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Selected physical and mechanical properties of black pepper seed (cv. *Panniyar-5*)

P. Barnwal[1*], K.K. Singh[2], Alka Sharma[3], A.K. Chaudhary[3], T.J. Zachariah[4] and S.N. Saxena[5]
[1]Dairy Engineering Division, ICAR-NDRI (Deemed University), Karnal
[2]Director, ICAR-Central Institute of Agricultural Engineering, Bhopal
[3]FG & OP Division, ICAR-CIPHET, Ludhiana
[4]ICAR-Indian Institute of Spices Research, Kozhikode, India
[5]ICAR-National Research Centre on Seed Spices, Tabiji, Ajmer

Abstract

In present study, selected physical and mechanical properties of black pepper seed (cv. Panniyar-5) have been evaluated as a function of moisture content (range: 4.1 to 23.5% dry basis). The major, medium and minor dimensions, geometric mean diameter, surface area, sphericity and seed volume of black pepper seed were found to be increased in quadratic manner with increasing moisture content. The geometric mean diameter, seed surface area, sphericity and volume increased quadratically from 4.37±0.18 to 5.26±0.19 mm, 59.98±5.26 to 86.96±6.19 mm^2, 96.30±0.01 to 98.08±0.01 % and 43.94±5.74 to 76.56±8.44 mm^3, respectively with increasing moisture content. The bulk density and true density decreased whereas porosity, angle of repose and thousand seed mass increased with increasing moisture content. The coefficient of static friction increased in quadratic way from 0.534±0.015 to 0.743±0.006, 0.469±0.005 to 0.704±0.008, 0.550±0.035 to 0.719±0.006 and 0.445±0.005 to 0.680±0.011 for plywood, mild steel, galvanized iron and glass sheet surfaces, respectively with increasing moisture. The highest value for the coefficient of static friction was observed for plywood sheet surface. The hardness and toughness was observed to be decreased with increase in moisture content. These moisture-dependent physical and mechanical properties will be helpful for its processing e.g. cleaning, grinding etc.

Key words: Black pepper, physical properties, angle of repose, hardness, toughness

Introduction

Black pepper *(Piper nigrum* L.) is a common spice produced in oriental countries especially in South East Asia including India, Indonesia and Malaysia. It is well known and being used worldwide for its characteristic pungent flavour and taste. *Piper nignrm* L., from which pepper is derived, is a perennial climbing vine or shrub. Fruits, botanically called drupes and generally called berries, are dark green in colour, turning bright orange and red when ripe, and having thin testa. On sun-drying, it turns greyish to dark brown colour, and hence popularly known as black pepper. Thanuja *et al.*, (18) investigated arbuscular mycorrhizae (AM) on induction of rooting and other root characteristics of pepper cultivar Panniyur-1 and found the beneficial effects of inoculation with AM fungi which resulted in enhanced rooting and root growth in black pepper cuttings. Bhat *et al.*, (7) reported that phytoplasma infecting black pepper in India belongs to aster yellows group. The biochemical profile varies in the leaf and berries of black pepper. The biochemical component, mainly the alkaloid piperine attribute pungency and components like α- and β-pinenes, sabinene, myrcene, limonene, β-caryophyllene, camphene, etc. attribute the aroma and flavour to black pepper (Zachariah *et al.*, 21). This spice is used in foods as whole, cracked, coarse, medium or fine ground form/powder, and also used in the form of oleoresin (total extract). The piperine, volatile oil, starch and fibre content values showed marked variations and were indicative of the quality of black pepper (Gopalan *et al.*, 9; Govindarajan, 10). It has many medicinal properties like to treat vertigo, asthma, chronic indigestion, colon toxins, obesity, sinusitis, congestion, fever, paralytic, arthritic disorders and also advised in diarrhea and cholera (Karsha and Lakshmi, 12).

In design of processing equipment such as for cleaning, grading, aeration and storage etc., there is a need of various properties such as physical, frictional and mechanical properties as a function of moisture content (Mohsenin, 13; Sahay and Singh, 15; Barnwal *et al.*, 3). In order to optimize the equipment design and improvement of relevant machines for harvesting,

*Corresponding author e-mail:pbarnwal@rediffmail.com

handling, storing and other processes of black pepper seed, its engineering properties are necessary. The size and shape (geometrical properties) are important in designing of separating, harvesting, sizing and grinding/size reduction machines. Bulk density and porosity affect the structural loads whereas angle of repose is important in design of storage, packaging and transport purposes. The coefficient of friction of the seed against the various structural surfaces is also necessary in design of conveying, transporting and storage structures (Sahay and Singh, 15).

