Moisture dependent physical properties of horse gram

Ashish V. Sonawane[1*], Yogesh A. Rajwade[2], Deepak Singh[1], Sujeet Desai[3], Gajanan B. Rajurkar[3]

(1. *College of Agricultural Engineering, Dediapada, Navsari Agricultural University, Gujarat-393040*;
2. *Department of Agricultural and Food Engineering, Indian Institute of Technology Kharagpur, West Bengal-721302, India*;
3. *Division of Agricultural Engineering, Indian Agricultural Research Institute, New Delhi-110012, India*)

Abstract: Some physical properties of horse gram grains (*Macrotyloma uniflorum)* were determined as a function of moisture content in the range of 8.66% to 20.76% dry basis (d.b.). Percentage increase in length, width and thickness was found to be 9.01%, 16.90% and 6.84% respectively; whereas, grain size and sphericity were increased from 4.18 to 4.63 mm and 0.708 to 0.731 mm with increase in moisture content. The thousand grain mass increased from 29.8 to 34.10 g, while bulk density and true density decreased from 855 to 689 kg m^{-3} and 1237 to 1102 kg m^{-3} respectively due to increase in moisture content. The value of bulk porosity increased linearly from 30.80% to 37.48%. Results also revealed that the terminal velocity and angle of repose were increased from 8.45 to 10.52 m s^{-1} and 8.66^o to 20.76^o respectively. The static coefficient of friction, for different test materials, varied from 0.190 to 0.532 in the specified moisture level.

Keywords: physical properties, horse gram, moisture content, thousand grain mass, static coefficient of friction

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1 Introduction

Moisture dependent physical properties of agricultural grains are essential data for designing of various process equipments, storage structures, estimation and efficiency of a machine etc. Several investigators reported the physical properties of seeds and grains at various moisture contents such as pigeon pea (Shepherd and Bhardwaj, 1986), soybean (Deshpande et al.,1993), pumpkin grains (Joshi et al., 1993), lentil (Tang and Sokhansanj, 1993), sunflower grain (Gupta and Das,1997), white lupine (Öğüt, 1998), green gram (Nimkar and Chattopadhyay, 2001), locust been seed (Ogunjimi et al. 2002), pigeon pea (Baryeh and Mangope, 2002), chick pea grain (Konak et al., 2002), cotton (Özarslan, 2002), okra grain (Sahoo and Srivastava, 2002), hemp (Saçılık et al., 2003), quinoa seeds (Vilche et al., 2003), vetch (Yalçın and Özarslan, 2004), lentil seed (Amin et al., 2004), caper seed (Dursun and Dursun, 2005), sweet corn seed (Coskun et al., 2006), black-eyed pea (Unal et al., 2006), Turkish Göynük Bombay beans (Tekin et al., 2006), some grain legume seeds (Altuntas and Demirtola, 2007) and Red lentil seed (Gharibzahedi et al., 2011).

Horse gram (*Macrotyloma uniflorum* (Lam) Verdc.) is an important pulse crop which is grown in the dry areas of India, Australia, Burma and Sri Lanka. (Sudha et al., 1995) . In India, it is cultivated extensively,. Horse gram is popularly known as poor man's pulse in south India. The direct use of horse gram is limited due to poor cooking quality; therefore, it is consumed in sprouted form. It also possess medical value, specifically used for patients with kidney stone, piles and urinary diseases.

Earlier studies reported that Horse gram is good source of protein (17.9%-25.6%), carbohydrates (51.9%-

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* **Corresponding author: Ashish V. Sonawane,** Moisture dependent physical properties of horse gram, Assistant Professor, College of Agricultural Engineering, Dediapada, Navsari Agricultural University, Gujarat-393040. Email: ashishsonawane 1313@gmail.com.

