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Influence of Moisture Content on Germination and Physico-Mechanical Properties of Pulses

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ABSTRACT

Background: Pulses are a kind of legume crops which can be utilised for both food and animal feed. Pulses are also termed a "poor man's meat" because of high protein content. The physical properties of pulses are useful to design the processing equipment. The moisture content of agricultural materials greatly affects various physical properties. Nitty-gritty data on germination and physico-mechanical properties of pulses are provided in this paper at different moisture contents, which is extremely helpful in the design of equipment used in harvesting operations and food processing operations.

Methods: The experiment was conducted at Department of Agricultural Engineering, Indian Agricultural Research Institute, New Delhi. All the experiments were replicated thrice and mean±SD (standard deviation) values were taken using R software to check the level of significance ($p \leq 0.05$).

Result: Physical properties, mechanical properties and germination of pulses were evaluated as functions of moisture content. It was observed that average length, breadth, thickness and geometric mean diameter, sphericity, porosity, angle of repose and static coefficient of friction of pulses increased linearly and bulk density, true density, hardness and germination decreased density with increase in moisture content from 9.98 to 20.4% (db).

Key words: Chickpea, Germination, Lentil, Physical properties, Pigeonpea.

INTRODUCTION

Pulses are considered to be a healthy vegetarian cuisine with excellent source of protein for millions of people who cannot afford animal protein for a balanced diet. Chickpea (*Cicer arietinum*), lentil (*Lens culinaris*) and pigeonpea (*Cajanus cajan*) are an economically important pulses produced by millions of small Indian farmers. The estimated production of pulses in 2021-22 as per the Department of Agriculture and Farmers' Welfare (DA and FW) is 26.96 million tonnes, while chickpea 9.94, pigeonpea 3.32 and lentil 1.23 million tonnes (Anonymous, 2020). Pusa-547 (chickpea) and Pusa Arhar 16 (pigeonpea) were released by the ICAR in the year 2006 and 2016, respectively. Pusa-547 has attractive bold seeds, high yield performance, thin testa, good cooking quality and average yield 17 q/ha (Kharkwal *et al.,* 2008). Similarly, Pusa Arhar 16 has a maturity time of 120 days and yield around 20 q/ha. Lentil 4717 was released in 2017 by ICAR-IARI and is suitable for rainfed conditions of Central Zone and average yield is 12-13 q/ha.

Comprehension of physical properties of pulses is required for the design of equipment for handling, harvesting, processing and storing (Prasad *et al*., 2010). Dimensions of pulses are crucial in the design of separating, harvesting, grinding sizing, cleaning and grading machines. Bulk density, true density, porosity and angle of repose play a crucial role in different applications such as design of hopper, silos, storage bins and conveyor belt (Tavakoli *et al*., 2009). The coefficient of friction between seed and wall is a critical parameter in the prediction of seed pressure on walls.

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Several studies were reported on physical properties of different pulses viz., lentil seeds (Konak *et al.* 2002; Amin *et al*., 2004; E. Isik 2007; Isik and Izli, 2016; Bagherpour *et al*., 2010; Gharibzahedi *et al*., 2011). Nikoobin *et al.* (2009) for chickpea. Singh and Kotwaliwale (2010), Sangani and Davara (2013); Khanbarad *et al.,* 2014; Baryeh and Mangope (2002) for pigeonpea and Senthilkumar, *et al*., (2018) for beans. However, still, detailed measurements of the physical attributes of new variety of chickpea (Pusa 547), pigeonpea (Pusa Arhar 16) and lentil (Pusa 4717) at various levels of moisture content have not been investigated.

The objective of this study was to investigate influence of moisture content on germination and physico-mechanical properties namely linear dimensions, sphericity, density, porosity, angle of repose, hardness and coefficient of static friction against three structural surfaces of the chickpea, pigeonpea and lentil seed.

