khura,** Division of Agricultural Engineering, Indian Agricultural Research Institute, Pusa, New Delhi 110012, India. Phone: +91–11–25842336; Fax: +91–11–25846420. Email: tapankhura@gmail.com.

separating, sorting, cleaning, packaging and transportation systems (Singh and Reddy, 2006; Hacıseferoğulları et al., 2007). The physical and mechanical properties of the various fruits and nuts have been extensively reported by various researchers in literature, i.e., Sahoo and Srivastava (2002) for okra seed, Altuntaş and Yıldız (2007) for faba bean *(Viciafaba L)*, Davies (2010) for melon seed, Olalusi and Bolaji (2010) for jatropha seeds, Balakrishnan et al. (2011) for cardamom capsule and Gebreselassie (2012) for cardamom seed. Some of the literature had revealed the physico–mechanical properties of pods/capsules, i.e., Kushwaha et al. (2007) for okra pods and seeds, Bitra et al. (2010) for peanut pods, kernels, and shells but for thermal properties only, Balasubramania et al. (2011) for peanut pods.

This study is aimed to determine some moisture dependent physical properties of freshly harvested and dried large cardamom capsules (dimension, unit mass, volume, sphericity, bulk density, true density, porosity and coefficient of static and dynamic friction on three different surfaces.

2 Materials and methods

The large cardamom capsules were collected from Large Cardamom Farm of Spice Board, Govt. of India at Panthang, East Sikkim in the month of January 2009. The freshly harvested and collected large cardamom was manually cleaned to remove foreign materials like broken and immature nuts. Samples were collected randomly from the stock for this study. The dried large cardamom samples were collected after drying in the dryer at about 80 to 100ºC for two to three days in the farm (Karibasappa, 1987). The moisture content of samples was determined by using the standard of Association of Official Analytical Chemists (AOAC) official method 925.40 (AOAC 2002). The sample size of 100 pieces of each large cardamom capsules was selected randomly from the heap of freshly harvested and dried cardamom. The physical dimensions i.e. major (a), intermediate (b), and minor (c) diameters of randomly selected capsules were then measured by digital vernier caliper at an accuracy of ±0.02 mm (Figure 1). The geometrical mean diameter (D_g) was calculated by using standard relationship as given in Equation (1) (Mohsenin, 1986).

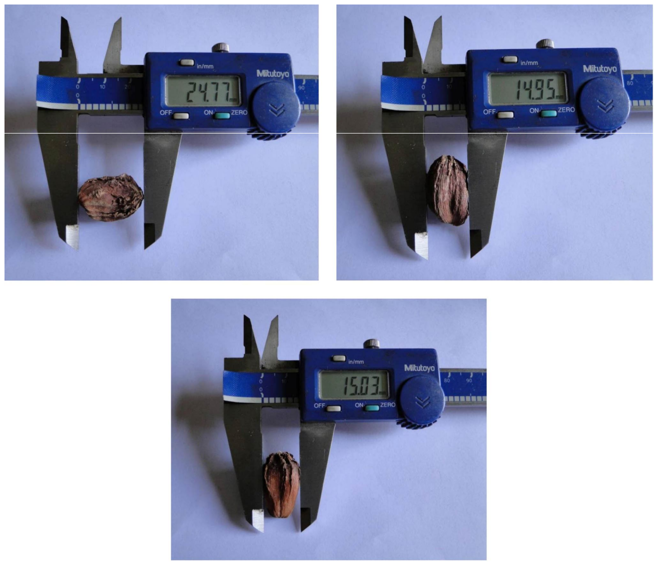

Figure 1 Showing the measurement of major, minor and intermediate diameters

$$D_g = (abc)^{1/3} \tag{1}$$

The sphericity (ϕ) of each sample was calculated using standard relationship as in Equation (2) (Mohsenin, 1986).

$$\phi = \frac{(abc)^{1/3}}{a} \tag{2}$$

The mass of individual fresh and dried large cardamom samples of size 100 was measured with electronic balance at an accuracy of ± 0.01 g. The bulk density of fresh and dried capsules was measured with a box container having dimension of 100×100×100 mm and electronic balance. The measurements were replicated 10 times for each fresh capsules and dried capsules. The bulk density was calculated from the standard relationship using Equation (3) (Mohsenin, 1986).

$$\rho_b = \frac{W}{V} \tag{3}$$

where, ρ_b is the bulk density, kg m^{-3}; W is the mass of capsules, kg; and V is the volume of container, m^3.

