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Physico-mechanical properties of black pepper (*Piper nigrum* L.)

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Abstract

The physical and mechanical properties of black pepper were determined as a function of moisture content in the range of 3.3% to 18.1% (d.b.). The average axial dimensions, major, medium and minor increased linearly from 4.92 mm to 5.37 mm, 4.59 mm to 5.08 mm and 4.42 mm to 4.89 mm, respectively. The geometric mean diameter, sphericity, unit volume, surface area and thousand seed weight increased from 4.63 mm to 5.10 mm, 0.94 mm^3 to 0.95 mm^3, 53.06 mm^3 to 70.35 mm^3, 67.65 mm^2 to 81.87 mm^2 and 42.82 g to 56.04 g, respectively with increase in moisture content from 3.3% to 18.1%. The true density increased linearly from 987.7 to 1012.2 kgm^{-3}, while the bulk density decreased linearly from 556.8 to 542.7 kgm^{-3} and the porosity increased linearly with increase in moisture content. The angle of repose increased linearly from 22.30° to 33.66° and the coefficient of friction increased linearly from 0.705 to 0.936 with increase in moisture content. The coefficient of friction was found to be maximum against plywood. The force and energy absorbed at rupture point decreased non-linearly from 74.6 N to 50.1 N and 42.9 kJ to 32.8 kJ while the deformation increased non-linearly from 0.575 mm to 0.650 mm with increase in moisture content.

Keywords: black pepper, density, mechanical property, physical property, *Piper nigrum*

Introduction

The data on physical and mechanical properties are useful in post harvest unit operations for the design of processing equipments (Sahay & Singh 2001). Several investigators have reported the moisture dependent physical and mechanical properties such as dimensions, geometric mean diameter, sphericity, unit volume, surface area, thousand seed weight, bulk density, true density, porosity, angle of repose, coefficient of friction, rupture force, deformation and energy absorbed for popcorn kernels (Karababa 2006), cumin seed (Saiedirad *et al.* 2008), wheat (Karimi *et al.* 2009), groundnut (Davies 2009), chickpea (Nikoobin *et al.* 2009), jatropha (Karaj & Muller 2010), agricultural grains (Gursoy & Guzel 2010) and nutmeg seeds (Abdullah *et al.* 2010). Murthy &

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Bhattacharya (1998) determined some of the physical and uniaxial compression properties of black pepper berries at moisture content varying from 8% to 32% (d.b.) and they reported that the increase in moisture content increased angle of repose but decreased floatability particularly when the moisture content was above 14% (d.b.). The deformation also decreased with increase in moisture content. Such information is lacking in black pepper, hence, this study was conducted to generate similar information.

Materials and methods

Black pepper (var. Panniyur-1) berries were obtained from the research farm of Indian Institute of Spices Research, Kozhikode, Kerala. The berries were cleaned manually and broken, foreign matter removed and split and deformed berries were discarded before the samples were prepared for the experiment. The initial moisture content of berry was determined by the vacuum oven method (Ranganna 1986) at a temperature of 80°C and pressure of 100 mm Hg until a constant weight was obtained. The initial moisture content of black pepper was found to be 10.4% (d.b.). Initially, the berries were stored at room temperature (25°C) for 2-3 weeks. For experimentation, predetermined quantity of black pepper was dried in tray dryer at the temperature 50°C to achieve the desired moisture content. To obtain higher moisture content of berries, calculated amount of water was added and mixed thoroughly to ensure uniform distribution. The samples were packed in low density polyethylene pouches and kept at 5°C for 48h in a refrigerator for uniform distribution of moisture throughout the berry. For measurement of the properties, the pouches were taken out from the refrigerator and allowed to warm up to room temperature for 2-3h. Five levels of moisture content (3.26%, 6.67%, 10.36%, 13.71% and 18.09% d.b.) were selected for this study.

Determination of physical properties

A digital vernier caliper (± 0.01 mm accuracy) was used to measure the size in three different orientations (major, medium and minor axes) for randomly selected 100 berries. As the berries look spherical in shape, the average geometric mean diameter, sphericity, surface area and unit volume were determined by using the following equations (Mohsenin 1986):

$$D_g = \sqrt[3]{(abc)} \quad (1)$$

$$\varphi = D_g / a \quad (2)$$

$$S = \pi D_g^2 \quad (3)$$

$$V = (\pi abc) / 6 \quad (4)$$

Where, D_g is the geometric mean diameter (mm); a, b, and c are the major, medium and minor axis of the black pepper corn. The bulk density was determined using the standard method by filling a measuring cylinder of 500 mL with the berries from a constant height (Balasubramanian & Visvanathan 2011) and it is the ratio of the mass to volume. The true density is the ratio of the mass of the berry to its pure volume. It was determined by the toluene displacement method (Mohsenin 1986). The volume of toluene displaced was found by immersing a weighed quantity of black pepper berries in toluene. The porosity was calculated from the following relationship

