Moisture-Dependent Physical Properties of Grass Pea (*Lathyrus sativus* L.) Seeds

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ABSTRACT

Knowledge on physical properties seeds and their dependence on moisture content is of paramount importance in designing equipment for handling, storing and processing. In view of this, the moisture dependence of some physical properties of grass pea (*Lathyrus sativus* L.) seeds were studied at 8.5, 15.13, 21.43, and 30.66% moisture content (wet basis). The length, width, thickness, geometric mean diameter, angle of repose and thousand grain mass increased linearly from 5.02 to 5.34 mm, 4.88 to 5.01 mm, 4.22 to 4.50 mm, 4.70 to 4.94 mm, 26.33 to 31.73° and 82.0 to 114.56 g, respectively with increase in moisture content from 8.5 to 30.66%. Sphericity and porosity increased from 93.53 to 94.17 % and 34.24 to 37.1 %, with increase in moisture content from 8.5 to 15.13 % followed by a decrease from 94.17 to 92.46 % and 37.1 to 35.39 %, respectively when the moisture content increased from 15.13 to 30.66 %. The bulk and true densities decreased linearly from 882.58 to 744.00 kg m^{-3} and 1343.51 to 1205 kg m^{-3}, respectively. The coefficient of static friction increased from 0.301 to 0.443, 0.353 to 0.521 and 0.222 to 0.515 for mild steel, plywood and glass surfaces, respectively with increase in moisture content from 8.5 to 30.66 %. The coefficient of static friction was found to be highest for plywood (0.521 at 30.66 %) among the surfaces considered.

Keywords: Physical property, grass pea, true and bulk densities, angle of repose, coefficient of static friction, Ethiopia.

1. INTRODUCTION

Grass pea (*Lathyrus sativus* L.) is a food, feed and fodder crop belonging to the family Leguminosae. Of the 187 species under the genus Lathyrus, only *Lathirus sativus* is widely cultivated as a food crop while other species are cultivated to a lessor extent for both food and forage (Campbell, 1997). Grass pea with its local names *guaya* in Ethiopia and *khesari* in India, is a daily food for millions in Asia and Africa (Campbell, 1997). It has been grown since neolithic times and still is popular and promising crop providing the cheapest dietary protein available (Hanbury et al., 2000). The plant is well known for its ability to withstand flooding as well as drought and is considered an insurance crop for subsistence farmers in drought prone areas. Like most legumes, it fixes atmospheric nitrogen, which makes it suitable for long-term sustainable farming system and intercropping with other economical crops. The seeds of *L. sativus* constitute protein 26.3-34.3 %, ash 2.6-3.9%, fat 5.3%, crude fibre 10%, lignin 0.8-1.5 % and starch 41.2 % (Hanbury et al., 2000). A strong epidemiological association is known to exist between the consumption of grass pea and a motor neuron disease called Lathyrism (paralysis of the lower limbs) (Campbe1l, 1997; Urga et al., 2005). Eliminating human lathyrism by improving the nutritional quality of grass pea and increasing its economic value especially through breeding, however, brought promising results in which the level of the toxic product, ODAP is reduced to a level which would not affect human health (Campbell, 1997).

Knowledge on physical properties of seeds is of paramount importance in designing equipment for handling, storing or processing. Wu et. al. (1999) reported the importance of difference in size and density during separating particles by segregating on gravity tables. Size, shape and density are important in the separation of seed from undesirable materials on oscillating chaffers (Zewdu, 2004; Scherer and Kutzbach, 1978; Hauhouot-O'Hara et. al., 2000). The bulk density and porosity are crucial properties in the development of aeration and drying systems as these properties affect the resistance to airflow of stored mass(Jekayinfa, 2006; Tran et al., 1999), whereas angle of repose is very important in designing equipment for mass flow and storage structures. Friction between seed and a surface has an influence on the movement of particles on oscillating conveyors, cleaning using oscillating sieves and loading and unloading operations (Zewdu, 2004; Kutzbach and Scherer, 1977, Molenda et. al 2002). Simonian et. al (2006) reported an increase in moisture content of grain and straw contributes to a decrease in cleaning efficiency.

