Effect of moisture content on physio-mechanical properties of coriander seeds (*Coriandrum sativum*)

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Abstract: Study to determine physical and mechanical properties of seeds at different moisture content is necessary for the design of equipment to handle, process, transport, and store the same. The physical properties of coriander seeds have been evaluated as a function of seed moisture content, varying from 8% to 16% (w.b.). In the moisture 11.2%, seeds major, minor and medium dimensions were 5.062, 3.27, and 3.404 mm respectively. Sphericity of the seeds was found to be 0.757 with a surface area of 46.167 mm^2. One thousand seed weight increased linearly from 8.89 to 9.826 g when the moisture content increases from 8.5 to 15.89% (w.b.). The true density of coriander seeds decreased when the moisture content increased 8.73 to 12%, from this point, true density increased with increasing moisture content while the bulk density of coriander seeds varied initially from 260 to 245.5 kg m^{-3} in 8 to 15% MC (w.b.). As the moisture content of seeds increased the bulk density decreased. Also, the porosity started at 24.284% and reduced nonlinearly to 22.88% at 11.50% seed moisture content then increased nonlinearly up to 27.466% at 16.67% seed moisture content. Static coefficient of friction was observed lowest for stainless steel sheet and maximum for galvanized iron sheet. The angle of repose increased linearly from 25.5° to 30.1° with the increase in moisture content. Mechanical properties was found to be a function of moisture content, as moisture content of the product increased failure force reduced but failure deformation increased.

Keywords: physical properties, mechanical properties

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1 Introduction

Physical and mechanical properties of agricultural products are the most important parameters required to determine the standards of design of product handling; processing and packaging systems (Altuntas et al., 2005). The major moisture-dependent physical properties of biological materials are shape, size, bulk density, true density, porosity, mass of products and friction against various surfaces (Murthy and Bhattachayra, 1998). The knowledge of shape, size and density is valuable in designing the planting, threshing and grading process equipment. Size of the grains was determined by measuring the length, breadth, and thickness (Mohsenin, 1970; Shepherd and Bhardwaj, 1986; Dutta et al., 1988, and Joshi et al., 1993). The frictional properties such as the angle of repose and the coefficient of friction are important properties in design of seed bins and other storage structures including the compressibility and flow behaviour of materials (Joshi et al., 1993; Singh and Goswami, 1996). Both dynamic and static frictions of coefficient were important parameters in the design of storage structures and handling equipment for granular materials (Stewart et al., 1969). It is increased with increasing moisture content of grain. Yalcın (2007) also studied the physical properties of coriander but not give any information about the change in the mechanical properties with the moisture content.

The mechanical properties of a material are those properties that involve a reaction to an applied load. Often food materials are subject to forces (loads) when they are processed. Deformation Force calculation and material

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deformation characteristics (elongate, compress, twist) were the function of applied load, time, temperature, and other condition. The results of such tests are used for engineering design (for example, failure theories based on strength, or deflections based on elastic constants and component geometry) and quality control either by the materials producer to verify the process or by the end user to confirm the material specification and quality. Mechanical properties are also used to help classify and identify material. The properties considered for food material are strength, failure force, failure deformation, fracture force and deformation. Many spices including coriander are ground to coarse or line particles to provide convenience to the human consumption. Further the unit operation of grinding adds to the cost and hence becomes a process of value addition. It is obvious that some portion of input mechanical energy is transformed in to thermal energy during grinding. The extent of transformation of mechanical energy depends on several factors including raw material attributes type and design of grinding system and grinding characteristic of the material.

Coriander has been selected as the row material for the present study. There is scarcity of information on physical and mechanical properties of coriander seed. In general, information on these aspects is necessary for designing or adopting any processing and handling equipment. However, these properties are directly useful for designing the grinding system of coriander seed. Hence, in the present study efforts have been made to determine these properties as a function of moisture content.