MATERIALS AND METHODS

Sample preparation

Ten kilograms of different types of pulses, namely chickpea (Pusa547), pigeonpea (Pusa Arhar 16) and lentil (Pusa 4717) were procured from Seed Processing Unit (SPU), ICAR-New Delhi. All experimental analysis was conducted in Division of Agricultural Engineering (IARI, New Delhi) in 2021. The seed moisture content investigated range was selected as 9.98-20.40% (db), since harvesting, transportation, storage, handling and processing operations of crops are performed in this moisture range. Moisture content of pulses seed was determined by AOAC (2012). The samples at the desired moisture levels were prepared by adding calculated amounts of distilled water (Eq. 1), mixed thoroughly and then sealed in separate polyethylene bags (Dursun and Dursun, 2005). Samples were kept at 278K for seven days to distribute moisture.

$$Q = \frac{w_i (M_f - M_i)}{100 - M_f} \quad ...(1)$$

Where;

Q= Mass of water to be added (gram).

w_i= Initial mass of the sample (gram).

M_i and M_f = Initial moisture content and final (desired) moisture content of the sample, % (db).

Determination of principal dimensions of pulses

The principal dimensions of pulses seed namely, length (L), breadth(W) and thickness(T), were measured by using a digital vernier calliper (Mitutoyo Digital Calipers 500-196) with 0.01 mm sensitivity. The mean value of length, breadth, thickness and geometric mean diameter of 500 seeds (chickpea, pigeonpea and lentil) were determined. The geometric mean diameter, (D_g) of chickpea, pigeonpea and lentil seeds were calculated (Eqs. 2-3) as relationship described by (Raigar and Mishra, 2015).

$$D_g = (L \times W \times T)^{1/3} \quad ...(2)$$

$$D_g = (D^2 T)^{1/3} \quad ...(3)$$

Where

D_g= Geometric mean diameter (mm).

L= Major dimension along the longest axis (mm).

W= Minor dimension along the longest axis perpendicular to L (mm).

T= Intermediate thickness dimension along the lowest axis perpendicular to both L and W.

Sphericity of pulses seed

The sphericity of chickpea and pigeonpea were calculated (Eq. 4) and sphericity of was determined for lentil as (Eq. 5) described by (Singh *et al*., 2004 and Bhattacharya *et al.*, 2005).

$$\phi = \frac{(L \times W \times T)^{1/3}}{L} \times 100 \quad ...(4)$$

$$\phi = \frac{(L \times W \times T)^{1/2}}{L} \times 100 \quad ...(5)$$

Bulk density, true density and porosity

The bulk density of pulses was determined by filling a 500ml beaker with seeds and dropping them from a height of 150 mm, then weighing them. No separate manual compaction of seeds was done to ensure that the seeds were evenly distributed in the beaker (Vashishth *et al*., 2020). The toluene displacement technique was used to determine the true density of pulses, which was determined as the proportion of seed mass to true volume. (Bajpai *et al*., 2020). Porosity of pulse seed at various moisture contents was computed using bulk and true densities using relationship (Eq.6),

$$\varepsilon = \frac{(\rho_b - \rho_i)}{\rho_i} \times 100 \quad ...(6)$$

Thousand seed mass

The thousand-seed weight of the seed of each variety was analysed using the method described by ISTA (2019).

Angle of repose

The angle of repose of pulses seed was determined by using an open-ended cylinder. The cylinder was raised slowly until the seeds formed a cone on the circular plate. The diameter and height of the cone were recorded and the angle of repose (Eq.7) was determined (Mishra *et al.,* 2019):

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

Static coefficient of friction

The static coefficient of friction of seeds was determined against galvanised iron (GI), mild steel(MS) and stainless steel(SS) surfaces at different moisture contents. An aluminium box of (150×100×40) mm^3 was filled with the sample and placed on an adjustable tilting plate, facing the test surface. The sample container was raised slightly so as not to contact the surface. The slope of the test surface was gradually increased until the box started to slide down, at which point the tilt angle was measured using a graduated scale. For each repetition, the sample in the container was emptied and refilled with a new sample. The co-efficient of static friction (Eq. 8) was calculated as given below (Aviara, Power and Abbas, 2013):

$$\mu = \frac{F\ (g)}{N\ (g)} \quad ...(8)$$

Hardness of pulses

The hardness of pulses seeds were determined using Stable micro system texture analyser (Model: TA+HDi, Stable Micro Systems, UK) equipped with a stainless steel probe (P75) and load cell of 500 kg having accuracy of ±0.001 mm in deformation and ±0.001N in force. The pre-test, test and post-test speeds during the analysis were 2, 1 and 3 mm/s respectively with 60% strain. The compression of individual seed along its thickness resulted in to a force-deformation diagram (Tavakoli *et al*., 2009). The average of 25 replications is reported (Altuntas and Yildiz, 2007).