60.9%), energy and low lipid (0.58%-2.06%) and essential amino acids (Bravo et al., 1999; Kadam and Salunkhe, 1985; Sudha et al., 1995). It is rich in iron and molybdenum content, but iron availability is reduced by presence of phytates, tannins etc. (Bravo et al., 1999; Kadam and Salunkhe, 1985; Sudha et al., 1995; Siddhuraju and Manian, 2007). Due to high protein and lysine content, horse gram acts as supplementary to cereal based diet.

However, moisture dependent physical properties in the range of 8%-20% d.b. of horse gram have not been reported in the literature that would be very useful for designing process equipments. The present study was carried out to investigate moisture dependent physical properties of horse gram namely axial dimensions, arithmetic and geometric mean diameters, sphericity, thousand grain mass, surface area, bulk and true densities, porosity, terminal velocity and coefficient of static friction.

2 Materials and methods

Horse gram of local variety used in the study was procured from the nearby market. The grains were cleaned manually to remove lighter foreign matter such as dust, dirt, chaff, immature and broken splits and stones. Distilled water was added to condition samples to obtain desired moisture content. The amount of distilled water was calculated from the relation given below (Isik and Unal, 2007).

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

where, Q is the mass of distilled water to be added (kg); W_i is the initial mass of grain sample (kg); M_i is the initial moisture content of grain sample (% d.b.) and M_f is the final moisture content (% d.b.). The samples were then tightly sealed into separate polyethylene bags and stored in the refrigerator at 5°C for two weeks to distribute the moisture uniformly throughout the grain sample. Required quantity of sample was taken out of the refrigerator two hours before commencement of the test to equilibrate the grain sample with room temperature (Sacilik et al., 2003).

As usual practice followed in the region, the grains are harvested at about 22%-25% d.b. moisture content and dried to desired moisture content of around 15%-18% d.b.; therefore, the physical properties of grains were determined at five levels of moisture contents viz., 8.66, 12.40, 14.86, 16.50, 20.76 % d.b. This technique has been reported by Sacilik et al. (2003), Isik and Unal (2007), Brusewitz (1975), Shepherd and Bhradwaj (1986), Nimkar and Chattopadhyay (2001).

To determine average seed size of grain, 100 grains were selected randomly and their linear dimensions, length (l), width (w) and thickness (t), were measured using digital vernier calipers with least count of 0.01 mm. Schematic diagram of measurement of linear dimensions is shown in Figure 1. Longest axis (also a major axis), denoted as ‘a’ in the figure, was considered to be the length of the grain, whereas axis ‘b’, which is also a medium axis, corresponds to the width of the grain. Thickness of the grain was measure along the axis ‘c’, which is the minor axis of the grain.

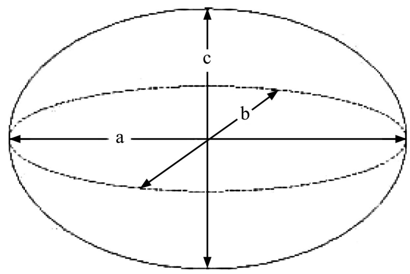

Figure 1 Schematic diagram of linear dimensions of the horse gram grain

The average diameter of grain was calculated using arithmetic and geometric mean of the three axial dimensions. The arithmetic mean diameter (D_a) and geometric mean diameter (D_g) of the grain were calculated using the relationship given by Mohsenin (1986) given as follows.

$$D_a = \frac{(L + W + T)}{3} \tag{2}$$

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

Degree of sphericity of grain was calculated using the relation expressed as follows (Mohsenin, 1986).

$$\phi = \frac{(LWT)^{1/3}}{L} \tag{4}$$

The one thousand grain mass was determined by the electronic weighing balance with least count of 0.001 g.

The surface area of grains was determined by analogy with a sphere of same geometric mean diameter, using the relationship given by Tunde-Akintunde and Akintunde (2004).

$$A_s = \pi D_g^{\,2} \quad (5)$$

Bulk density and true densities at various moisture levels were determined according to the standard test described by Mohsenin (1986), Singh and Goswami (1996) and Gupta and Das (1997) and Sacilik et al. (2003). For determination of bulk density, circular container of 500 ml was filled with the grains from 150 m height at a constant rate and subsequent weighing without any manual compaction. The mass of grains and the volume of the container give the bulk density.