2 Materials and methods

2.1 Sample preparation

For the present study, coriander was obtained from Central Institute of Post-Harvest Engineering and Technology (CPHET), Ludhiana, Punjab. The coriander seeds were cleaned manually to separate out the stones, dirt, dust broken, foreign and unwanted matters from the main sample of coriander. The initial moisture content of the coriander was determined by oven drying method at 105°C for 24 h until a constant weight was obtained (Pomeranz et al., 1996, and Ranganna, 1995). The moisture content of the samples was set at different levels between 3 to 15% M.C. (w.b.). To vary the moisture content of the sample, the predetermined quantity of coriander seed was dried down to the desired moisture content. To obtain higher moisture content, adding calculated amount of distilled water using the following Equation (Sahay and Singh, 2004).

$$Q = \frac{W_i(M_f - M_i)}{100 - M_f} \tag{1}$$

where, Q is quantity of water added (mL); W_i is initial mass of sample (g); M_i is initial moisture content (% d.b.); M_f is final moisture content (% d.b.).

The coriander seeds were kept in sealed and moisture resistant flexible polyethylene bags. The sample was kept at 5°C in a refrigerator for one week to enable the moisture to distribute homogeneously throughout the bulk coriander seeds. Before starting of experiment, samples were taken out from refrigerator and were allowed to warm up to the room temperature. The pouches were opened just before starting of the experiment (Singh et al., 1996; Altuntas et al., 2005). Different physical properties were investigated at five different moisture levels ranging from 5 to 15% (w.b.).

2.2 Physical properties coriander seeds

The size of coriander seeds was determined at the initial moisture content of 11.2%. Other physical properties like sphericity, true density, bulk density, porosity and coefficient of static friction at various surfaces were determined at different moisture contents.

To select an appropriate method for the determination of the above properties of coriander seeds, the literatures on other agricultural materials have been reviewed. In selecting methods, it was considered that the method should be simple to use, yield fairly accurate results and should have wide acceptability.

2.2.1 Size, Sphericity (Ψ), Surface area(S)

To determine the average size of the coriander seeds, one hundred seeds were randomly picked and their three principal dimensions, namely length, breadth and thickness were measured using a travelling microscope reading to an accuracy of ±0.01 mm. Sphericity of coriander was calculated by using Equation (2).

$$\psi = \frac{\sqrt[a]{XYZ}}{X} \tag{2}$$

Seed volume, V and seed surface area, S may be calculated by

$$V = \frac{\pi B^2 X^2}{6(2X - B)} \tag{3}$$

$$S = \frac{\pi B X^2}{2X - B} \tag{4}$$

where, $B=(YZ)^{0.5}$; X = Length, mm; Y = Width, mm; Z = Thickness, mm.

2.2.2 Bulk density

Bulk density is a property of powders, granules and other "divided" solids, especially used in reference to mineral components (soil, gravel), chemical substances, (pharmaceutical) ingredients, foodstuff or any other masses of corpuscular or particulate matter. It is defined as the mass of many particles of the material divided by the total volume they occupy (11, 12). The total volume includes particle volume, inter-particle void volume and internal pore volume. The average bulk density of coriander was determined by using a container of known volume. Coriander seed volume was determined by subtracting Container weigh before and after filling with coriander.

$$\text{Bulk density (kg m}^{-3}) = \frac{\text{Weight of known volume of Grains}}{\text{Volume of Grains}}$$

2.2.3 True density

True density (ρ_t) is the ratio of unit mass to the space occupied by the material. In the present study the average true density at various moisture levels was determined by multivolume pycnometer. The average true density of coriander seeds was calculated by using following Equation (5).

$$\rho_t = \frac{W_{samp}}{V_{samp}} \tag{5}$$

where, W_{samp} = weight of sample kept in pycnometer, g; V_{samp} = volume of sample, cc; $V_{samp} = V_{cell} - \frac{V_{\exp}}{\left[\left(\frac{P_1}{P_2}\right) - 1\right]}$, V_{cell} = Volume of cell, cc, = 142.91 cc, $V_{\exp}$ = Volume observed by experimental, cc, = 70.24 cc, P_1 & P_2 = pressure of multivolume pycnometer before and after nob revolution, bars.