Germination of pulses

The germination of seed was carried out as per procedure described by (ISTA 2021) using equation as follows:

$$\text{Germination (\%)} = \frac{\text{Number of germinated seed}}{\text{Total number of seed}} \times 100 \quad ...(9)$$

Statistical analysis

All the experiments were replicated thrice and mean ± SD (standard deviation) values were taken. The values were subjected to single factor analysis of variance by using R software to check the level of significance ($p \leq 0.05$). The post hoc Duncan test was used to separate the means. Linear regression analysis was also performed in Microsoft Excel (2019) to obtain the regression equation and coefficient of determination (R^2).

RESULTS AND DISCUSSION

Principal dimensions of pulses seed

The effect of moisture content on the principal dimensions of pulses seed is shown in Table 1. The average values for chickpea's length, breadth, thickness and geometric mean diameter were ranged from 8.893±0.569 to 11.063±0.495 mm, 7.021±0.506 to 7.387±0.430 mm, 6.767±0.459 to 7.125 ±0.462 mm and 7.482±0.386 to 7.847±0.388 mm, respectively; for pigeon pea, the mean values varied from 5.882±0.424 to 6.108±0.408 mm, 4.646±0.391 to 4.867±0.321 mm, 3.873±0.226 to 4.135±0.321 mm and 4.278±0.201 to 4.955±0.232 mm, respectively. However, the average length, thickness sand GMD of lentils ranged from 4.114±0.394 to 4.465±0.33 mm, 2.31±0.154 to 2.56±0.153 and 3.387±0.257 to 3.739±0.202 mm, respectively. All the mean principal dimensions were significantly ($p \leq 0.05$) increased for chickpea, pigeon pea and lentil an increase in moisture content from 9.98% to 20.40% (db) (Table 1). The linear regression equations between moisture content and principal dimensions of pulses were developed (Table 2). As moisture content increased the moisture migration take place in the intercellular space of seed and resulted expansion and swelling. Similar results have been reported by (Singh and Kotwaliwale, 2010) for Pigeon pea, (Konak *et al.,* 2002) for chickpea and (Kiani Deh Kiani *et al*., 2008) for red bean grain all showed similar trends. The linear relationship between different pulses and moisture content (M_c) are presented as follows:

Shape of pulses seed

The shape of the seed, in terms of sphericity, was studied. It was espied that the average values of sphericity for chickpea, pigeonpea and lentil seeds were not significant ($p \leq 0.05$) and increased from 84.359±5.416 to 84.905±3.175%, 80.42±4.572 to 81.406±4.614% and 75.115±3.384 to 75.828 ± 3.387, respectively [Fig 1(ii)] while moisture level increased 9.98 to 20.40% (db). The sphericity increased with moisture content might due to higher rate of expansion in breadth and thickness compared to length due to moisture absorption. Similar findings were reported for yellow lentil and soybean by Isika and Izlİa (2016) and Kakade *et al*. (2019), respectively. The variation in sphericity (ö) with moisture content (M_c) of pulses can be represented by the following equation:

For chickpea: $\varphi = 0.0525\,M_c + 89.809\ (R^2 = 0.97)$ ...(10)

For pigeonpea: $\varphi = 0.0981 M_c + 79.602\ (R^2 = 0.85)$ ...(12)

For lentil: $\varphi = 0.068 M_c + 74.393\ (R^2 = 0.97)$ ...(13)