A number of research findings on engineering properties are reported for cereals (Tabatabaeefar, 17), coarse grain (Viswanathan *et al.*, 19), and legumes (Altuntas and Demirtola, 1). The data on the physical and mechanical properties of spices like fenugreek, coarinder seeds, bay laurel seeds and cumin (Altuntas *et al.*, 2; Coskuner and Karababa, 8; Yurtlu *et al.*, 20; Mollazade *et al.*, 14), respectively is available. It has been revealed that there is limited published information on detailed measurements of physical and mechanical properties of black pepper seed (cv. *Panniyar-5*) at various levels of moisture content. Hence, the objective of this study was to investigate some moisture-dependent physical and mechanical properties, namely, geometrical, frictional and mechanical properties of black pepper seed (cv. *Panniyar-5*) for its further processing applications.

Materials and methods

The black pepper seed (cv. *Panniyar-5*) was procured from Indian Institute of Spices Research, Kozhikode, India. The seeds were manually cleaned to remove foreign matter, including dust, dirt, broken and immature seeds. Moisture content of the seed was determined by vacuum oven method (temperature 70°C and pressure 100 mm Hg) until a constant weight was attained (Singh and Goswami, 16). Initial moisture content of the seed was found to be 9.06% dry basis (d.b.). The moisture content of black pepper seeds were moisture conditioned to 4.1, 7.5, 11.1, 14.9, 19.0 and 23.5% d.b. to carry out the study. For moisture conditioning of the sample, the predetermined quantity of black pepper seed was dried in a tray dryer at 55°C to achieve desired low moisture content level. The samples of the high level desired moisture contents were prepared by adding the calculated amount of distilled water using following equation (Mohsenin, 13; Barnwal *et al.,* 4; Barnwal *et al.*, 3):

$$Q = W_i \left[\frac{M_f - M_0}{100 + M_o} \right] \tag{1}$$

Where, Q is the mass of water to be added (kg); W_i is the initial mass of the sample (kg); M_o is the initial moisture content of the sample (%d.b.) and M_f is the desired moisture content of the sample (%d.b.).

The samples were filled in separate polyethylene bags, and the bags were sealed tightly. The samples were kept at 5°C in a refrigerator for a week to enable the moisture to be distributed uniformly throughout each sample. For starting the experiment, a required amount of the samples were taken out of the refrigerator and allowed to equilibrate with room temperature for about 2 hrs. For each moisture content, the major (X), medium (Y) and minor (Z) dimensions of black pepper seeds were measured for randomly selected 100 seeds using a digital vernier calliper (accuracy: 0.01 mm). The geometric mean diameter and sphericity of the seeds were calculated by using standard equations (Mohsenin, 13; Barnwal *et al.,* 5; Barnwal *et al.*, 6):

$$d_g = (XYZ)^{(1/3)} \tag{2}$$

$$\phi = \frac{(XYZ)^{1/3}}{X} = \frac{d_g}{X} \tag{3}$$

The thousand seed mass was determined using a digital electronic balance (accuracy: 0.001 g). The surface area of the grain, S, was found by analogy with a sphere of the same geometric mean diameter, using the established relationship (Yurtlu et al., 20) whereas seed volume was determined using following relations (Jain and Bal, 11).

$$S = \pi d_g^2 \tag{4}$$

$$V = \frac{\pi B^2 X^2}{6(2X - B)} \tag{5}$$

Where, $B = (YZ)^{0.5}$

The bulk density (ρ_b), a ratio of mass to volume, was determined by filling an empty plastic container of predetermined volume with the grains by pouring from a constant height (15 cm), striking off the top level and weighing. The true density (ρ_b) was determined using the toluene displacement method (Mohsenin, 13). The volume of toluene displaced was found by immersing a known quantity (weight) of black pepper seeds in the measured toluene. The porosity (ε) of the grains was calculated from bulk and true densities using the following relationship (Mohsenin, 13):

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

The angle of repose is the angle with the horizontal at which the material will stand when piled. Angle of repose (θ) of the black pepper seed was calculated from the measurement of height and diameter of the naturally formed heap of the seeds on a circular plate by using following equations. (Tabatabaeefar, 17; Singh and Goswami, 16; Barnwal *et al.*; 4) :

$$\theta = \tan^{-1}\left(\frac{2H}{D}\right) \quad (7)$$

where H is the height of heap and D is the diameter of heap formed by free fall of black pepper seeds.