In view of this, several studies have been conducted on the physical properties such as size, shape, bulk density, true density, porosity, angle of repose and coefficient of static and dynamic friction of different cereals and beans in relation to moisture content. Moisture-dependent physical properties of sorghum seeds (Mahapatra, et al., 2002), chick pea seeds (Konak et al., 2002), lentil seeds (Amin et al., 2004), coriander seeds (Coskunar and Karababa, 2006), rapeseeds (Calisir et. al., 2005), faba bean (Altuntas and Yildiz, 2005), linseed (Selvi et. al., 2006) Pumpkin seeds (Joshi et. al., 1993), Sunflower seeds (Gupta and Das, 1997), safflower seeds (Baumler, et. al., 2005), white lupin (Ogut, 1998), popcorn kernels (Karababa, 2006), arecanut kernels (Kaleemullah and Gunasekar, 2002), green gram (Nimkar and Chattopadhyay, 2001), canola and sunflower pellets (White and Jayas, 2001), hulless barley (Rameshbabu, et al., 1996), parchment coffee bean (Pérez-Alegría, 2001), wheat, oats, rye, maize, rape and barley seeds (Scherer and Kutzbach, 1978) and tef seeds (Zewdu and Solomon, 2006) had been reported indicating that these properties are indeed affected by moisture content. Asoegwu et. al., (2006) investigated physical properties of African oil bean seed and reported the dependence of these properties against mass of the grain.

However, information on the moisture-dependent physical properties of grass pea seeds is non-existent in literature. The objective of this study is, therefore, to determine moisture-dependence of some physical properties of grass pea including size, thousand grain mass (TGM), sphericity, bulk density, true density, porosity, angle of repose and coefficient of static friction.

2. MATERIALS AND METHODS

Grass pea seeds were procured from the local market and cleaned to remove foreign materials and impurities. The moisture content of the seeds as brought from the market was determined by drying samples in hot air oven set at 105°C (±1) for 24 hours (ASAE, 1994) and was found to be

8.5% wet basis (wb). The drying condition was decided based on a preliminary study and previous related study (Dursun and Dursun, 2005; Selvi et. al., 2006). In order to attain the desired moisture levels for the study, samples were conditioned by adding a calculated amount of water followed by thorough mixing and sealing in plastic bags. The conditioned samples were kept in refrigerator set at 5°C (± 1) for 7 days for the moisture to distribute uniformly throughout the seeds (Konak, et. al., 2002; Carmen, 1996; Aydin, 2002). Accordingly, moisture levels of 8.5, 15.13, 21.43, and 30.66 % wb were obtained. The required amount of sample was withdrawn from the refrigerator and reconditioned at room temperature (≈ 25 °C) before conducting each test (Carmen, 1996; Cuskuner and Karababa, 2006).

The average length, width and thickness were determined based on 30 randomly selected seeds. Digital vernier calliper with an accuracy of 0.01 mm was used to measure these dimensions. The geometric mean diameter, D_m was calculated using the relationship in Eq. (1) (Mohsenin, 1986).

$$D_m = (LWT)^{1/3} \tag{1}$$

where *L, W* and *T* are the length, width and thickness, respectively in mm. The sphericity, ϕ was determined using Eq. (2) (Mohsenin, 1986).

$$\phi = \frac{(LWT)^{1/3}}{L} 100\% \tag{2}$$

Seeds were counted using a seed counter for thousand grain mass (*TGM*) measurement. The bulk density was measured by pouring the seeds in stainless steel cylinder of known volume till the top and removing excess seeds by rolling cylindrical glass rod on the ream of the container without compacting the seed (Konak et al., 2002; Carmen, 1996). The weight of the seeds filled in the cylinder divided by the volume of cylinder gave the bulk density. True density was determined as the ratio of sample mass to the true volume of the particles using toluene displacement method (Konak et al., 2002; Nimkar and Chattopadhyay, 2001). The porosity ε was determined using Eq. (3) (Mohsenin, 1986).

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \tag{3}$$

Where ρ_b and ρ_t are the bulk and true densities, respectively in kg m^{-3}.

A tapering hopper made of sheet metal with the top and bottom having a dimension of 300 mm × 300 mm and 100 mm × 100 mm, respectively and a height of 300 mm was used to measure the angle of repose. At 200 mm from the top, a circular disc of 100 mm diameter was fixed so that enough gap was left between the hopper walls and the disc, which allows the seeds to flow through during the test. A horizontal sliding gate was provided right below the disc for sudden release of the seed during the test. Similar device was used to determine angle of repose for green gram, okra seeds and tef seed (Nimkar and Chattopadhyay, 2001; Sahoo and Srivastava, 2002; Zewdu and Solomon, 2006). While testing, seeds were filled in the hopper and the horizontal sliding gate was suddenly opened. The height of seeds piled on the circular disc was measured and used to calculate the angle of repose, θ using Eq. (4),

$$\theta = \tan^{-1}\left(\frac{h}{r}\right) \tag{4}$$

where h and r represent height of piled seeds and the radius of the disc in mm, respectively.