2.2.4 Porosity

Porosity is the void space in the bulk grain which is not occupied by the grain (Thompson and Isaac, 1967). Porosity was calculated from the following relationship (ISI, 1967) Equation (6)

$$P_f = (1 - \frac{\rho_b}{\rho_t}) \times 100 \tag{6}$$

where, P_f = Porosity,%; ρ_b = Bulk density, kg m^{-3}; ρ_t = True density, kg m^{-3}.

2.2.5 Thousand seed mass

The weight of 1,000 seed was obtained by counting 250 seeds for the desired moisture content and weighed on an electronic balance and then multiplied by four to give the mass of 1,000 seeds.

2.2.6 Angle of repose

To determine emptying or dynamic angle of repose, a plywood box 300 × 300 × 300 mm^3 in size, having a removable front panel was used. The box was filled with the sample, then the front panel was quickly removed, allowing the seeds to flow and assume a natural slope. The angle of repose was calculated from the measurement of the height of the free surface of the sample at the centre.

2.2.7 Static coefficient of friction

The static coefficient of friction of coriander seeds was determined against four metallic surfaces, made of mild steel, galvanized iron, stainless steel and aluminium following the methodology described by many research workers (Brusewitz, 1975, Dutta et al., 1988, and Joshi et al., 1993).

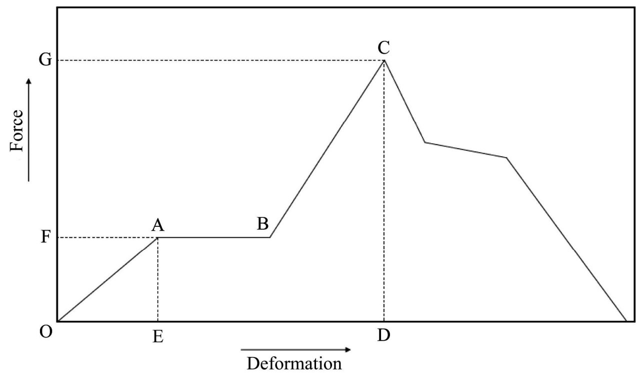
A polyvinyl chloride pipe of 50 mm diameter and 50 mm height was placed on an adjustable tilting plate, faced with the surface, and filled with the sample. The cylinder was raised about 2 mm above the base of the bulk seed so as not to touch the surface. The structural surface with the cylinder resting on it was inclined gradually with a screw device until the cylinder along with the sample just started to slide down and the angle of tilt was read from a graduated scale. The coefficient of friction was calculated from the following relationship.

$$\mu = \tan\Phi \tag{7}$$

where, μ = coefficient of friction; Φ = angle of tilt, degree.

3 Mechanical properties: Uniaxial Compression and Failure behaviour

A Texture Analyser (Model No TA-XT2i) was used to compress the seed at a crosshead speed 10 mm/s using a load cell with a capacity of 25 kg. The seeds were compressed to 40% of their original size for estimation of failure characteristics. Typical uniaxial compression curve along with the different parameters estimated. These were failure force, failure deformation, fluence force, fluence deformation, failure energy. Mohsenin (1986), describe the failure energy can be denoted as the work required to cause rupture or failure, and is a rough measure of toughness of the sample. Saiedira et al. (2008), describe effect of different property and parameter on mechanical properties of cumin. The number of seeds tested at each moisture level was 20 with two replications.