Average true density and grain volume were found out by liquid displacement method using toluene (C_7H_8). (Nimkar et al., 2005).

Porosity of horse gram at various moisture levels was estimated using the relationship given by Mohsenin (1986).

$$P_f = 1 - \left(\frac{\rho_b}{\rho_t}\right)100 \quad (6)$$

where, P_f is the porosity in %; ρ_b is the bulk density in kg/m^3; and ρ_t is the true density in kg/m^3.

Terminal velocities of grain at different moisture contents were determined with the help of cylindrical air column device (Sacilik et al., 2003). A grain sample was dropped from the top of air column device into an air stream. Airflow rate was then gradually increased and adjusted until the grains became suspended in an air stream. The air stream velocity, displayed on the digital meter, was then noted down. The procedure was repeated for different moisture contents with five replications each.

The coefficient of static friction "μ" of horse gram was determined against different materials, namely stainless steel, galvanized iron, plywood and rubber. An open ended plastic pipe having 50 mm diameter and 100 mm height, filled with grain sample was placed on the adjustable tilting platform, faced with the test surface. The pipe was kept in raised position to avoid surface contanct. The structural surface was then raised gradually with the pipe rested on it with the help of provided screw. The process of gradual tilting was continued till the cylinder just started to slide over the surface. The respective angle α was measured from the scale attached. The coefficient of static friction was calculated from the relationship as given below (Isik and Unal, 2007; Yalçin and Ozarslan, 2004).

$$\mu = \tan\alpha \quad (7)$$

The experiment was repeated for different moisture content levels. For each test, the pipe was emptied and refilled with a different sample of same moisture level.

All of the above experiments were replicated five times, unless stated otherwise and average values are used in calculations.

3 Results and discussion

The results of the experiments carried out to determine physical properties of horse gram as a function of moisture content are discussed below.

3.1 Seed dimensions

The variation in the linear dimensions of horse gram in the moisture range of 8.66 to 20.76% (d.b.) is shown in Table 1. It was observed that all dimensions increased linearly with moisture content. Major, minor and medium axes are shown in the Figure 1.

The relationship between linear dimensions and moisture content (M) may be represented as follows:

Table 1 Means and standard errors of grain dimensions at different moisture content

Moisture content /% d.b.	Major axis (a) /mm	Medium axis (b) /mm	Minor axis (c) /mm
8.66	5.88±0.04	4.23±0.02	2.92±0.03
12.40	6.02±0.06	4.30±0.04	2.96±0.05
14.56	6.15±0.08	4.36±0.06	3.02±0.06
16.50	6.32±0.12	4.45±0.07	3.06±0.07
20.76	6.41±0.06	4.98±0.07	3.12±0.08

The variation in linear dimensions is shown graphically in Figure 2. The relationships between moisture content and linear dimensions can be represented as follows:

$$a = 0.043M + 5.485, \quad R^2 = 0.979 \quad (8)$$

$$b = 0.062M + 3.566, \quad R^2 = 0.926 \quad (9)$$

$$c = 0.026M + 2.675, \quad R^2 = 0.955 \quad (10)$$

It was observed that, there is very high correlation exists between moisture content and linear dimensions of grains. This indicated that, as the grain absorbs the moisture, the linear dimensions increase.