1000 Seed weight

The experimental value obtained for thousand seed weight for chickpea, pigeonpea and lentil seeds M_{1000} increased linearly from 180.95±0.11 to 232.37±0.07 g, 62.52±0.55 to 77.42±0.39 g and 21.09±0.042 to 23.66±0.146 g, respectively [Fig 1 (i)] for chickpea, pigeonpea and lentil ($p<0.05$) when the moisture content was increased from 9.98 to 20.40% d.b. These values were smaller than results reported for lentil (Bagherpour, 2010) and pigeonpea (Sangani and Davara, 2013). A linear equation was fitted

Table 1: Variation of principal dimensions and geometric mean diameter of pulses with moisture content.

Pulses	Moisture content (% db)	Length (mm)	Breadth (mm)	Thickness (mm)	GMD (mm)
Chickpea	9.98	8.893 (0.569)[c]	7.021 (0.506)[c]	6.767±(0.459)[c]	7.482 (0.386)[c]
	15.03	9.068 (0.480)[b]	7.202 (0.460)[b]	6.955±(0.454)[b]	7.659 (0.402)[b]
	20.40	11.063 (0.495)[a]	7.387 (0.430)[a]	7.125±(0.462)[a]	7.847 (0.388)[a]
Pigeonpea	9.98	5.882 (0.424)[c]	4.646 (0.391)[c]	3.873±(0.226)[c]	4.278 (0.201)[c]
	15.03	5.936 (0.427)[b]	4.765 (0.29)[b]	3.955±(0.271)[b]	4.807 (0.237)[b]
	20.40	6.108 (0.408)[a]	4.867 (0.324)[a]	4.135±(0.321)[a]	4.955 (0.232)[a]
Lentil	9.98	4.114 (0.394)[c]	-	2.311±(0.154)[c]	3.387 (0.257)[c]
	15.03	4.338 (0.380)[b]	-	2.453±(0.160)[b]	3.564 (0.231)[b]
	20.40	4.465 (0.330)[a]	-	2.56±(0.153)[a]	3.739 (0.202)[a]

Note: Number of replications were 500. Values are mean ± SD of respective replication, mean values in same row with same superscript alphabets are not significantly different ($p \leq 0.05$).

between thousand grain mass (M_{1000}) and moisture content can be represented as.

For chickpea; $M_{1000} = 4.929M_c + 132.76$ ($R^2 = 0.995$) ...(13)

For pigeonpea; $M_{1000} = 1.436\ M_c + 46.914$ ($R^2 = 0.923$) ...(14)

For lentil; $M_{1000} = 0.429\ M_c + 18.453$ ($R^2 = 0.973$) ...(15)

Bulk density

The bulk density of pulses at various moisture levels were found to be statistically significant at the 5% level. The mean values of bulk density was varied from 793.19±1.92 to 752.46 ± 4.16 kgm^{-3},828.10±2.02 to 772.61±3.86 kg m^{-3} and 882.58±2.01 to 797.28±3.86 kg m^{-3}, respectively [Fig 1(iii)] for chickpea, pigeonpea and lentil, respectively, at 9.98 to 20.40% (db) moisture levels. It was observed that increasing the moisture content resulted in decreased bulk density for all three pulses. The decline in bulk density of pulses probably due to increase in volumetric expansion in the seed is greater than seed mass. Similar trend was reported for rice bean and pigeonpea by Bhusan and Raigar (2020) and Singh and Kotwaliwale, (2010). Negative linear equations were obtained for the bulk density (ρ_b) of chickpea, pigeonpea and lentils are represented in Equations (16) and (18):

For chickpea: $\rho_b = 832.13\text{-}3.908M_c$ ($R^2 = 0.999$) ...(16)

For pigeonpea: $\rho_b = 880.92\text{-}5.323M_c$ ($R^2 = 0.999$) ...(17)

For lentil: $\rho_b = 962.82\text{-}8.177M_c$ ($R^2 = 0.997$) ...(18)

True density.