The coefficient of static friction μ was determined for three different surfaces (plywood, glass and mild steel). A plastic cylinder of 155 mm diameter and 105 mm height was filled with sample and placed on tilting table covered with the different surfaces and having a scale to read the tilting angle directly. The seed-filled cylinder was raised slightly so that it will not have direct contact with the surface. The table was raised gradually using a screw device till the seed-filled cylinder just started to slide down and the corresponding tilting angle, φ was recorded (Mahapatra et al., 2002; Nimkar and Chattopadhyay, 2001; Dursun and Dursun, 2005; Sahoo and Srivastava, 2002). The value of μ was calculated using Eq. (5).

$$\mu = \tan\varphi \tag{5}$$

One-way analysis of variance (ANOVA) was carried out to test the significance of the effect of moisture content on physical properties using SPSS version 10 (SPSS, 1999) whereas regression analysis was employed to describe the relationship between moisture content and respective physical properties.

3. RESULTS AND DISCUSSION

3.1 Seed Size

The length, width and thickness of seeds increased significantly ($p<0.05$) from 5.02 to 5.34 mm, 4.88 to 5.01 mm, and 4.22 to 4.50 mm, respectively with increase in moisture content from 8.5 to 30.66% (Fig. 1). Similarly, the geometric mean diameter increased from 4.70 to 4.94 mm in the same moisture content range indicating that moisture content significantly influences these properties. The relationship between these dimensions of grass pea seeds and moisture content was found to be linear in the moisture content considered as described by Eqs. (6 to 9).

$$L = 0.016M + 4.885 \quad (R^2 = 0.916) \tag{6}$$
$$W = 0.006M + 4.852 \quad (R^2 = 0.895) \tag{7}$$
$$T = 0.013M + 4.153 \quad (R^2 = 0.853) \tag{8}$$
$$D_m = 0.012M + 4.617 \quad (R^2 = 0.907) \tag{9}$$

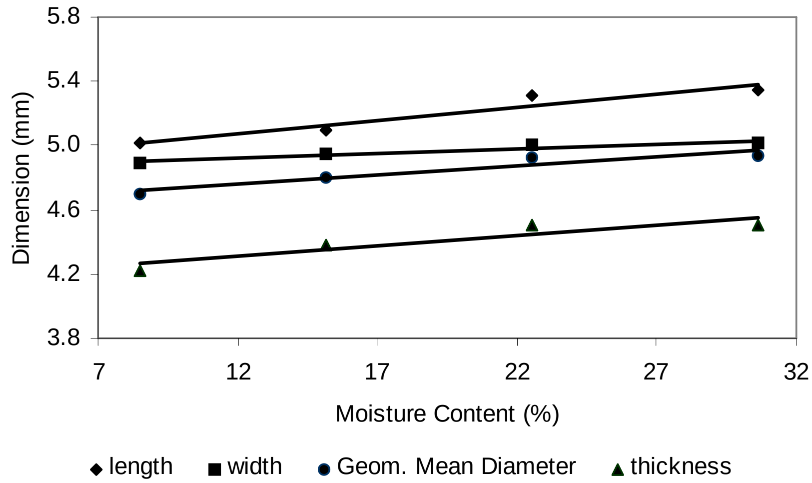

Figure 1 Effect of moisture content on seed dimension

The results in this study were in agreement with other related studies. The length, width, thickness and geometric mean diameter of barley, wheat, rye and maize showed a linear increase with increased moisture content (Scherer and Kutzbach, 1978). Similarly, the diameter and thickness of lentil seeds were reported to increase linearly with increase in moisture content (Amin et. al., 2004). However, the length and height of pistachio nuts were found to increase with increase in moisture content and described by a second-degree polynomial equation (Kashaninejad et al., 2006). In other studies logarithmic relationship between length, width, thickness and geometric mean diameter and moisture content was reported for okra seeds (Sahoo and Srivastava, 2002), and arecanut kernels (Kaleemullah and Gunasekar, 2002).