Where, A = Fluence point, C = Rupture point, OD = Rupture deformation, OE = Fluence deformation, F = Fluence force, G = Fracture force, OA = Initial elastic index (slope), ABCDE (area) = Rupture energy

Figure 1 Characteristic force–deformation curve

4 Results and discussion

4.1 Physical properties of coriander seeds

4.1.1 Coriander seeds dimensions

The mean dimensions of 100 coriander seeds are taken at 11.2 % moisture content on dry basis were found to be as follows:

Length = 5.06 mm

Width = 3.27 mm

Thickness = 3.40 mm

Arithmetic mean diameter =3.91 mm

Geometric mean diameter = 3.83 mm

Sphericity = 75.74

Surface area = 46.17

4.1.2 Bulk density (ρ_b)

The bulk density of coriander seeds varied initially from 260 to 245.5 kg m^{-3} in 8 to 15% MC (w.b.). As the moisture content of seeds was increased the bulk density decreased as shown in Figure 2. The relationship between moisture level variation and bulk density can be represented by a linear regression Equation (8).

$$\rho = 264.48 - 0.6039M \quad (R^2=0.9741) \tag{8}$$

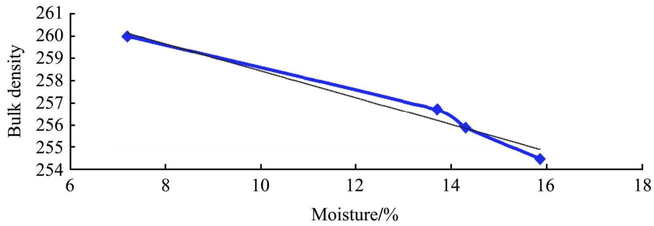


Figure 2 Variation in bulk density with moisture content of coriander seeds

A similar trend of bulk density for other seed material was reported by many researchers such as for Pistachios (Hsu, 1991), for cumin seed (Singh et al., 1996), for black pepper (Murthy, 1998), for millet (Singh et al., 2010). The initial increase in the bulk density is due to greater increase in mass than volume. On the other hand, as the moisture content was increased beyond 15% (d.b.), volume expansion and pore spaces became proportionally greater which resulted in a decrease of bulk density of cumin (Singh and Goswami, 1996).

4.1.3 True density (ρ_t)

It was found that as the moisture content varied from 8 to 15% (w.b.) true density of coriander seeds varied from 343.89 to 348 kg m^{-3} and the results are shown in Figure 3.

$$\rho_t = 421.46 - 14.901M + 0.6256M^2 \tag{9}$$

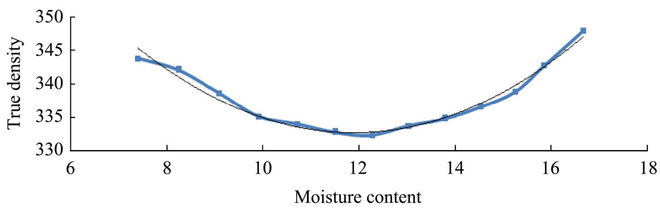


Figure 3 Variation in true density with moisture content for coriander rhizome

The true density values of coriander seeds decreased when the moisture content increased 8.73 to 12% (Figure 3), from this point, true density increased with increasing moisture content. The particular increase of true density indicates that the increase in weight gain in the sample is greater than volume increase of seed between 12 and 15.85% moisture content. Baryeh (2002) described that could be due to the cell structure, and the volume and mass increase characteristics of grains and seeds as moisture content increases. A similar trend of true density for other seed also was found by recent researcher's, for instance, for pomegranate seed (Kingsly, 2006), Tef seed (Zewdu, 2007) and linseed (Selvi, 2006). Trend of true density with rising moisture content can be shown by following regression Equation (9).

4.1.4 Porosity (€)

The porosity was calculated with the help of Equation (6). The variation in porosity is shown in Figure 4. The porosity started at 24.284% and reduced nonlinearly to 22.88% at 11.50% seed moisture content then increased nonlinearly up to 27.466% at 16.67% seed moisture content. The variation in porosity with respect to varying moisture content can be represented by the following polynomial Equation (10).