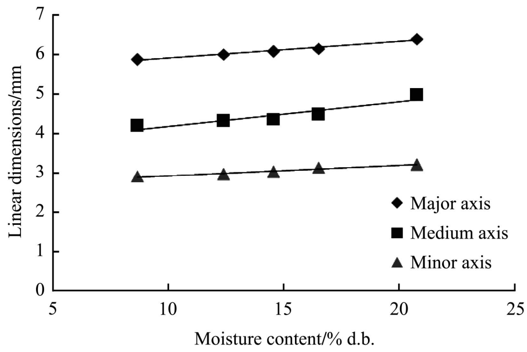

Figure 2 Effect of moisture content on linear dimensions

3.2 Grain size

Variation in size of horse gram at different moisture content is shown in the Figure 3. It was observed that with increase in moisture content, the grain size increases from 4.18 to 4.63 mm linearly. The percentage increase in grain size was found to be 10.84% for corresponding increase in the moisture level from 8.66 to 20.76% d.b. The variation in grain size due to change in moisture levels was found to be significant at 5% level when analyzed statistically. The results were similar as reported by Grover and Kumar (1985) for pulses, Kulkarni et al. (1993) and Deshpande et al. (1993) for soya bean, Munde (1999) for black gram, Sutar et al. (2001) for delinted cotton seed, Baryeh (2002) for millet, Nimkar et al. (2005) for moth gram and Kiliçkan et al. (2010) for black grape seed. The relationship between size of horse gram and moisture content could be represented by following relationship with a R^2 value of 0.958 as shown in Figure 2.

$$D_m = 0.043M + 3.747 \tag{11}$$

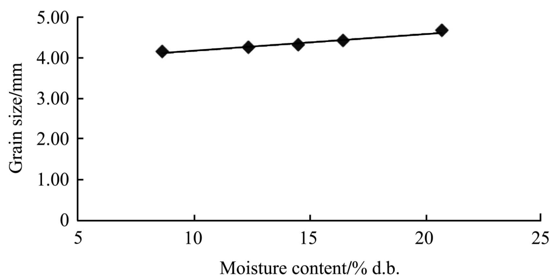

Figure 3 Effect of moisture content on grain size

3.3 Sphericity

It was found that with increase in moisture content, the spericity increased from 0.708 to 0.731, as represented in Figure 4. The results were found to be in agreement with earlier findings for soya bean (Unde and More, 1996), hemp seed (Sacilik et al., 2003), vetch seed (Yalcin and Ozarslan, 2004) and moth gram (Nimkar et al., 2005). Relation between moisture content and sphercity could be given by following equation with R^2 value of 0.855.

$$\phi = 0.002M + 0.686 \tag{12}$$

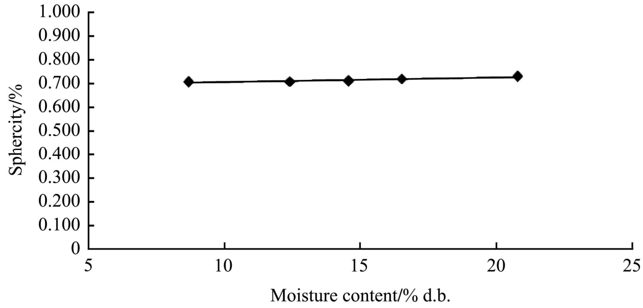

Figure 4 Effect of moisture content on sphercity

3.4 Thousand grain mass

Data obtained for thousand grain mass of horse gram are shown graphically in Figure 5. It was observed that the average thousand grain mass varied from 29.8 to 34.10 g with corresponding increase in moisture levels from 8.66 to 20.76% d.b. It was revealed that thousand grain mass increased linearly with increase in moisture content and this change was significant at 5% level of significance. Percent increase in thousand grain mass was found to be 14.43% for corresponding increase in moisture from 8.66 to 20.74% d.b. This trend was in agreement with the work reported for chickpea (Gupta and Prakash, 1990), soya bean (Kulkarni et al., 1993; Deshpande et al., 1993), black gram (Munde, 1999) and paddy (Reddy and Chakraverty, 2004), moth gram (Nimkar et al., 2005), black grape seed (Kiliçkan et al., 2010), red kidney beans (Isik and Unal, 2011). The thousand grain mass as a function of moisture content could be represented by following relationship:

$$W_g = 0.368M + 26.30 \tag{13}$$

with a R^2 value of 0.974.