The true density was measured using liquid displacement method (Aviara et al., 2005; Ogunjimi et al., 2002). Mass of the single capsules was taken with electronic balance having least count of 0.01 g and a capsule was immersed carefully in 100 mL measuring cylinder partially filled with toluene (C_7H_8). The volume of the toluene displaced by the capsules was noted down. True density was calculated using standard relationship as given in Equation (4) (Mohsenin, 1986).

$$\rho_t = \frac{W}{V_d} \tag{4}$$

where, ρ_t is the true density, kg m^{-3}; W is the mass of the individual capsules, kg; and V_d is the volume of the toluene displaced, m^3.

The porosity was calculated from the average values of bulk densities and true densities using Equation (5) (Thompson and Issac, 1967; Mohsenin, 1986).

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \tag{5}$$

where, ε is the porosity in percentage; ρ_t is the true density, kg m^{-3} and; ρ_b is the bulk density, kg m^{-3}.

The angle of repose was measured using a vertical cylinder made form a sheet with open at both end was filled with the capsules and carefully lifted (Dutta et al., 1988). The angle of repose was calculated using standard Equation (6).

$$\varphi = \tan^{-1}\frac{2h}{d} \tag{6}$$

where, φ is the angle of repose in degree; h is the height of the cone in mm and; d is the diameter of the cone in mm.

The frictional resistance of material movement carrying box over the surface was determined by texture analyzer (Reddy et al., 2004). The coefficients of static and dynamic friction were measured in three different test surfaces (plywood, plastic film and mild steel). A 10 mm clearance was maintained between the bottomless edges of the box frame and test surface after the box was filled. The clearance prevents direct contact between the box and test surface. A 3 mm thread cable was attached to a bottom front edge of the box via an eyebolt and passed around a pulley to the vertical moving cross head of texture analyzer. The pulley was supported on needle bearing in order to minimize friction with the support shaft. An adjustable table top was used to rest the test surfaces over it during the measurements. The table top was so adjusted that the cable between the pulley and box always remained horizontal. The horizontal pull (frictional force) was measured by texture analyzer and was continually recorded by computer software, “Exponent lite”. A typical graph of forces distance travel is shown in Figure 2. For each test, the values of vertical speed of the texture analyzer and vertical distance were fixed as 2 mm s^{-1} and 40 mm, respectively. The discontinuity in the linearly increasing force line on the graph was the static force. This was the level of force used to calculate the peak static coefficient of friction (COF). The maximum amplitude of the consequent undulating, dynamic force line was the peak (peak load) force. This was the maximum force recorded as the box traveled over the test surface and used to calculate the peak dynamic COF. This force was used to determine the static and dynamic coefficient of friction using the Equation (7) (Aydin, 2002; Chung and Verma, 1989).

$$\mu = \frac{F_m}{W} \tag{7}$$

where, μ is the coefficient of friction; F_m is the measured force and; W is the weight of the sample with the box.