$$\in = [(P_t - P_b) / P_t] \times 100 \quad (5)$$

Thousand berries weight was measured by weighing thousand pepper berries in an electronic balance reading to 0.001 g. To determine the angle of repose, a tapering hopper made of mild steel sheet with the top and bottom having a dimension of 250 mm × 250 mm × 250 mm and 20 mm × 20 mm opening at the bottom. At 210 mm from the bottom of hopper, a circular disc of 100 mm diameter was used so that enough gap was left between the hopper wall and the disc which allows the berry to flow through during the test. A horizontal sliding gate was provided right below the disc for sudden release of the berries during the test (Balasubramanian & Visvanathan 2011). The angle of repose was calculated from the measurement of the height of the heap of berries on a circular plate as given in following equation:

$$\theta = \tan^{-1} (2H / D) \quad (6)$$

Where, H is the height of the cone in cm and D is the diameter of mild steel plate in cm. The static coefficient of friction of black pepper was determined using laboratory setup (Sessiz *et al.* 2007) against four surfaces: plywood, galvanized iron (GI) sheet, mild steel (MS) sheet and aluminum sheet. These materials are mostly used for construction of storage structures. During the experiment a leveled rectangular box was filled with black pepper berries at desired moisture content and moved on the frictional surface with the help of rope and pulley. The frictional force and normal strength was noted and the same quantity of berries was used on the other frictional surfaces at the same moisture content. It was calculated by using the equation,

$$\mu_s = F / N_f \quad (7)$$

where, F is the measured force in N and N_f is the normal strength of the samples in N.

Determination of mechanical properties

Mechanical properties such as rupture force, energy absorbed and toughness of the black pepper were calculated at different moisture levels by using TA-HDI texture analyser (*model:* TA-HD*i*) UK, equipped with a 500 N load cell and graph recorder and the measurement accuracy was ± 0.001 N in force and 0.001 mm in deformation. A test and post test speed of 1 mm s^{-1} and 2 mm s^{-1} was used with a strain of 20% and every experiment count of 5 times for each test. The force range of 0 to 200 N was selected for each experiment for all moisture contents ranging from 3.3% to 18.1% (d.b.). For each experiment 20 berries were randomly selected and tested with the help of stainless steel probe (P5) at each moisture content level and the average values of all the 20 berries are reported. The individual berry was loaded between probe and base plate for the machine and compressed at the preset condition until rupture point (failure) occurred in the force deformation curve and the curve was reached on the peak force. The deformation (strain) was taken as change in dimensions to original dimensions of the berry and the energy absorbed was calculated by measuring area under the force deformation curve up to the berry rupture point.

Data analysis

One way analysis of variance (ANOVA) was carried out to test the significance of moisture content on physical, frictional and mechanical properties of black pepper berries and regression analysis on all the properties using MS-Excel 2003.

Results and discussion

The relationships between the physico-mechanical properties of black pepper with respect to moisture content (M) are expressed using regression equations (Table 1).

Physical properties

The mean axial dimensions along major, medium and minor axis of black pepper berries increased from 4.92 mm to 5.37 mm, 4.59 mm to 5.08 mm and 4.42 mm to 4.89 mm, respectively with increase in moisture content from 3.3% to 18.1% (d.b.) (Fig. 1). The geometric mean diameter increased from 4.63 mm to 5.10 mm with increase in moisture content (Fig. 2).

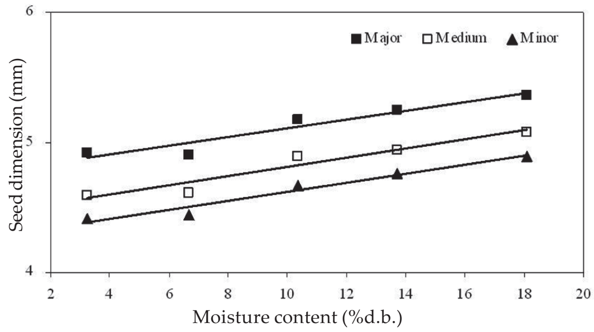

Fig. 1. Variation of seed dimensions on moisture content (■ major; □ medium; ▲ minor)