The experiment on coefficient of static friction was performed with black pepper seeds at different moisture contents; using various structural surfaces such as plywood, glass, aluminium, galvanized iron sheet and stainless steel. These properties are commonly used for handling and processing of spices and construction of storage and drying bins. The coefficient of static friction was calculated (Viswanathan *et al.*, 19) as the ratio of weight added (frictional force) and mass of the material (normal force).

$$\mu = \frac{F}{N_{\acute{z}}} \quad (8)$$

where μ, is the coefficient of static friction, N_f is the normal force in static friction (N), and F is the frictional force in static friction (N).

A single seed hardness of black pepper at different moisture contents was measured using texture analyzer (Model TA-HDi, USA). Black pepper seed was placed individually in its natural resting position on the platform and load was applied until the seed crushed. The measurement was repeated for 5 different samples and the mean value was reported. Experimental conditions followed were load cell: 5 kg, test mode: measure force in compression, test option: return to start, pre test speed: 2 mm sec^{-1}, test speed: 0.1 mm s^{-1}, post test speed: 2 mm sec^{-1} and test probe: P 5. The hardness and toughness was calculated from force deformation curve (Barnwal *et al.*, 4).

Data were analyzed as per one factor analysis of variance (ANOVA) using SPSS 12.0 package. Regression analysis was carried out using Microsoft Excel 2003 software to determine the relationship between moisture content and the engineering properties of black pepper seed.

Results and discussion

All geometric properties such as major, medium and minor dimensions, geometric mean diameter, surface area and seed volume increased with increasing moisture content within the studied moisture range of 4.1-23.5% dry basis (Table 1). The major, medium and minor dimensions of black pepper seeds increased from 4.46±0.20 to 5.39±0.22 mm, 4.37±0.18 to 5.26±0.20 mm, and 4.27±0.19 to 5.13±0.17 mm, respectively with increase in moisture content (Table 1). The values of geometric mean diameter, surface area, sphericity and seed volume increased from 4.37±0.18 to 5.26±0.19 mm, 59.98±5.26 to 86.96±6.19 mm^2, 96.30±0.01 to 98.08±0.01 % and 43.94±5.74 to 76.56±8.44 mm^3, respectively for increase of moisture content from 4.1 to 23.5% d.b. Similar trend for geometrical properties such as axial dimensions, geometric mean diameter, surface area, sphericity and kernel volume were also reported for fenugreek seeds and bay laurel seeds (Altuntas *et al.*, 2; Yurtlu *et al.*, 20).

Bulk density and true density decreased from 578.61 to 543.52 kgm^{-3}, 1461.59 to 1277.75 kgm^{-3} (Figure 1) and porosity decreased (Figure 2) from 60.41% to 57.54%, respectively with increase in the moisture content of black pepper seeds. Similar decreasing trend for bulk and true densities were also reported (Coskuner and Karababa, 8) for coriander seeds. The decrease in bulk density, with an increase in moisture content, may be due to the increase in volume than the corresponding increase in mass of the material. It facilitates the same weight of material to occupy more volume of the cylinder thus decreasing the bulk density. Thousand seeds mass was increased in second order regression pattern from 49.14 to 63.01g (Figure 2) with increase in the moisture content. The similar trend of increase of thousand grains mass was reported for fenugreek seeds and coriander seeds (Altuntas *et al.*, 2; Coskuner and Karababa, 8).

Table 2 presents the various frictional properties of black pepper seeds *viz.* angle of repose and coefficient of static friction on different structural surfaces. Angle of repose was increased in second order regression manner from 29.108±0.735° to 35.675±0.323° (Table 3) with increase in moisture content. The increasing trends were reported (Mohsenin, 13) for the most of biological materials. The increase in angle of repose with moisture content may be due to an increase in the internal friction with the moisture content. The coefficient of static friction is highest against plywood surface and lowest against glass surface (Table 2). The coefficient of static friction of black pepper seeds on plywood sheet, mild steel sheet, galvanized iron sheet and glass sheet surfaces increased in second order regression pattern from 0.534±0.015 to 0.743±0.006, 0.469±0.005 to 0.704±0.008, 0.550±0.035 to 0.719±0.006 and 0.445±0.005 to 0.680±0.011, respectively (Table 2) for the studied moisture range of 4.1-23.5% d.b. This is so because increased moisture content may result in an increase in adhesion characteristics and roughness of the surface of black pepper seeds. The similar increasing trend for coefficients of static friction were reported by Altuntas *et al.*, (2), Coskuner and Karababa (8), Yurtlu *et al.*, (20) and Mollazade *et al.*, (14) for fenugreek seeds, coriander seeds, bay laurel seeds and cumin seed, respectively.