Fig 1(iv) depicted the affects moisture levels on true density of chickpea, pigeonpea and lentil, which increased linearly from 1281.17±10.05 to 1248.37±12.43 kg m^{-3}, 1363.15±3.05 to 1315.53±7.66 kg m^{-3} and 1304.14±3.95 to 1242.05±5.01 kg m^{-3}, respectively as a result of increasing the moisture content from 9.98 to 20.40% db. The decreasing trend of true density may be attributed to the possible higher weight increase of seeds in comparison to their volume expansion with moisture gain and discrepancies could be due to the cell structure and the volume and mass increase characteristics of seeds as moisture content increases. Similar trends of results have also been reported by Chowdhury, *et al*. (2001) for gram and Sahoo and Srivastava (2002) for okra seed. The relationship between the moisture content and true density presented in eqs (19)-(21).

For pigeonpea: $\rho_t = 1410.3\text{-}4.733M_c$ ($R^2 = 0.993$) ...(19)

For lentil: $\rho_t = 1365.5\text{-}6.172M_c$ ($R^2 = 0.999$) ...(20)

For chickpea: $\rho_t = 1314.8\text{-}3.260M_c$ ($R^2 = 0.998$) ...(21)

Porosity

The porosity of chickpea, pigeonpea and lentil as a function of moisture content was observed from given Fig 1(v), significantly increased from 38.08 to 39.72%, 39.25 to 41.26% and 32.32 to 35.80% respectively with an increase in moisture level. A similar trend for the porosity was also obtained by Vashishth *et al.* (2020) for horse gram seeds and Kakade *et al.* (2019) for soyabean. The linear relationships for porosity of pulses are presented below :

For pigeonpea: $\varepsilon = 0.200\times + 37.24$ ($R^2 = 0.99$) ...(22)

For chickpea: $\varepsilon = 0.162\times + 36.46$ ($R^2 = 0.99$) ...(23)

For lentil: $\varepsilon = 0.346\times + 28.90$ ($R^2 = 0.98$) ...(24)

Angle of repose

It was observed from Fig 1(vi), angle of repose for chickpea, pigeonpea and lentil increased with increasing the moisture content. The mean value angle of repose for chickpea, pigeonpea and lentil seeds were 23.87, 24.78 and 25.31°C at 9.98% (db). The percentage increase observed in the angle of repose was 22.99, 11.10 and 8.67% for chickpea, lentil and pigeonpea. The increasing rate of the angle of repose was not significant for chickpea and pigeonpea seeds. The increase in the angle of repose on moisture absorption was due to the moisture which surrounds the surface of seed cause increase in stickiness of the kernel surface of pulses, which in turn increases stability and reduces flowing ability. The variation is somewhat similar to feba bean (Haciseferogullari *et al*., 2003) and Konak *et al.* (2002) for chickpea. A linear equation was fitted between the angle of repose (θ) of pulses seed and moisture content (M_c) is given as follows.

For chickpea; $\theta = 0.545\ M_c + 18.669$ ($R^2 = 0.978$) ...(25)

For pigeonpea; $\theta = 0.213\ M_c + 22.516$ ($R^2 = 0.953$) ...(26)

For lentil; $\theta = 0.280\ M_c + 22.682$ ($R^2 = 0.958$) ...(27)

Table 2: Relationships between principal dimensions and moisture content (M_c) of pulses seeds with coefficient of determination (R^2).

Principal dimensions (mm)	Regression equations		
	Chickpea	Pigeonpea	Lentil
Length (L)	$L = 0.215M_c+6.4391$ ($R^2 = 0.814$)	$L = 0.022M_c+5.638$ ($R^2 = 0.915$)	$L = 0.035M_c+3.781$ ($R^2 = 0.975$)
Breadth (W)	$W = 0.036M_c+6.657$ ($R^2 = 0.999$)	$W = 0.022M_c+4.429$ ($R^2 = 0.996$)	-
Thickness (T)	$T = 0.035M_c+6.414$ ($R^2 = 0.999$)	$T = 0.026M_c+3.596$ ($R^2 = 0.954$)	$T = 0.0248M_c+2.069$ ($R^2 = 0.993$)
Geometric mean diameter (D_g)	$D_g = 0.035\ M_c+7.132$ ($R^2 = 0.999$)	$D_g = 0.064\ M_c+3.702$ ($R^2 = 0.893$)	$D_g = 0.033\ M_c+3.052$ ($R^2 = 0.999$)