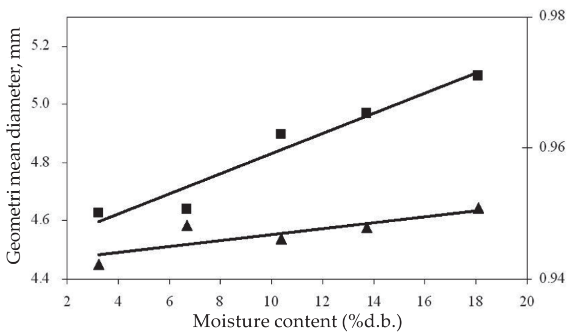

Fig. 2. Variation of geometric mean diameter and sphericity on moisture content (■ geometric mean diameter; ▲ sphericity)

Table 1. Regression between the physico-mechanical properties of black pepper with respect to moisture content (M)

Properties	Regression equation	
	mx+c	R^2
a	0.03M+4.77	0.91
b	0.035M+4.45	0.93
c	0.035M+4.27	0.96
D_g	0.035M+4.49	0.94
ö	0.0005M+0.94	0.71
V	1.27M+47.65	0.94
S	1.05M+63.27	0.94
ñ$_b$	-0.967M+560.24	0.99
ñ$_t$	1.7M+983.1	0.98
å	0.19M+43.04	0.99
M_{1000}	0.886M+39.106	0.95
è	0.814M+19.51	0.96
Coefficient friction		
Plywood sheet (ì$_{pw}$)	0.0047M+0.85	0.99
Mild steel sheet (ì$_{ms}$)	0.0047M+0.708	0.99
Galvanized iron sheet (ì$_{gi}$)	0.005M+0.832	0.99
Aluminum sheet (ì$_{al}$)	0.0071M+0.675	0.96
Mechanical properties		
Rupture force (F_r)	$-0.065M^2+78.19$	0.90
Deformation of seed (D_r)	$-0.0002M^2+0.0095M+0.547$	0.99
Rupture energy ($E_{a)}$	$-0.0615M^2+0.4908M+42.827$	0.81

The dimension of black pepper increased with increase in moisture content due to absorption of moisture that resulted in swelling of capillaries and expressing expansion in major, medium and minor axes along with the geometric mean diameter. Similar results have been reported by Karababa (2006) for popcorn kernel and Ghadge *et al.* (2008) for chick pea split. The values for sphericity increased from 0.942 to 0.951 with increase in moisture content from 3.3% to 18.1% (d.b.) (Fig. 2). Similar results were reported by Solomon & Zewdu (2009) for niger berries. The unit volume of berry increased linearly from 53.1 mm^3 to 70.4 mm^3 with increase in moisture content from 3.3% to 18.1% (d.b.) (Fig. 3). Similar trends have been reported by Deshpande *et al.* (1993) for soybean; Karababa (2006) for popcorn kernel. The mean surface area increased linearly from 67.7 mm^2 to 81.9 mm^2 with increase in moisture content from 3.3% to 18.1% (d.b.) (Fig. 3). This is in agreement with the results reported by Baryeh (2002) for millet and Karababa (2006) for popcorn kernel. The bulk density decreased linearly from 556.85 to 542.71 kg m^{-3} with increase in moisture

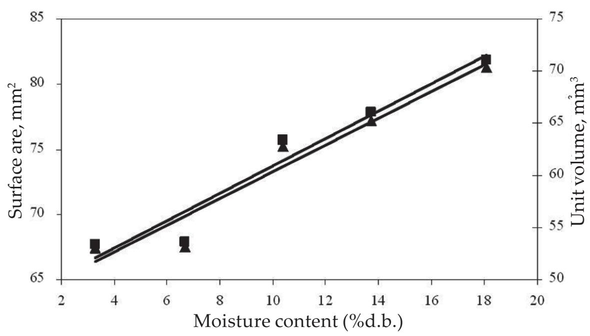

Fig. 3. Variation on surface area and unit volume on moisture content (■ surface area; ▲ unit volume)

content from 3.3% to 18.1% (d.b.) (Fig. 4). The decrease in bulk density with increase in moisture content could be due to the fact that the increase in volumetric expansion of the sample was greater than the mass of the sample (Coskuner & Karababa 2007). The relationship between the true density and moisture content