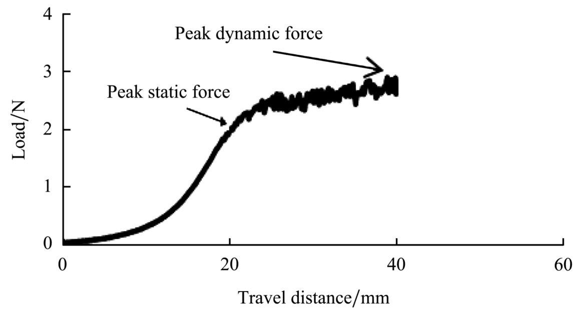

Figure 2 Typical force–travel distance curve for friction coefficient test of large cardamom

3 Results and discussion

3.1 Moisture content of large cardamom

The moisture content of freshly harvested and dried large cardamom capsules is presented in Table 1. The initial moisture content of freshly harvested large cardamom capsules was observed in the range of 68.98 - 80.56%, with an average value of 74.32±3.47% on wet weight basis. Whereas, for dried large cardamom capsules it ranged from 9.87 to 11.52%, with an average value of 10.91±0.61% on wet weight basis. The reported moisture content of the large cardamom at the time of harvesting and after drying is about 70-80% and below 10% on wet basis of mass, respectively. Similar results were reported by Mande et al. (1999).

Table 1 Shape and size of raw large cardamom capsules

Parameter	Fresh large cardamom capsules		Dried large cardamom capsules	
	Mean	Range	Mean	Range
Major diameter/mm	24.48 (2.97)	31.25-18.31	19.98 (2.84)	26.52-12.40
Minor diameter/mm	12.92 (1.79)	16.76-8.83	7.23 (0.97)	10.82-5.17
Intermediate diameter/mm	20.32 (2.16)	25.38-14.93	9.65 (1.13)	12.05-6.49
Geometrical mean diameter/mm	18.53 (1.73)	22.47-14.51	11.113 (0.92)	13.50-8.94
Sphericity	0.76 (0.07)	0.603-0.903	0.563 (0.06)	0.64-0.813
Moisture content/% (wb)	74.32 (3.47)	68.98-80.56	10.91 (0.61)	9.87-11.52

Note: values in parenthesis represent the value of standard deviation.

3.2 Size and shape of large cardamom

The shape of the large cardamom is defined by major, minor and intermediate dimension of the large cardamom. The observations recorded for freshly harvested capsules and dried capsules are presented in Table 1. The average major, minor and intermediate diameters of the freshly harvested capsule were 24.48±2.97 mm, 12.92 ±1.79 mm and 20.32 ±2.16 mm, respectively. Whereas, the major, minor and intermediate mean diameters of dried large cardamom capsules were found as 19.98±2.84, 7.23±0.97 mm 9.65±1.13 mm, respectively. In the freshly harvested capsules samples about 74% had a thickness in the range of 8-12 mm, about 75% had a width in the range of 14-22 mm and about 76% had a length in the range of 18-24 mm. The frequency distribution curves of the fresh and dried large capsules are shown in Figure 3. About 80% of dried large cardamom capsules had a thickness range of 4-8 mm, about 84% had a width range of 6-10 mm and about 74% had a length range of 12-18 mm. The geometrical mean diameter of the fresh large cardamom and dried large cardamom was 18.53±1.73 mm and 11.11±0.92 mm, respectively. The geometric mean diameter (GMD) values of dried large cardamom decreased by 40% from the freshly harvested capsules. Many other researchers like Razavi et al. (2007), Davies (2010), Olalusi and Bolaji (2010) and Balakrishnan et al. (2011) have confirmed the influence of moisture content on the physical properties of cardamom and other seeds.

The sphericity of the freshly harvested and dried large cardamom capsules were 0.76 and 0.56, respectively. The sphericity of dried large cardamom was reduced by about 26.0% compared to the freshly harvested large cardamom capsules. Balasubramanian et al. (2011) reported the range of sphericity for peanut pods as 0.6–0.7. Similar trends of increase in sphericity have been reported by Altuntaş and Yıldız (2007) for faba bean, Vilche et al. (2003) for quinoa seed, Aydin et al. (2002) for Turkish mahaleb and Sahoo and Srivastava (2002) for okra seed.