3.2 Sphericity

The sphericity of seeds calculated at different moisture content increased from 93.53 to 94.17% with increase in moisture from 8.5% to 15.13% and reduced to 92.46% with further increase in moisture content to 30.66% (Fig. 2).

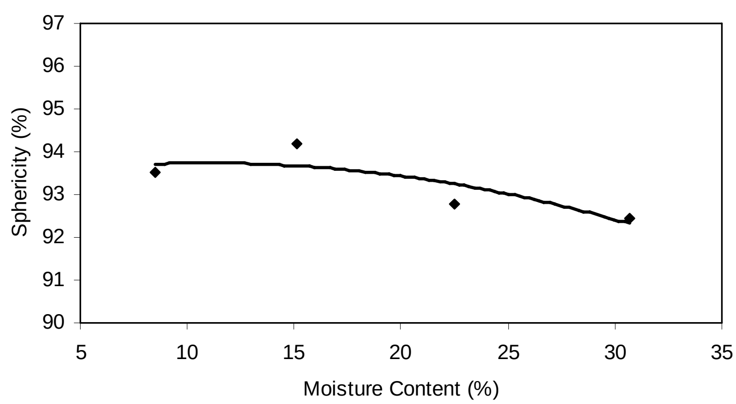

Figure 2 Effect of moisture content on sphericity

The initial increase of sphericity could be due to relatively proportional increase in length, width and thickness. However, beyond 15.13% moisture content there was relatively greater increase in length as compared to width and thickness which might probably resulted in slight reduction in sphericity. The relationship between sphericity and moisture content is described by a second-degree polynomial equation Eq. (10).

$$\phi = -0.0036M^2 + 0.0783M + 93.31 (R^2 = 0.713) \tag{10}$$

Previous studies for other seeds, however, had indicated that sphericity could be affected by moisture content in different ways. The sphericity of sorghum seeds were found to be unaffected by moisture content (Mahapatra, et al., 2002). An increase in the sphericity with increase in moisture content was observed for pistachio kernel (Kashaninejad, et. al., 2006), fenugreek seeds (Altuntas, et al., 2005), and arecanut kernel (Kaleemullah and Gunasekar, 2002). An initial increase in sphericity up to 20% of moisture content and a decrease with further increase in moisture content was reported for okra seed (Sahoo and Srivastava, 2002). This indicates that different seeds might behave differently in terms of the relative changes in length, width and thickness which could affect sphericity.

3.3 Thousand Grain Mass (TGM)

The TGM shown in Fig. 3 significantly ($p<0.05$) increased from 82.0±2.54 to 114.56±4.36 g with the corresponding increase in moisture content from 8.5 to 30.66%, which could be attributed to the moisture absorbed by the seeds. The relationship between TGM and moisture content was found to be linear (Eq. (11)).

$$TGM = 1.4323M + 68.937 \quad (R^2 = 0.979) \tag{11}$$

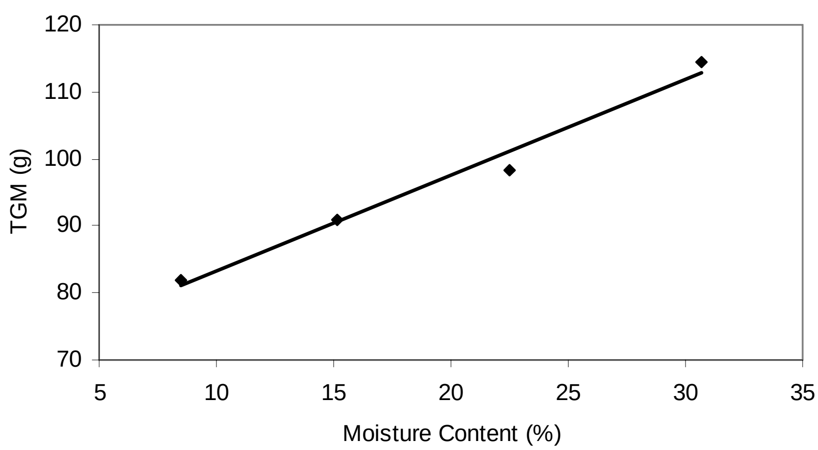

Figure 3 Effect of moisture content on thousand grain mass (TGM)

Such linear relationship between TGM and moisture content was reported for caper seed (Dursun and Dursun, 2005), sorghum (Mahapatra et al., 2002), raw cashew nut (Balasubramanian, 2001), green gram (Nimkar and Chattopadhyay, 2001), and wheat, oats, rye, rape seed and barley (Scherer and Kutzbach, 1978). However, logarithmic relationship between *TGM* and moisture content has been reported for okra seed (Sahoo and Srivastava, 2002).