The various textural/mechanical properties of black pepper seeds are shown in Fig. 3. From this figure, it is clear that hardness and toughness decreased with increase in moisture content within the studied moisture range of 4.1-23.5% d.b. The decreased hardness at higher moisture content might have resulted from the fact that the seed became soft and more sensitive to cracking at high moisture. It indicates that greater force was necessary to break the seed with lower moisture. The similar observation was reported by Mollazade *et al.*, (14) for cumin seed.

Table 1. Geometrical properties of black pepper seeds

Moisture content, % d. b.	Major dimension, mm	Medium dimension, mm	Minor dimension, mm	Geometric mean diameter, mm	Surface area, mm^2	Sphericity, %	Volume, mm^3
4.1	4.46±0.20[a]	4.37±0.18[a]	4.27±0.19[a]	4.37±0.18[a]	59.98±5.26[a]	96.30±0.01[a]	43.94±5.74[a]
7.5	4.52±0.21[ab]	4.44±0.18[a]	4.33±0.21[a]	4.43±0.16[a]	61.72±4.68[a]	97.14±0.02[b]	46.27±6.08[b]
11.1	5.21±0.25[b]	5.05±0.23[b]	4.92±0.24[b]	5.06±0.23[b]	80.43±7.10[b]	97.63±0.01[c]	67.72±8.86[c]
14.9	5.30±0.28[c]	5.11±0.25[c]	4.96±0.21[b]	5.15±0.22[c]	82.72±7.08[b]	97.77±0.03[d]	70.53±9.96[d]
19.0	5.33±0.26[cd]	5.22±0.21[d]	5.09±0.18[c]	5.21±0.21[cd]	85.42±6.81[cd]	97.90±0.01[e]	74.77±8.77[e]
23.5	5.39±0.22[d]	5.26±0.20[d]	5.13±0.17[c]	5.26±0.19[d]	86.96±6.19[d]	98.08±0.01[f]	76.56±8.44[e]
F-value							
Moisture	204.25*	160.61*	116.90*	180.66*	171.91*	5.47*	153.62*
CD (0.05)	0.084	0.087	0.098	0.083	2.57	0.008	3.33

* *Significant at 5% level*

Table 2. Frictional properties of black pepper seeds on different structural surfaces

S. No	Moisture, % d.b	Angle of repose,	Coefficient of static friction, fraction			
			Plywood	Mild steel	Galvanized Iron	Glass
1	4.1	29.108±0.735[a]	0.534±0.015[a]	0.469±0.005[a]	0.550±0.035[a]	0.445±0.005[a]
2	7.5	30.610±0.315[b]	0.550±0.010[a]	0.492±0.007[b]	0.564±0.011[a]	0.472±0.003[b]
3	11.1	31.455±0.470[b]	0.562±0.013[ab]	0.546±0.005[c]	0.574±0.008[a]	0.498±0.016[c]
4	14.9	32.693±0.631[c]	0.647±0.119[bc]	0.559±010[d]	0.580±0.009[a]	0.510±0.010[c]
5	19.0	34.645±0.354[d]	0.705±0.016[cd]	0.614±0.006[e]	0.687±0.007[b]	0.613±0.015[d]
6	23.5	35.675±0.323[e]	0.743±0.006[d]	0.704±0.008[f]	0.719±0.006[c]	0.680±0.011[e]
F-Value						
Moisture		82.07*	8.71*	634.92*	58.19*	259.23*
CD (0.05)		0.890	0.094	0.011	0.031	0.018

* *Significant at 5% level*

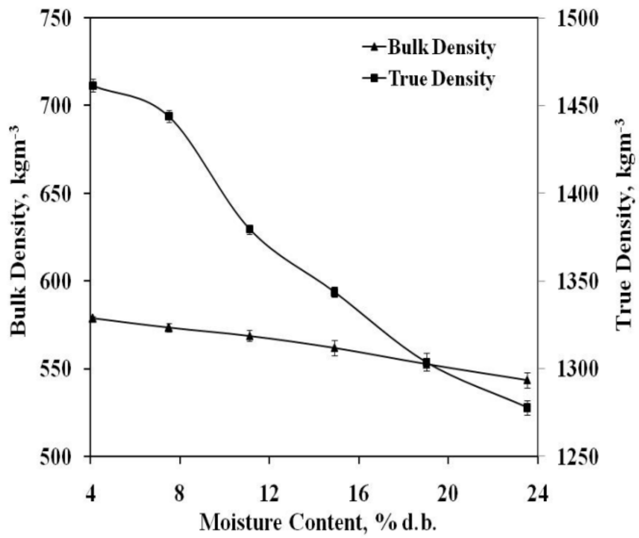

Fig 1: Influence of moisture content on bulk density and true density of black pepper seeds