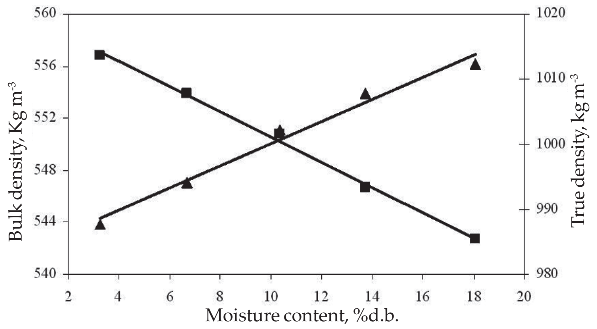

Fig. 4. Variation of bulk and true density on moisture content (■ bulk density; ▲ true density)

is shown in Fig. 4. It was found to increase linearly from 987.7 to 1012.2 kg m^{-3} with increase in the moisture content from 3.3% to 18.1% (d.b.). The increasing trend of true density may be attributed to the increase in mass of berries in comparison to its volume expansion on moisture gain (Singh & Goswami 1996). The porosity increased linearly from 43.6% to 46.4% with increase in moisture content from 3.3% to 18.1% (d.b.). The relationship between porosity and moisture content is shown in Fig. 5. A similar trend of porosity of black pepper berry and other grains was reported by Altuntas *et al.* (2005) and

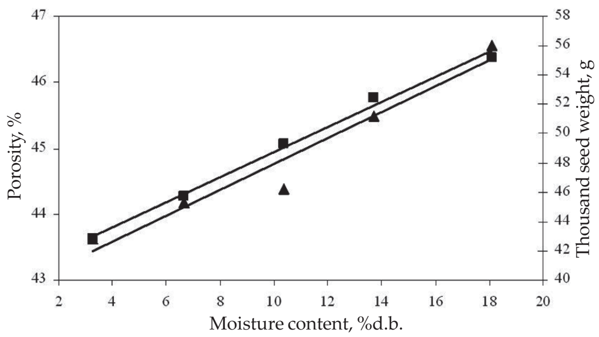

Fig. 5. Variation of porosity and thousand seed weight on moisture content (■ Porosity; ▲ Thousand seed weight)

Coskuner & Karababa (2007). The relationship between thousand seed weight and moisture content is shown in Fig. 5. It increased linearly from 42.8 g to 56.0 g when the moisture content increased from 3.3% to 18.1% (d.b.). Similar trends were reported by Singh & Goswami (1996) and Altuntas *et al.* (2005) for cumin and fenugreek berries, respectively.

The angle of repose increased linearly from 22.30° to 33.66° with increase in moisture content from 3.3% to 18.1% (d.b.) as shown in Fig. 6. The trend of increase in angle of repose with moisture content was similar to that

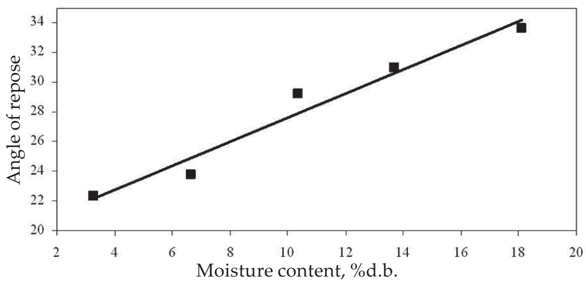

Fig. 6. Variation of angle of repose on moisture content (■ angle of repose)

reported by Altuntas *et al.* (2005) for fenugreek; and Coskuner & Karababa (2007) for coriander berries. The static coefficient friction with respect to moisture content on four structural surfaces namely plywood, GI, MS and aluminum sheets is given in Fig. 7. The static coefficient of friction ranged from 0.867 to 0.936, 0.846 to 0.920, 0.726 to 0.813 and 0.705 to 0.813, respectively for plywood, mild steel sheet, galvanized iron sheet and aluminum sheet as the moisture content increased from 3.3% to

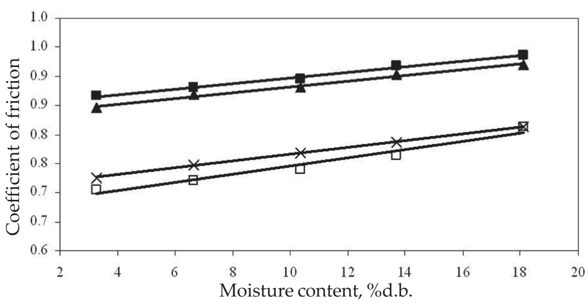

Fig. 7. Variation of coefficient of friction on moisture content (■ plywood; ▲ mild Steel; □ galvanized iron; × aluminum sheet)

18.1% (d.b.). The values of static coefficient of friction were found lower against the aluminum surface at all moisture levels. This may be due to smoother and more polished surface of aluminum sheet compared to other test surfaces. The static coefficient of friction increased linearly with respect to moisture contents for all the test surfaces. The static coefficient of friction was highest on plywood followed by MS, GI and aluminum sheets, respectively. Static coefficient of friction increased with increase in moisture content on all four surfaces. It may be because at higher moisture contents the berries become rougher and sliding characteristics are diminished, so that the static coefficient of friction increased. Similar trends were found by other researchers for coriander (Coskuner & Karababa 2007) and wheat berries (Kheiralipour *et al.* 2008).