$$\in = 40.361 - 3.1457M + 0.1416M^2 \quad (R^2=0.9895) \quad (10)$$

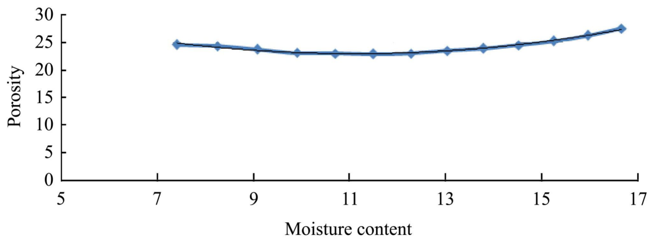


Figure 4 Variation in porosity with moisture content of coriander seeds

The porosity varied from 24.28% to 27.466% with increasing moisture content level from 8 to 15% (w.b.). A similar trend of increase in porosity with increase in M.C. was observed by many researchers such as for millet (Baryeh, 2002), and for fuzzy cotton seed (Manimehalai, 2006). Since the porosity depends on the bulk and true densities the magnitude of variation in porosity depends on these factors only. Therefore the dependency of porosity on density was different, for each seed or grain with increasing moisture content.

4.1.5 Thousand seed mass

The relationship between moisture content and 1,000 seed mass is shown in Figure 5. It increased linearly from 8.89 to 9.826 g when the moisture content changed from 8.5% to15.89% (w.b.). The relationship can be represented by the Equation (11).

$$W_{1000} = 7.7629 + 0.1639M - 0.0023M^2 \quad (R^2=0.9888) \quad (11)$$

where, W_{1000} is the one thousand seed mass in g.

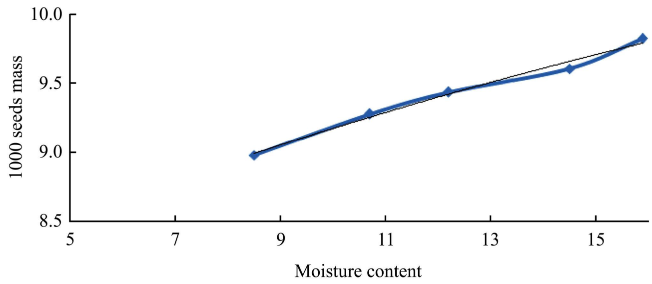


Figure 5 Effect of moisture content on 1000 seed weight of coriander seed

4.1.6 Angle of repose

The experimental values of the dynamic angle of repose (θ) of coriander seed increased from 25.5 to 31 with increase of moisture content from 8.5% to 15.89% (w.b.) as shown in Figure 6. The relationship can be expressed in Equation (12) form as follows:

$$\theta = 26.579 - 0.05966M + 0.0548M^2 \quad (R^2=0.9942) \quad (12)$$

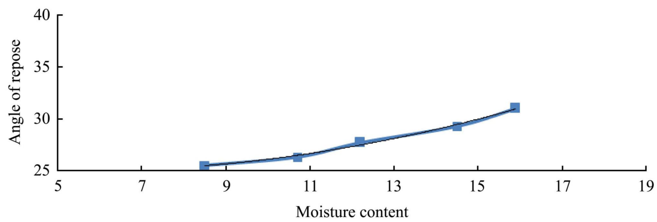


Figure 6 Effect of moisture content on angle of repose of coriander seed

A nonlinear increase in angle of repose with the increase in the seed moisture content has also been noted by Singh and Goswami (1996) for cumin seeds. The angle of response values of coriander seeds are lower than millet (Baryeh, 2002), higher than fenugreek seed (Altuntas et al., 2005).

4.1.7 Coefficient of static friction (μ)

The static coefficient of friction for coriander seeds was experimented on different surfaces and the results are shown in Figure 7. Static coefficient of friction was observed lowest for stainless steel sheet and maximum for galvanized iron sheet.