3.4 Bulk and True Density

The bulk and true densities of grass pea seeds significantly ($p<0.05$) decreased with increase in the moisture content range considered in the study (Fig. 4). A decrease from 882.58±17.39 to 744.0±15.89 and 1343.51±59.44 to 1205.40±41.10 kg m^{-3} was observed for bulk and true density, respectively for a corresponding change in the moisture content from 8.5 to 30.66% wb.

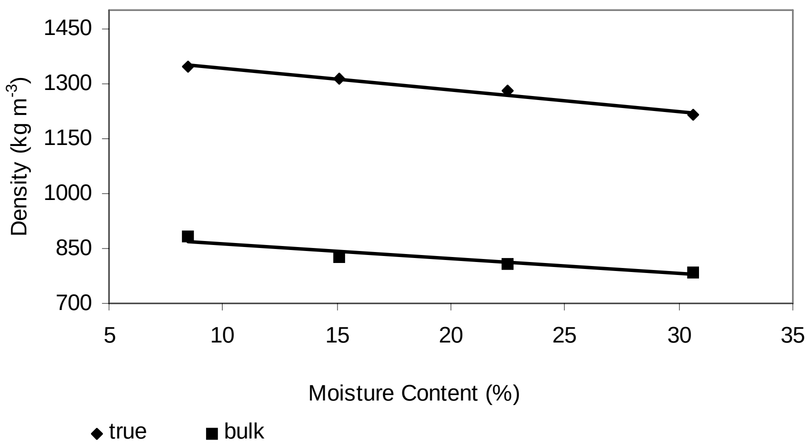

Figure 4 Effect of moisture content on true density and bulk density

The relative reduction in the densities at high moisture content could be attributed to less weight gain due to the added moisture in relation to the concomitant volumetric expansion of the seeds. The reduction in the bulk density could also be associated to the reduction in sphericity at higher moisture content which could cause loose packing patterns of seeds and increased bulk volume. The same trend has been observed for sorghum, chick pea, wheat, maize and okra seeds (Mahapatra et al., 2002; Konak et. al., 2002; Scherer and Kutzbach, 1978; Sahoo and Srivastava, 2002). A linear relationship described the moisture-dependence of true and bulk densities (Eqs. (12 and 13).).

$$\rho_t = -5.7508M + 1397.7 \qquad (R^2 = 0.979) \qquad (12)$$

$$\rho_b = -4.1569M + 905.25 \qquad (R^2 = 0.905) \qquad (13)$$

3.5 Porosity

The porosity increased significantly ($p<0.05$) from 34.24±3.04 to 37.1±1.53% with increase in moisture content from 8.5 to 15.13% followed by a drop from 37.1±1.53 to 35.39±1.39% with the corresponding change in moisture content from 15.13 to 30.66% (Fig. 5). The increase in porosity in the moisture content range from 8.50% to 15.13% could be associated to the greater decrease in bulk density as compared to true density and based on the Eq (3). For the moisture content beyond 15.13%, however, the decrease in true density was higher than that of bulk density, which might have resulted in increase in porosity. The moisture-dependence of porosity is described using Eq. (14).