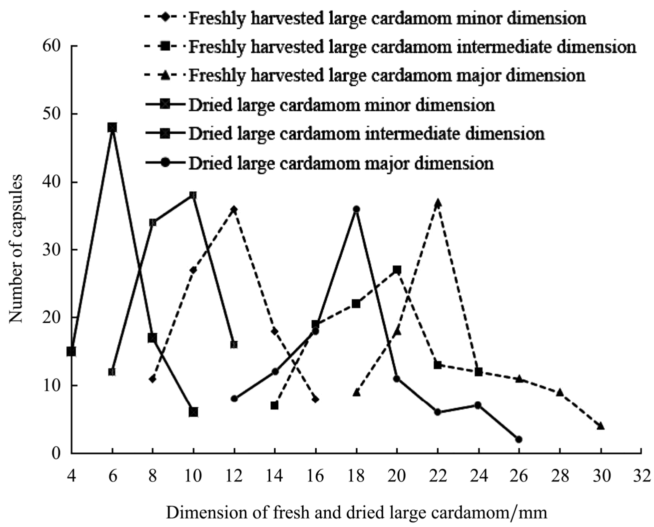

Figure 3 Frequency distribution curves for freshly harvested and dried large cardamom dimension

3.3 Mass of large cardamom capsules

The mass of freshly harvested and dried large cardamom capsules is shown in Table 2. The mass of freshly harvested large cardamom capsules was found ranging from 2 g to 7 g with a mean mass per unit capsules of 4.34±1.140 g. The mass of dried large cardamom capsules varied from 0.16 g to 1.45 g with an average value of unit capsules of 0.782±0.45 g. Similar, results have been reported by Altuntaş and Yıldız (2007) for faba bean (*Viciafaba L*), Gezer et al. (2002) for apricot kernel and Baryeh (2002) for millet.

Table 2 Mass, bulk density, true density, porosity and angle of repose of large cardamom capsules

Parameter	Freshly harvested large cardamom		Dried large cardamom	
	Mean	Range	Mean	Range
Mass/g	4.34 (1.14)	2.198-6.80	0.782 (0.45)	0.16-1.45
Bulk density/kg m^{-3}	332.21 (14.24)	284.16-355.07	393.11 (9.62)	371.57-403.26
True density/kg m^{-3}	879.67 (87.49)	730.43-1047.52	789.49 (169.46)	479.8-1187.0
Porosity/%	54.86 (5.13)	44.82-64.52	55.97 (9.74)	31.39-71.70
Angle of repose/(°)	28.74 (4.04)	25.3-35.48	29.84 (2.98)	27.3-31.26

Note: Values in parenthesis represent the value of standard deviation.

3.4 Bulk density, true density and porosity

The physical properties of large cardamom, including bulk density, true density and porosity, which are of prime importance and represents the volume of material involved in various handling operations, are shown in Table 2. The average values of bulk density of freshly harvested and dried large cardamom were 332.21±14.24 kg m^{-3} and 393.109±9.622 kg m^{-3}, respectively. The bulk density of the large cardamom was found to decrease with increase in moisture content and similar results, which were reported by Aviara et al. (2005) for balanites aegyptiaca, Pradhan et al. (2009) for jatropha seed, Balakrishnan et al. (2011) for cardamom capsule and Gebreselassie (2012) for cardamom seed. The true densities of freshly harvested and dried large cardamoms were found as 879.67±87.49 kg m^{-3} and 789.489±169.46 kg m^{-3}, respectively. The true density of the large cardamom capsule showed a positive relationship with the moisture content. Similar trend with moisture content has been reported by Aviara et al. (2005) for balanites aegyptiaca. The porosity of freshly harvested and dried large cardamom increased with the increase in moisture content of the capsules. Similar trends of porosity have been reported by Aydin (2003) for almond nut, Konak et al. (2002) for chick pea seeds, Aydin (2002) for hazel nuts and Abalone (2004) for amaranth seeds.