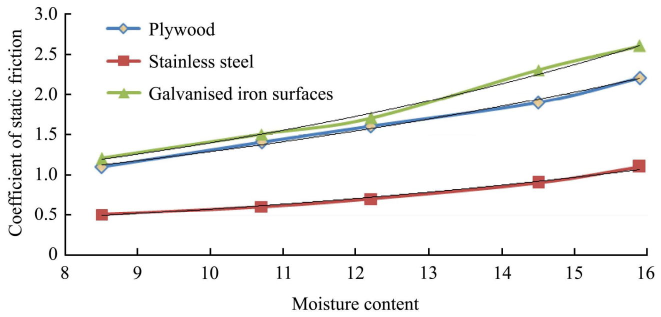


Figure 7 Coefficient of static friction with moisture content of coriander seeds

The relationship between moisture content and static coefficient of friction for surfaces are shown as

For plywood surface

$$\mu_p = 0.425 + 0.0466M + 0.004M^2 \quad (R^2=0.996)$$

For stainless steel surface

$$\mu_s = 0.8425 + 0.1035M + 0.0075M^2) \quad (R^2=0.0079)$$

For galvanised iron

$$\mu_g = 1.2232 - 1.073M + 0.0123M^2 \quad (R^2=0.9962)$$

The static coefficient of friction increased linearly with respect to moisture content for all four surfaces. As the moisture contents were increased, the seed became rougher and sliding characteristics diminished, so that the static coefficient of friction increased (Singh and Goswami, 1996).

4.2 Mechanical properties

Compression is the most common force applied in grinding of coriander seed. Hence, compression of the seeds at different moisture contents was studied employing the technique of uniaxial compression. The failure characteristics were also determined. The different parameters (failure force, failure deformation, and fluence force, fluence deformation), derived from the uniaxial compression study on coriander seed at various moisture contents are shown in Table 1. Initially, at low compression force, the seed offered little resistance towards compression, and exhibited a linear relationship that could be designated as the elastic behaviour of the seed. The soft outer coat possibly could offer little resistance during the initial stages of compression. Once the outer coat was compressed the inside hard core offered considerable resistance resulting in a line with large gradient thus denoting plastic behaviour. As the extent of compression was increased the seed suddenly ruptured into segments (this was the failure point) and thus the force decreased drastically the portion of the curve beyond the failure point would have little importance. An increased moisture content reduced failure force. Decrease in failure force being uniform. At low moisture content it was the outer coat that mostly absorbed moisture, whereas increased moisture addition allowed the inner core to absorb moisture gradually. Thus, with the increase in the moisture content the inner core became markedly soft only when the moisture was high. This was expected as the whole seed becomes soft at high moisture level. Further moisture altered the mechanical strength of the product by plasticising and softening the starch/protein matrix.

Table 1 Parameters derived from compression test of coriander seeds at different moisture content

Moisture content % M(w.b)	Failure force F/g	Failure deformation/mm	Fluence force/g	Fluence deformation/mm
8.73	823.24	1.1156	499.75	0.26375
13.69	774.925	1.128	417.77	0.3194
14.29	782.425	1.1285	417.32	0.4534
15.85	693.66	1.4374	348.24	0.7987

5 Conclusions

1) Dimension of coriander seed were major 5.062333 mm, miner 3.271333 mm and medium 3.404333 mm.

2) The bulk density of coriander seeds increased from 260 to 245.5 kg m^{-3} in 8 to 15 % MC (w.b).

3) True density varied from 343.89 to 348 kg m^{-3} for coriander seeds as the moisture content raised from 8 to 15% (w.b.).

4) The porosity of coriander started at 24.284% and reduced nonlinearly to 22.88 % at 11.50% seed moisture content then increased nonlinearly up to 27.466% at 16.67% seed moisture content.

5) 1,000 seed mass of coriander seeds increased linearly from 8.89 to 9.826 grams when the moisture content changed from 8.5 to15.89% (w.b.).

6) Dynamic angle of repose (θ) of coriander seed increased from 25.5 to 31 with increase of moisture content from 8.5% to 15.89% (w.b.).

7) The static coefficient of friction increased linearly

with respect to moisture content for all four surfaces.

8) As the moisture content of the seed increased, failure force decreased but failure deformation increased and absorbed energy increased.

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