$$\varepsilon = -0.0189M^2 + 0.7766M + 29.187 \quad (R^2 = 0.908) \tag{14}$$

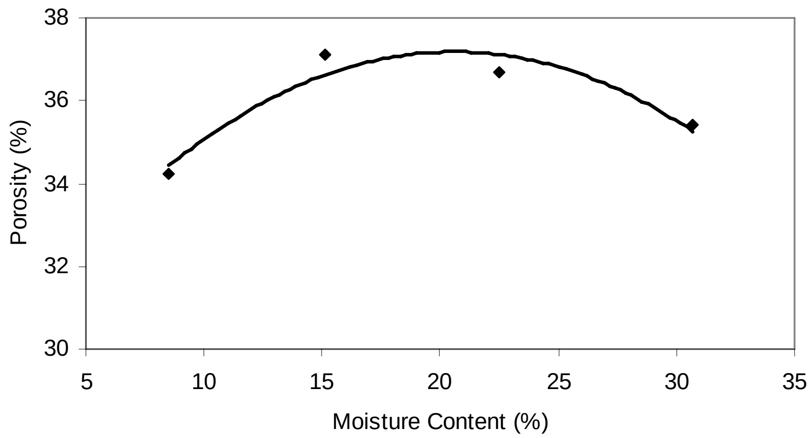

Figure 5 Effect of moisture content on porosity

An increase in porosity with moisture content were reported for arecanut kernel (Kaleemullah and Gunasekar, 2002), chickpea seeds (Konak et. al., 2002), green gram (Nimkar and Chattopadhyay, 2001), and barley and rapeseed (Scherer and Kutzbach, 1978). However, a reverse relationship had been found for sorghum and okra seed (Mahapatra et al., 2002; Sahoo and Srivastava, 2002), this indicated that porosity of seeds of different crops could respond differently for changes in the moisture content, which could be attributed to the relative changes in length, width and thickness, and associated bulk and true densities.

3.6 Angle of Repose

The angle of repose, θ obtained at different moisture contents is shown in Fig. 6. A rise in the moisture content from 8.5 to 30.66% resulted in a significant ($p<0.05$) increment of θ from 26.33±0.53 to 31.73±0.81°. At higher moisture content within the experimental range, seeds might tend to stick together resulting in better stability and less flowability, which increases the value of θ. The relationship between angle of repose and moisture content was found to be linear (Eq. (15)).

$$\theta = 0.2346M + 24.601 \quad (R^2 = 0.982) \tag{15}$$

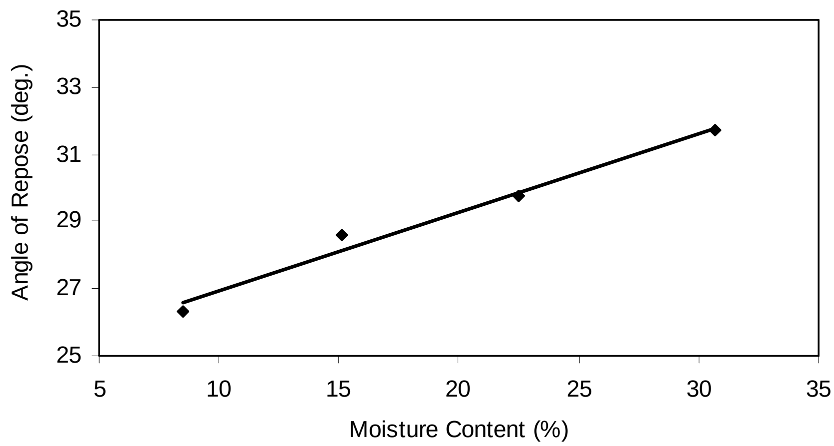

Figure 6 Effect of moisture content on angle of repose

Similarly a linear relationship between angle of repose and moisture content was observed for chick pea, popcorn and green gram (Konak et al., 2002; Karababa, 2006; Nimkar and Chattopadhyay, 2001), whereas, a logarithmic relationship was reported for okra seed (Sahoo and Srivastava, 2002). A parabolic curve was used to describe the relationship between angle of repose and moisture content with an initial decrease followed by an increase in angle of repose with increase in moisture content for wheat, oats, rye, maize, rape seed and barley (Scherer and Kutzbach, 1978).

3.7 Coefficient of Static Friction

The coefficient of static friction, μ determined at different moisture levels on the three surfaces (mild steel, glass and plywood) shown in Fig. 7 significantly ($p<0.05$) increased for all surfaces with increase in moisture content from 8.5 to 30.66%.