Mechanical properties

The force required to rupture (failure) the berry at different moisture content is shown in Fig. 8. It can be observed from the figure and ANOVA (Table 2) that increase in moisture content from 3.3% to 18.1% (d.b.) decreased the rupture force non-linearly following second order polynomial relationship. The rupture force varied from 74.6 to 50.1 N as the moisture content increased from 3.3% to 18.1% (d.b.). The decrease in rupture force may be due to the fact that at higher moisture content the inner core of berry becomes markedly softer and required less force, whereas at the lower moisture content only outer coat of berry absorbed moisture and required higher force. Similar trend was reported by Saiedirad *et al.* (2008) for cumin and Murthy & Bhattacharya (1998) for black pepper berry. The deformation of berry at the rupture point as a function of moisture content is presented in Fig. 8. It can be observed that the deformation at berry rupture increased non-linearly as the moisture content increased from 3.3% to 18.1% (d.b.) and was significantly affected at 5% level of significance (Table 2). The deformation at rupture point varied from 0.575 mm to 0.656 mm with increase in moisture content (3.3%–18.1%, d.b.). It can also be observed that the deformation increased and the berry rupture force decreased as the moisture content increased. Energy absorbed varied from 42.9 to 32.8 kJ as the moisture content increased from 3.3% to 18.1% (Fig. 9). The energy absorbed at berry rupture decreased non-linearly with increase in moisture content and was found statistically significant (Table 2) at 5% level of significance. Singh & Goswami (1996) also reported decrease in energy absorbed by cumin berry both in vertical and horizontal orientations with increase in moisture content from 7% to 13%.

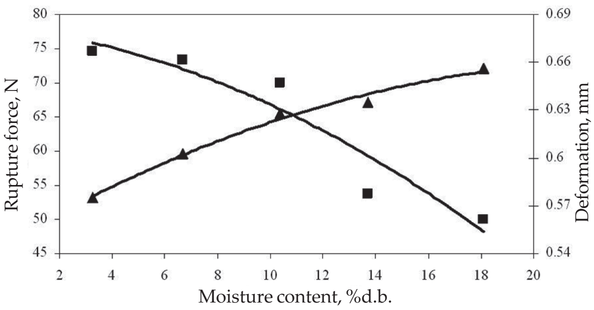

Fig. 8. Variation of rupture force and deformation on moisture content (■ rupture force; ▲ deformation)

Table 2. Analysis of variance for effect of moisture content on rupture force, deformation and energy absorbed

Source	d.f.	Mean Square	F-value	P-value
Rupture Force	1	7271.17	87.09*	1.42E-05
Deformation	1	240.03	14.23*	0.0055
Energy Absorbed	1	2143.59	66.91*	3.72E-05

$F_{1,8,\ 0.05}$=5.32; *P< 0.05

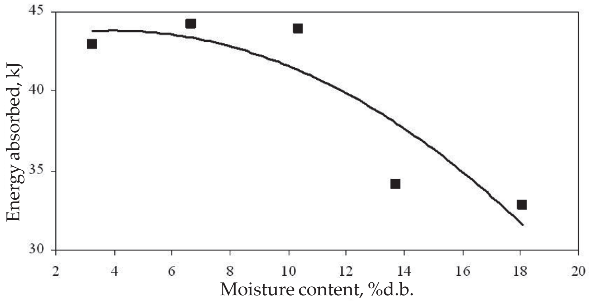

Fig. 9. Variation of energy absorbed up to the rupture point on moisture content (■ energy absorbed)

Overall, the study revealed that the average axial dimensions major, medium, minor, geometric mean diameter, sphericity, unit volume and surface area increased linearly with increase in moisture content. The bulk density showed a decreasing trend. However, true density, porosity, thousand seed weight and angle of repose showed an increasing trend. Also, the static coefficient of friction on all structural surfaces showed an increasing trend. The mechanical rupture force and energy absorbed showed a decreasing trend with respect to its corresponding deformation for the studied moisture range.

Acknowledgment

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