3.5 Angle of repose

The angles of repose of freshly harvested and dried large cardamom were found to range from 35.48° to 25.3° and 31.26° to 27.3° with mean value of 28.74±4.04° and 29.84±2.93°, respectively. The angle repose of the freshly harvested large cardamom was found to be more than that of dried large cardamom capsules.

3.6 Frictional properties

The frictional properties (peak static coefficient of friction, peak dynamic coefficient of friction and average coefficient of friction) of freshly harvested and dried large cardamom observed over the different surfaces are summarized in Table 3. It was observed that the peak static coefficient of friction of freshly harvested large cardamom over the surface of mild steel, plywood and plastic film surfaces were 0.386, 0.463 and 0.359, respectively. Whereas, the peak static coefficient of friction of dried large cardamom over the surface of mild steel, plywood and plastic film surfaces were found as 0.436, 0.394 and 0.155, respectively. The peak static frictional force was found lowest over the plastic film surface in comparison to the mild steel and plywood surfaces in both the cases of freshly harvested and dried large cardamom, which is clearly evident from Figures 4 and 5. The peak dynamic coefficient of friction of freshly harvested and dried large cardamom was 0.166 and 0.124 for mild steel surface, respectively; 0.198 and 0.218 for plastic plywood, respectively and; 0.85 and 0.105 for polythene surface, respectively. The observed result showed that the peak dynamic coefficient of friction for the plastic film surface is lowest in comparison to the mild steel and plastic surfaces.

The average coefficient of friction of freshly harvested large cardamom capsules on mild steel, plywood and plastic film surfaces were 0.276, 0.331 and 0.222, respectively, however, for dried large cardamom the average coefficient of friction were found as 0.280, 0.306 and 0.130, respectively. The dynamic coefficient of friction on galvanized mild steel surface, plywood and plastic film surfaces for freshly harvested large cardamom was found more than that the dried large cardamom. The effect of the moisture content on dynamic coefficient of friction was observed to have more significant effect as reported by Ögüt (1998) for white lupin and Aydin (2002) for hazel nuts (see Figure 4 and Figure 5 please).

Table 3 Coefficient of friction of freshly harvested and dried large cardamom capsules

Test surface	Freshly harvested capsules			Dried capsules		
	Peak static COF	Peak dynamic COF	Average COF	Peak static COF	Peak dynamic COF	Average COF
Mild steel	0.386 (0.61)	0.166 (0.84)	0.276 (0.59)	0.436 (0.03)	0.124 (0.89)	0.280 (1.06)
Plywood	0.463 (0.35)	0.198 (0.42)	0.331 (0.74)	0.394 (0.01)	0.218 (0.71)	0.306 (0.54)
Plastic film	0.359 (0.57)	0.085 (0.34)	0.222 (0.85)	0.155 (0.01)	0.105 (0.53)	0.130 (0.23)

Note: Values in parenthesis represent the value of standard deviation.

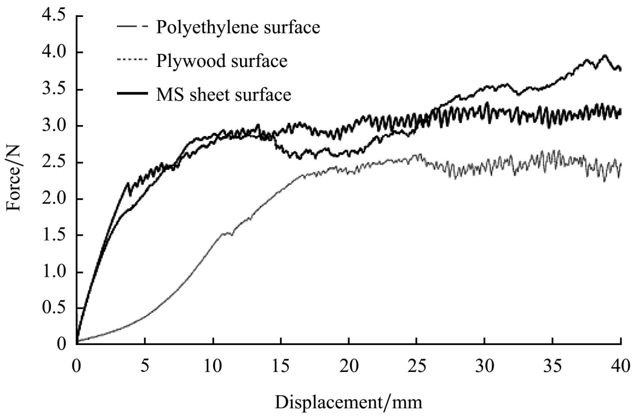

Figure 4 Force–displacement relationships, for freshly harvested large cardamom capsules