Static coefficient of friction

It was espied that the coefficient of friction of pulses increased with an increasing moisture content for all structural surfaces (Table 3). The static coefficient of friction between a seed and a surface is lower for all three pulses on stainless steel compared to galvanized iron and mild steel due to the smooth and hard nature of stainless-steel surface. The rough and soft nature of galvanized iron and mild steel results in a higher static coefficient of friction. The experimental data of coefficient of friction of chickpea at various moisture levels were resulted significantly ($p \leq 0.05$) increased for stainless steel sheet while in GS

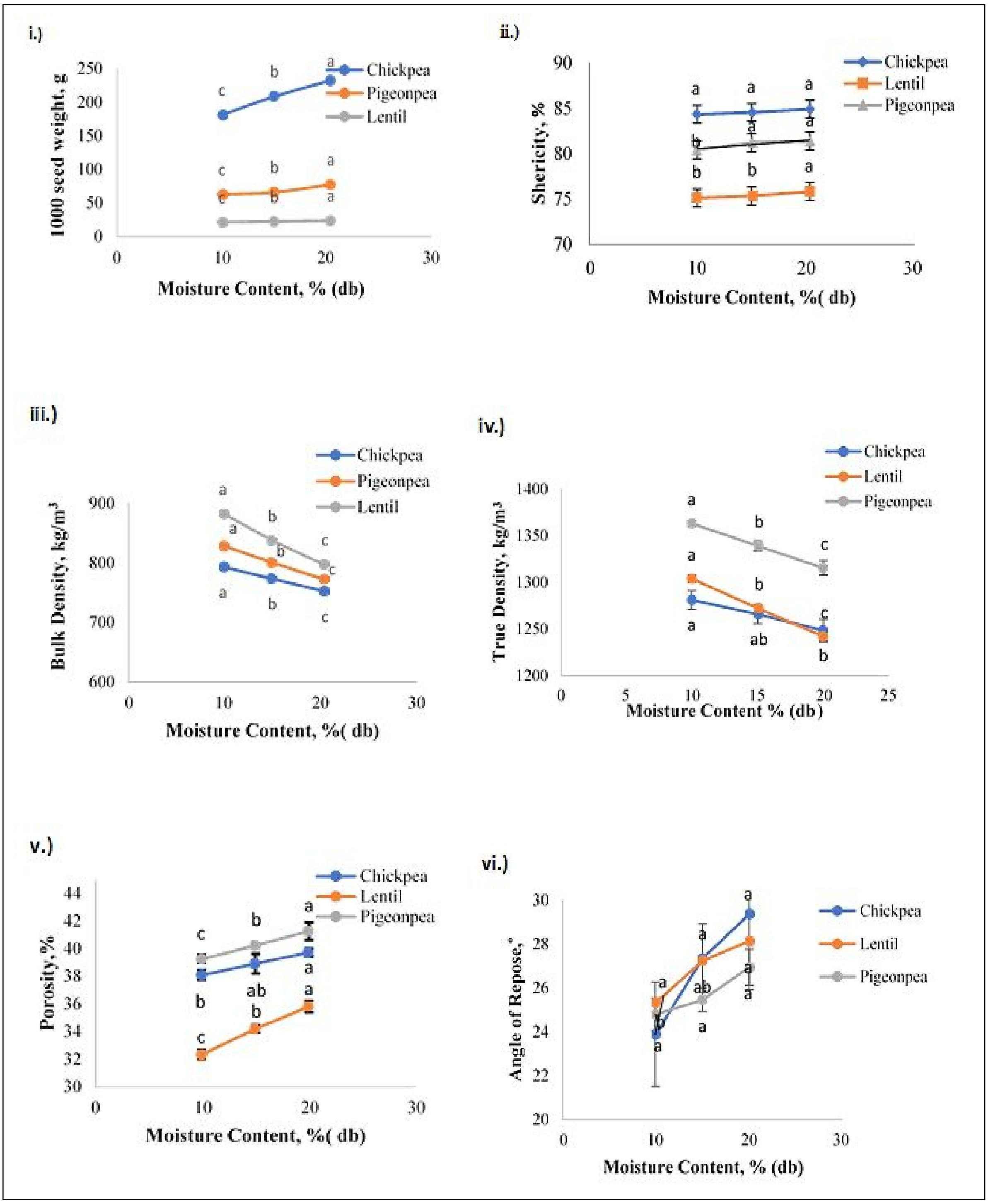

Fig 1: Effect of moisture content on (i) thousand seed weight (g), (ii) sphericity (%), (iii)bulk density (kg/m^3), (iv) true density (kg/m^3), (v) porosity (%) and (vi) angle of repose (0.) of chickpea, pigeonpea and lentil.

and MS showed statically insignificant. Similar trend observed by Pandiselvam *et al*. (2014) for onion seed and Gharibzahedi *et al.* (2011) for red lentil. The changes in coefficient of friction with changes in moisture content of pulses seeds on different surfaces followed linear relationships represented in Table 4.

Germination

The germination of seeds decreased linearly from 98.6±1 to 79.23±1.1, 99.24±0.8 to 88.53±1.07 and 97.38±0.6 to 76.82±1.11 for chickpea, pigeonpea and lentil with increased moisture content [Fig 2(ii)]. The decline rate of germination for all three pulses were more at higher moisture content (20.40%) which may be due to ageing occurred or seed may not receive enough oxygen, leading to seed rot and reduced germination. Maintaining optimal moisture content is crucial to ensure seed viability, maximize germination and minimize seed decay. The linear relationships for germination of pulses are presented below:

For chickpea; Germination (%)= $115.46-1.849M_c$ ($R^2 = 0.928$) ...(28)

For pigeonpea; Germination (%) =$109.56-1.028\ M_c$ ($R^2 = 0.999$) ...(29)

For lentil; Germination (%) = 118.46-1.980 MC ($R^2 = 0.956$) ...(30)

Mechanical properties

Hardness of pulses

The estimated mean values of hardness for chickpea, pigeonpea and lentil seeds were found significantly decrease with the increase in moisture content (Fig 2(i)). This may be due to the decreased surface roughness at higher moisture

Table 3: Static coefficient of friction of chickpea, pigeonpea and lentil seeds and their relationship at different moisture content.

Moisture content (% db)	Galvanized sheet (GI)	Mild steel sheet (MS)	Stainless steel sheet (SS)
Chickpea (9.98)	0.436 (0.052)[a]	0.426 (0.017)[a]	0.344 (0.0145)[b]
Chickpea (15.03)	0.468 (0.0123)[a]	0.442 (0.0426)[a]	0.365 (0.008)[ab]
Chickpea (20.40)	0.470 (0.036)[a]	0.480 (0.021)[a]	0.382 (0.0174)[a]
Pigeonpea (9.98)	0.382 (0.021)[a]	0.383 (0.032)[a]	0.337 (0.023)[a]
Pigeonpea (15.03)	0.392 (0.055)[a]	0.396 (0.024)[a]	0.355 (0.026)[a]
Pigeonpea (20.40)	0.405 (0.011)[a]	0.404 (0.025)[a]	0.372 (0.020)[a]
Lentil (9.98)	0.356 (0.038)[a]	0.377 (0.021)[a]	0.329 (0.021)[a]
Lentil (15.03)	0.38 (0.033)[a]	0.387 (0.0311)[a]	0.338 (0.016)[a]
Lentil (20.40)	0.40 (0.039)[a]	0.393 (0.055)[a]	0.359 (0.018)[a]

Note: Values are mean (SD) of respective triplicate replication, mean values in same row with same superscript alphabets are not significantly different ($p \le 0.05$).

Table 4: Relationships between static coefficient of friction (μ) and moisture content (M_c) of pulses seeds with coefficient of determination (R^2).