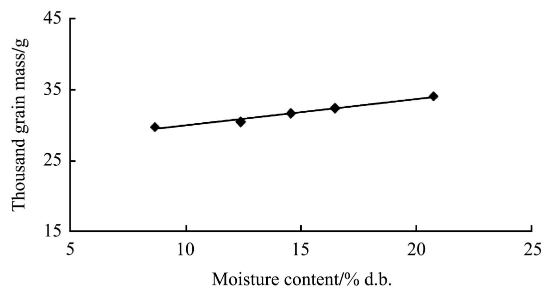

Figure 5 Effect of moisture content on thousand grain mass

3.6 Bulk density

Experimental data for bulk density values of horse gram are represented graphically as shown in Figure 6. It was observed that with increase in moisture content the bulk density of horse gram decreased linearly from 856 to 689 kg/m^3. This change in bulk density was found to be significant at 5% level of significance. With the increase in moisture content from 8.66 to 20.76% d.b., the percent decrease in bulk density was found to be 24.24%. This decrease in bulk density was due to fact that, the increase in mass due to increase in moisture was lower than that of volumetric expansion of bulk grains. Similar kinds of results were reported for fababeans (Fraser et al., 1978), pigeonpea (Shepherd and Bhardwaj, 1986), chickpea (Dutta et al., 1988; Gupta and Prakash, 1990), lentil (Çarman, 1996), soya bean (Deshpande et al., 1993) and green gram (Nimkar and Chattopadhyay, 2001), moth gram (Nimkar et al., 2005), black grape seed (Kiliçkan et al., 2010), red kidney beans (Isik and Unal, 2011). The relationship between moisture content and bulk density of horse gram could be given by following equation with R^2 value of 0.997.

$$\rho_b = 983.4 - 14.32M \tag{14}$$

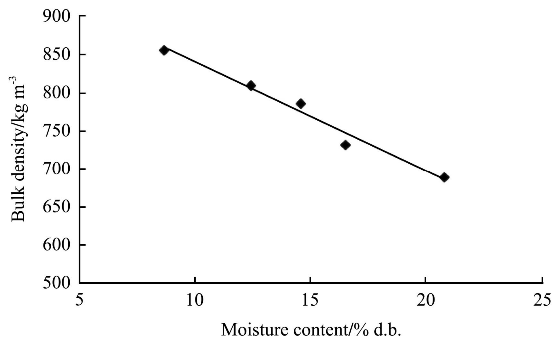

Figure 6 Effect of moisture content on bulk density

3.7 True density

Data obtained for true density of horse gram at various moisture levels are graphically shown in Figure 7. It was observed that true density decreases from 1,237 to 1,102 kg/m^3 with corresponding increase in moisture from 8.66 to 20.77% d.b. This change was significant at 5% level of significance. The maximum percentage decrease in true density was found to be 12.25% for the corresponding change in moisture.

Decrease in true density with increase in moisture level was probably due to relatively higher true volume as that of compared to corresponding mass of grain attributed due to water absorption. Similar results were reported for soya bean (Deshpande et al., 1993), chickpea (Dutta et al., 1988) and pigeonpea (Shepherd and Bhardwaj, 1986), moth gram (Nimkar et al., 2005), and black grape seed (Kiliçkan et al., 2010). The linear relationship between moisture content and true density of horse gram was found to as;

$$\rho_t = 1324 - 11.16M \tag{15}$$

with R^2 value of 0.977.