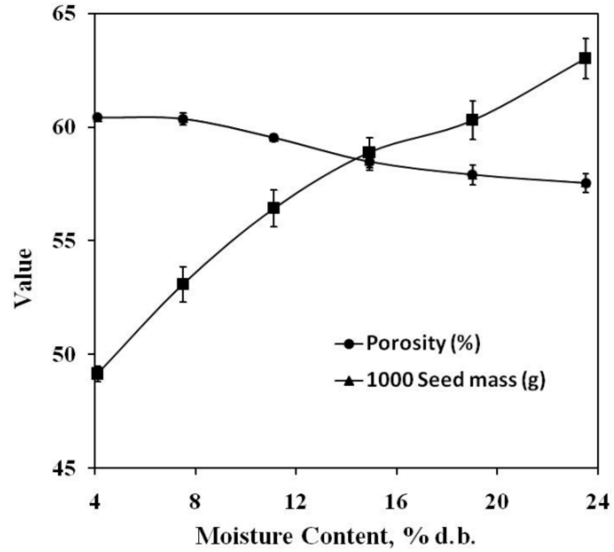

Fig 2: Influence of moisture content on porosity and thousand seed mass of black pepper seeds

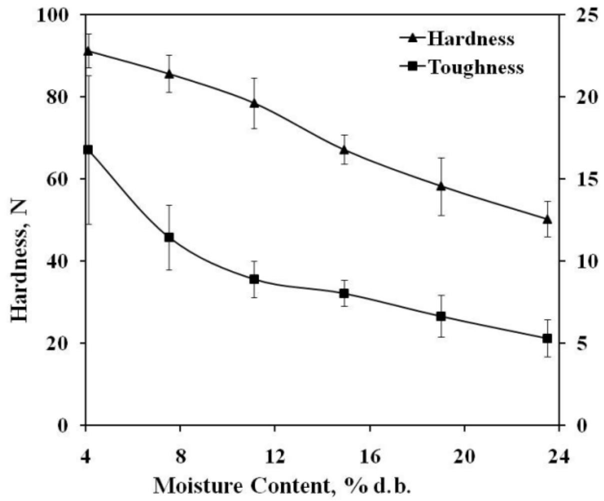

Fig 3: Influence of moisture content on hardness and toughness of black pepper seeds

Conclusion

From present study, following conclusions may be drawn:

1. For black pepper seeds, the seed major, medium, minor dimension, and geometric mean diameter increased quadratically from 4.46±0.20 to 5.39±0.22 mm, 4.37±0.18 to 5.26±0.20 mm, and 4.27±0.19 to 5.13±0.17 mm and 4.37±0.18 to 5.26±0.19 mm, respectively with the increasing moisture content (4.1-23.5% d.b.).
2. The seed surface area, sphericity and volume increased quadratically from 59.98±5.26 to 86.96±6.19 mm^2, 96.30±0.01 to 98.08±0.01 % and 43.94±5.74 to 76.56±8.44 mm^3, respectively with increasing the moisture content.
3. The bulk density, true density and porosity decreased in quadratic manner from 578.61-543.52 kgm^{-3}, 1461.59-1277.75 kgm^{-3} and 60.41-57.54%, respectively whereas thousand seed mass increased in quadratic manner from 49.14-63.01g with increase of the moisture content.
4. The coefficient of static friction increased in quadratic way from 0.534±0.015 to 0.743±0.006, 0.469±0.005 to 0.704±0.008, 0.550±0.035 to 0.719±0.006 and 0.445±0.005 to 0.680±0.011 for plywood sheet, mild steel sheet, galvanized iron sheet and glass sheet surfaces, respectively with increasing moisture. The highest value for the coefficient of static friction was observed for plywood sheet surface.
5. Within the studied moisture range (4.1-23.5% d.b.), the hardness and toughness decreased with increase in moisture content.

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