Material	Equations		
	Chickpea	Pigeonpea	Lentil
Galvanized Iron sheet	$\mu = 0.003\ M_c + 0.409$ (R^2=0.779)	$\mu = 0.002\ M_c + 0.359$ (R^2=0.996)	$\mu = 0.004\ M_c + 0.314$ (R^2=0.995)
Mild steel sheet	$\mu = 0.005\ M_c + 0.370$ (R^2=0.995)	$\mu = 0.02\ M_c + 0.363$ (R^2=0.976)	$\mu = 0.001\ M_c + 0.362$ (R^2=0.974)
Stainless steel sheet	$\mu = 0.003\ M_c + 0.308$ (R^2=0.993)	$\mu = 0.003\ M_c + 0.303$ (R^2=0.998)	$\mu = 0.002\ M_c + 0.298$ (R^2 =0.956)

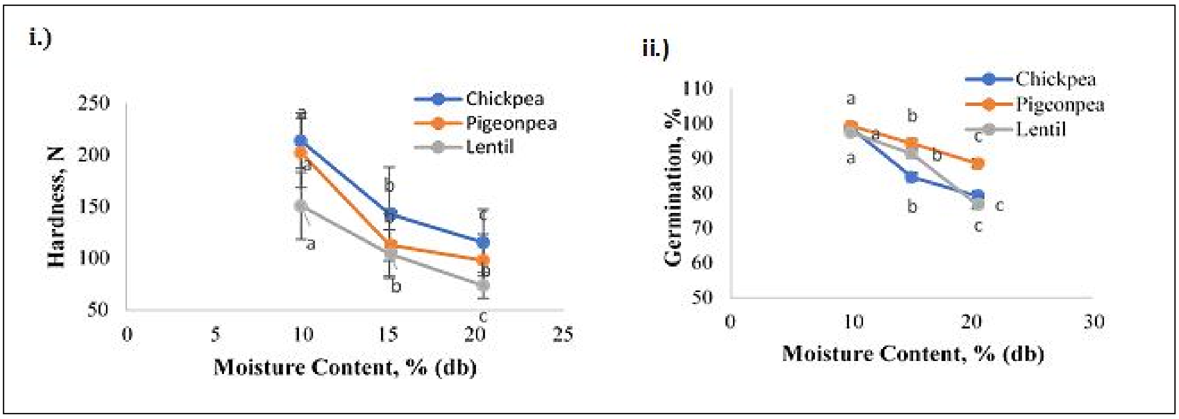

Fig 2: Effect of moisture content on (i) hardness and (ii) germination of chickpea, pigeonpea and lentil.

values. The seed may have become more susceptible to rupturing at high moisture levels, which may have caused the lower forces at increasing moisture content. The calculated results are higher to those reported by Konak *et al.* (2002); Unal *et al.* (2008) for mung bean and Bagherpour *et al.* (2010) for lentil. The variation in hardness in N with moisture content of pulses can be represented by the following equation:

For chickpea; $H = 1558.6M_c^{-0.87}$ (R^2=0.994) ...(31)

For pigeonpea; $H = 2102.5\ M_c^{-1.039}$ (R^2= 0.958) ...(32)

For lentil; $H = 1514.8\ M_c^{-0.998}$ (R^2= 0.996) ...(33)

CONCLUSION

The following conclusions were drawn from the investigation on germination and physico-mechanical properties of pulses for moisture content range of 9.98% to 20.40% d.b. The mean value of principal dimensions of the pulses increased linearly with an increase in seed moisture content with high correlation. The length, breadth, thickness and geometric mean diameter for chickpea and pigeonpea increased by 22.15%, 8.53%, 5.29%, 4.87% and 3.84%, 4.75%, 6.76%, 10.39%, respectively. The average value of length, thickness and geometric mean diameter for lentil seed increased by 8.41%, 10.77% and 10.39%. The sphericity, thousand seed weight, porosity, angle of repose, static coefficient of friction, hardness increased whereas bulk density, true density and germination linearly decreased with increase in moisture content.

Conflict of interest: None.

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