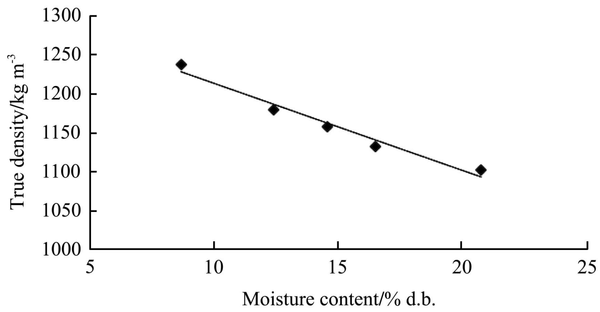

Figure 7 Effect of moisture content on true density

3.8 Bulk porosity

The variation in bulk porosity with corresponding increase in moisture content is shown in Figure 8. It was observed that the bulk porosity increases linearly from 30.80% to 37.48%, with increase in moisture levels. This change was found to be significant at 5% level of significance. The results showed that increase in bulk porosity of horse gram is 17.82% with corresponding increase in moisture from 8.66 to 20.76% d.b. Similar findings were reported for lentil seed (Çarman, 1996), gram (Dutta et al., 1988), pigeon pea (Shepherd and Bhardwaj, 1986), red kidney beans (Isik and Unal, 2011).

The best fitted linear relationship could be represented by following with R^2 value of 0.884.

$$\varepsilon = 0.597M + 24.71 \tag{16}$$

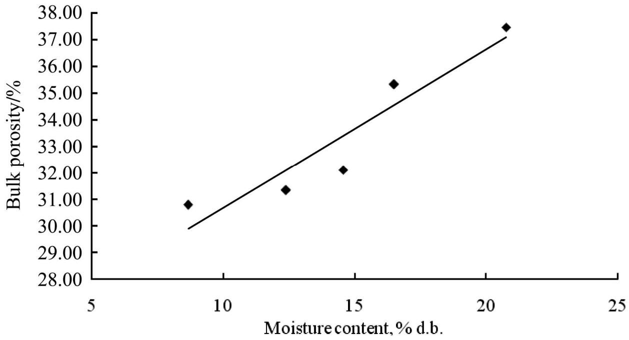

Figure 8 Effect of moisture content on bulk porosity

3.9 Terminal velocity

Experimental data for terminal velocity values of horse gram are represented graphically as shown in Figure 9. It was observed that with increase in moisture content the terminal velocity of horse gram increased linearly from 8.45 to 10.52 m/s. This change in terminal velocity was found to be significant at 5% level of significance. With the increase in moisture content from 8.66 to 20.76% d.b. the percent decrease in bulk density was found to be 24.50%. These results were found to be in conformity with some of the studies reported for lentil (Çarman, 1996), pumpkin (Joshi et al., 1993) and green gram (Nimkar and Chattopadhyay, 2001), moth gram (Nimkar et al., 2005), black grape seed (Kiliçkan et al., 2010), red kdney beans (Isik and Unal, 2011). The terminal velocity as a function of moisture content can be given by following relationship.

$$V_t = 0.177M + 6.859 \quad (17)$$

with R^2 value of 0.984

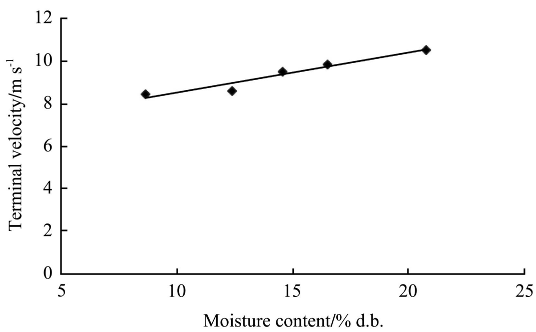

Figure 9 Effect of moisture content on terminal velocity

3.10 Angle of repose

Variation in angle of repose of horse gram at different moisture content is shown in the Figure 10. It was observed that with increase in moisture content, the angle of repose increased from 19.78° to 24.35° linearly. The percentage increase in angle of repose was found to be 23.10% for corresponding increase in the moisture level from 8.66 to 20.76% d.b. The variation in grain size due to change in moisture levels was found to be significant at 5% level when analyzed statistically. Similar results were reported for black gram (Munde, 1999), chickpea (Dutta et al., 1988), pigeonpea (Shepherd and Bhardwaj, 1986), fababeans (Fraser et al., 1978), moth gram (Nimkar et al., 2005). The linear relationship between moisture content and angle of repose of horse gram was found to be as following:

$$\theta = 0.394M + 15.86 \quad (18)$$

with R^2 value of 0.943.