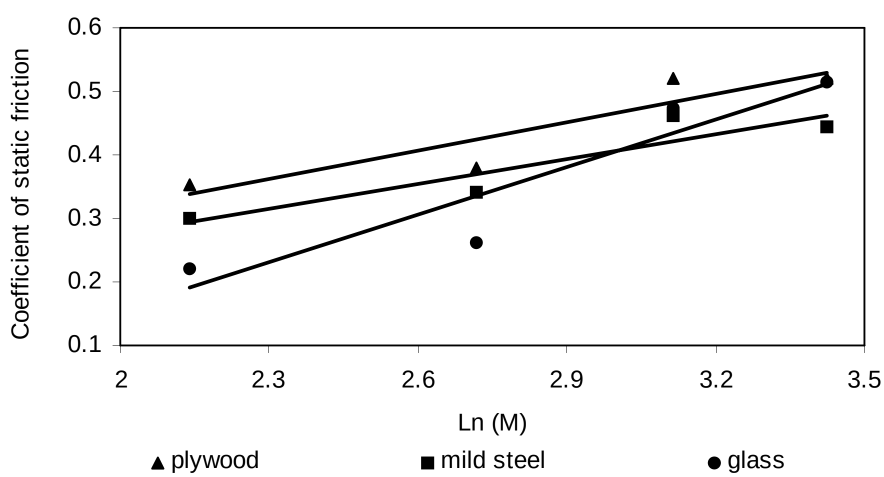

Figure 7 Effect of moisture content on coefficient of static friction

Accordingly, μ increased from 0.301±0.001 to 0.443±0.002, 0.353±0.0006 to 0.521±0.001 and 0.222±0.0008 to 0.515±0.002 for mild steel, plywood and glass, respectively. This could be due to the fact that the surface of the seeds got better adhesive property with increased moisture content considered in this study. The maximum coefficient of friction was found to be 0.521 at 30.66% for plywood among the surfaces used. The relationship between coefficient of static friction and moisture content for the surfaces considered is described using Eqs. (16 to 18).

$$\mu_g = 0.2501 \ln(M) - 0.3444 \quad (R^2 = 0.881) \tag{16}$$

$$\mu_{pw} = 0.1495 \ln(M) + 0.0175 \quad (R^2 = 0.851) \tag{17}$$

$$\mu_{ms} = 0.1301 \ln(M) + 0.0165 \quad (R^2 = 0.842) \tag{18}$$

A linear increase in coefficient of static friction with moisture content was observed for sorghum, popcorn kernels and lentil seeds (Mahapatra et al., 2002; Karababa, 2006; Carmen, 1996). However, a logarithmic and exponential relationship between coefficient static friction and moisture content has been reported for chickpea and okra seeds on different surfaces (Konak et al., 2002; Sahoo and Srivastava, 2002).

4. CONCLUSIONS

The moisture-dependence of various physical properties of grass pea (*Lathyrus sativus* L.) seed in the moisture content range of 8.5 to 30.66% w.b. was determined. The length, width, thickness, geometric mean diameter, thousand grain mass, angle of repose and coefficient of static friction of seeds increased with increase in moisture content from 8.5 to 30.66% wb. The bulk and true densities decreased linearly from 882.58 to 744.00 kg m^{-3} and 1343.51 to 1205 kg m^{-3}, respectively, whereas the porosity exhibited an initial increase followed by a decrease with increase in moisture content. Sphericity of grass pea seeds increased linearly from 93.53 to 94.17% with increase in moisture content from 8.5 to 15.13% and dropped to 92.46% with increase in moisture content to 30.66%.

5. ACKNOWLEDGEMENTS

The authors are very much grateful to Mr. Tamirat Redai and Mr. Habtamu Kide, technical staff of the Department of Food Science and Postharvest Technology, Haramaya University for their unreserved assistance while running the experiments.

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7. NOMENCLATURE

D_m	geometric mean diameter (mm)
L	seed length (mm)
M	moisture content, (% w. b.)
R^2	coefficient of determination (-)
T	thickness (mm)
TGM	thousand grain mass (g)
W	seed width (mm)
ε	porosity (%)
φ	angle of tilt in determination of coefficient of static friction (^{o})
ϕ	sphericity (%)
μ	coefficient of static friction (-)
μ_g	coefficient of static friction between seed and glass surface (-)
μ_{pw}	coefficient of static friction between seed and plywood surface (-)
μ_{ms}	coefficient of static friction between seed and mild steel surface (-)
ρ_b	bulk density (kg m^{-3})
ρ_t	true density (kg m^{-3})
h	height of piled seed in the determination of angle of repose (mm)
r	radius of disk in the determination of angle of repose (mm)
θ	angle of repose (°)

FIGURE CAPTION

Figure 1 Effect of moisture content on seed dimension
Figure 2 Effect of moisture content on sphericity
Figure 3 Effect of moisture content on thousand grain mass (TGM)
Figure 4 Effect of moisture content on true density and bulk density
Figure 5 Effect of moisture content on porosity
Figure 6 Effect of moisture content on angle of repose
Figure 7 Effect of moisture content on coefficient of static friction