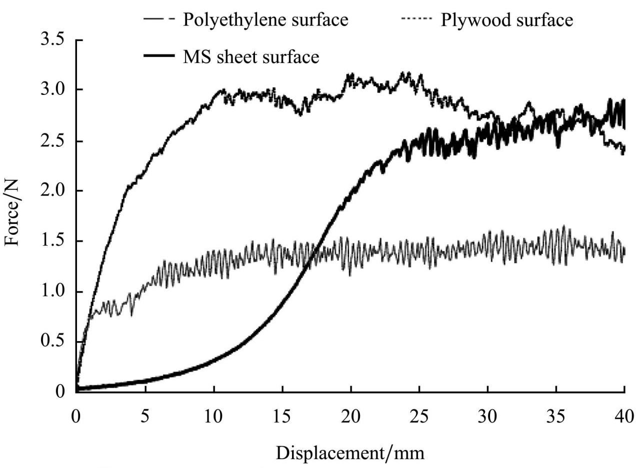

Figure 5 Force–displacement relationships, for dried large cardamom capsules

Kushwaha et al. (2007) reported that the compressive strength of okra pod varied from 146.1 N to 238.3 N at the corresponding displacement of 5.8 to 7.0 mm. However, the mean value of peak compressive force required to rupture the seed occurred to 96.9 N at the corresponding displacement of 0.9 mm.

4 Conclusions

The investigations on physical properties of freshly harvested and dried large cardamom capsules revealed that the properties are largely dependent on moisture content, and were observed as followings:

1) The dimensions of the large cardamom capsules decreased with decrease in moisture content, i.e., the major diameter of dried capsules (contained moisture range 9.87-11.52% on wet basis) were ranged 26.52-12.40 mm, in comparison to freshly harvested 31.25-18.31 mm having moisture content range of 68.98-80.56% on wet basis. Similar effect on minor and intermediate diameters had been observed. The mean values of major diameter for freshly harvested and dried large cardamom were 24.48 mm, and 19.98 mm, respectively. The values of error among the data for freshly and dried large cardamom were found 2.97, and 2.84, respectively, in term of standard deviation.

2) The bulk density of the large cardamom capsules was increased with decrease in moisture content, i.e., 284.16–355.07 kg m^{-3} for freshly harvested to 371.57–403.26 kg m^{-3} for dried large cardamom capsules. The mean values of bulk density for freshly harvested and dried large cardamom were 332.21 kg m^{-3}, and 393.11 kg m^{-3}, respectively. The values of error among the data in term of standard deviation were found 14.24, and 9.62, respectively, for freshly and dried large cardamom.

3) The true density of the large cardamom capsules decreased with decrease in the moisture content, i.e., ranged between 730.43-1,047.52 kg m^{-3} for freshly harvested to 479.8-1187.0 kg m^{-3} for dried large cardamom. The average values of true density for freshly harvested and dried large cardamom were 879.67 kg m^{-3}, and 789.49 kg m^{-3}, respectively, with a standard deviation of 87.49, and 169.46, respectively.

4) The porosity of the large cardamom capsules was marginally decreased with decrease in the moisture content, i.e., ranged between 44.82-64.52% for freshly harvested to 31.39-71.70% for dried large cardamom. The average values of porosity for freshly harvested and dried large cardamom were 54.86%, and 55.97%, respectively, with a standard deviation of 5.13, and 9.74, respectively.

5) The angle of repose of the freshly harvested large cardamom capsules was higher than that of the dried large cardamom capsules. The value of angle of repose was ranged to be 25.3-35.48°for freshly harvested capsules to 27.30-31.26°for dried capsules. The average values of angle of repose for freshly harvested and dried large cardamom were 28.74°, and 29.84°, respectively.

6) The dynamic coefficient of friction of the freshly harvested large cardamom capsules was also higher than that of the dried large cardamom capsules over all three tested surfaces.

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Nomenclature

ρ_b	bulk density
ϕ	Sphericity
ρ_t	true density
ε	Porosity
φ	angle of repose
μ	coefficient of friction
°	angle in degree
C_7H_8	Toluene
COF	coefficient of friction
GMD	geometric mean diameter
wb	wet basis

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