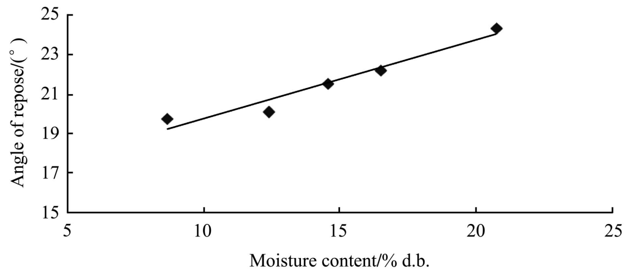

Figure 10 Effect of moisture content on angle of repose

3.11 Static coefficient of friction

Experimental data for determining static coefficient of friction values of horse gram against various materials like stainless steel, galvanized iron, plywood and rubber are represented graphically in Figure 11. It was revealed that static coefficient of friction for horse gram increased with increase in corresponding moisture content of 8.66 to 20.76% d.b. It was also found that the values for static coefficient of friction of horse gram were in range of 0.19 to 0.53 against different materials stated above at various moisture contents. Similar results were reported for soya bean (Mandhyan and Prasad, 1994); for black gram (Munde, 1999), moth gram (Nimkar et al., 2005), black grape seed (Kiliçkan et al., 2010), red kdney beans (Isik and Unal, 2011).

It was observed that rubber had highest static coefficient of friction while stainless steel had lowest static coefficient of friction. This was may be due to the smoother surface of stainless steel compared to other surfaces. Rubber provides rougher surface than any other test material. The static coefficient of friction as a function of moisture content may be given by following equations:

$$\mu_r = 0.005M + 0.445, \quad R^2 = 0.924 \quad (19)$$

$$\mu_g = 0.006M + 0.368, \quad R^2 = 0.948 \quad (20)$$

$$\mu_p = 0.002M + 0.387, \quad R^2 = 0.961 \quad (21)$$

$$\mu_s = 0.005M + 0.139, \quad R^2 = 0.985 \quad (22)$$

where, μ_r, μ_g, μ_p and μ_s are the static coefficient of friction on rubber, galvanized iron, plywood and stainless steel, respectively.

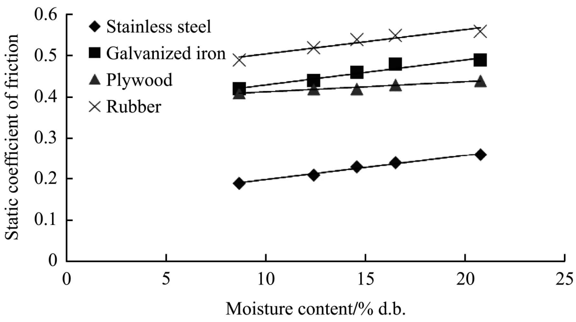

Figure 11 Effect of moisture content on static coefficient of friction for various sheet materials

4 Conclusions

1) Linear dimensions, viz. major axis, medium axis and minor axis of horse gram increased from 5.88 to 6.41, 4.32 to 4.98 and 2.92 to 3.12 respectively due to increase in moisture content from 8.66 to 20.76% d.b.

2) With the increase in moisture content from 8.66 to 20.76% d.b., the size of grains increased from 4.18 to 4.63 mm and sphericity increased from 0.708 to 0.731.

3) Increasing trend was observed for thousand grain mass (29.8 to 34.10 g), while the decreasing trend was observed in case of bulk density (855 to 689 kg/m^3) and true density (1,237 to 1,102 kg/m^3). However, bulk porosity was found to be increased linearly from 30.80% to 37.48%.

4) Terminal velocity of horse gram varied from 8.45 to 10.52 m/s. Whereas the angle of repose varied linearly from 8.66° to 20.76°.

5) The static coefficient of friction, when tested for different material surface, was found to vary between 0.190 to 0.532, and the moisture content of horse gram grain increased from 8.66 to 20.76% d.b.

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