African Journal of Biotechnology Vol. 9(24), pp. 3555-3562, 14 June, 2010
Available online at http://www.academicjournals.org/AJB
ISSN 1684–5315 © 2010 Academic Journals

Full Length Research Paper

Effects of moisture content on some physical properties of red pepper (*Capsicum annuum* L.) seed

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Accepted 27 April, 2010

The physical properties of red pepper seed were evaluated as a function of moisture content. The average length, width and thickness were 4.46, 3.66 and 0.79 mm, respectively, at 7.27% d.b. moisture content. In the moisture range of 7.27 to 20.69% dry basis (d.b.), studies on rewetted red pepper seed showed that the thousand seed mass increased from 7.97 to 8.89 g, the projected area from 8.40 to 9.09 mm^2, the sphericity from 0.525 to 0.555 and the terminal velocity from 4.36 to 4.51 m s^{-1}. The static coefficient of friction of red pepper seed increased linearly against surfaces of four structural materials, namely, rubber (0.394 to 0.477), aluminium (0.255 to 0.382), stainless steel (0.298 to 0.416) and galvanised iron (0.319 to 0.395) as the moisture content increased from 7.27 to 20.69% d.b. The bulk density decreased from 402.1 to 360.0 kg m^{-3}, the true density from 795.2 to 746.3 kg m^{-3} and the porosity increased from 49.43 to 51.76%, respectively, with an increase in moisture content from 7.27 to 20.69% d.b.

Key words: Red pepper seed, physical properties, moisture content, terminal velocity.

INTRODUCTION

Red pepper (*Capsicum annuum* L.) as other vegetables is a good source of antioxidant substances such as carotenoids (provitamin A) and vitamin C which confer protection against carcinogenic components and delay the aging process. Dried red pepper is one of the most important vegetable spices, its quality being determined mainly by colour (Scala and Crapiste, 2008). Red pepper is eaten as a raw and cooked vegetable and also used commonly in making paste, pickle and sauce. Red ground pepper made by drying and pulverizing the hot red pepper is used as a spice and flavor ingredient in the food industry (Doymaz and Pala, 2002). Red pepper is sensitive to aflatoxin contamination depending on atmospheric temperature, humidity, drying and processing conditions (Aydin et al., 2007).

Red pepper is one of the most widely used food colorants for culinary and industrial purposes. Because of its high colouring capacity and in some cases its peculiar pungency, red pepper is used to modify the colour and flavour of soups, stews, sausage, cheese, snacks, salad dressing, sauces, pizza and confectionary products, among others (Topuz et al., 2009).

Red pepper is one of the main agricultural products in Turkey. Turkey is one of the major red pepper producing countries together with China, Mexico and Spain (Doymaz and Pala, 2002; FAO, 2007).

To design equipment for aeration and storage, there is a need to know various physical properties as a function of moisture content (Altuntaş et al., 2005). Recently, scientists have made great efforts in evaluating basic physical properties of agricultural materials and have pointed out their practical utility in machine and structural design and in control engineering (Amin et al., 2004). Recent scientific developments have improved the handling and processing of bio-materials through mechanical, thermal, electrical, optical and other techniques, but little

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Notation: A_p, Projected area, mm^2; L, length of seed, mm; m_{1000}, thousand seed mass, g; M_c, moisture content, % d.b.; M_f, final moisture content of sample, % d.b.; M_i, initial moisture content of sample, % d.b.; P_f, porosity, %; Q, mass of water to added, kg; T, thickness of seed, mm; V_t, terminal velocity, m s^{-1}; W, width of seed, mm; W_i, initial mass of sample, kg; α, angle of tilt, degree; μ, static coefficient of friction; ρ_b, bulk density, kg m^{-3}; ρ_t, true density, kg m^{-3}; ϕ, sphericity of seed; *al*, aluminium; ***gi***, galvanised iron; ***ru***, rubber; ***ss***, stainless steel.

is known about the basic physical characteristics of bio-materials. Such basic information is important not only to engineers but also to food scientists, processors, plant breeders and other scientists who may find new uses (Mohsenin, 1970).

Several investigators determined the physical properties of seeds at various moisture contents such as Shepherd and Bhardwaj (1986) for pigeon pea, Amin et al. (2004) for lentil seed, Ogunjimi et al. (2002) for locust bean seed and Konak et al. (2002) for chickpea seeds. However, no published work seems to have been carried out on the physical properties of red pepper seed and their relationship with moisture content. The objective of this study was to investigate some moisture-dependent physical properties of red pepper seed namely, linear dimensions, thousand seed mass, projected area, sphericity, bulk density, true density, porosity, terminal velocity and static coefficient of friction against different materials.

MATERIALS AND METHODS

The dry seeds of red pepper cultivar, local variety were used for all the experiments in this study. The seeds were cleaned manually to remove all foreign matter such as dust, dirt, stones and chaff as well as immature, broken seeds. The initial moisture content of the seeds was determined by oven drying at 105 ± 1°C for 24 h (Gupta and Das, 1997; Özarslan, 2002). The initial moisture content of the seeds was 7.27% dry basis (d.b.).

The samples of the desired moisture contents were prepared by adding an amount of distilled water as calculated from the following relation (Yalçın, 2007; Kılıçkan et al., 2010).

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

The samples were then poured into separate polyethylene bags and the bags sealed tightly. The samples were kept at 5°C in a refrigerator for a week to enable the moisture to distribute uniformly throughout the sample. Before starting a test, the required quantity of the seed was taken out of the refrigerator and allowed to warm up to room temperature for about 2 h (Yalçın and Özarslan, 2004; Baümler et al., 2006). All the physical properties of the seeds were assessed at moisture levels of 7.27, 10.98, 15.45 and 20.69% d.b. with ten replications at each moisture content.

To determine the average size of the seed, 100 seeds were randomly picked and their three linear dimensions namely, length L, width W and thickness T were measured using a micrometer reading to 0.01 mm (Özarslan, 2002).

The sphericity of seeds ϕ was calculated by using the following relationship (Mohsenin, 1970):

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

The one thousand seed mass was determined by means of an electronic balance reading to 0.001 g (Baryeh, 2002).The projected area of a seed was measured by a scanner connected to a computer. For this purpose, a special computer program was used (Özarslan, 2002; Yalçın and Özarslan, 2004). The average bulk density of the red pepper seed was determined using the standard test weight procedure (Singh and Goswami, 1996) by filling a container of 500 ml with the seed from a height of 150 mm at a constant rate and then weighing the content. No separate manual compaction of seeds was done. The bulk density was calculated from the mass of the seeds and the volume of the container (Yalçın, 2007).

The true density defined as the ratio between the mass of red pepper seed and true volume of seed was determined using the toluene displacement method. Toluene was used in place of water because it is absorbed by seeds to a lesser extent. The volume of toluene displaced was found by immersing a weighed quantity of red pepper seed in toluene (Singh and Goswami, 1996).

The porosity of red pepper seed at various moisture contents was calculated from bulk and true densities using the relationship given by Mohsenin (1970) as follows:

$$P_f = (1 - \rho_b / \rho_t) \times 100 \quad (3)$$

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}

The terminal velocities of seeds at different moisture contents were measured using a cylindrical air column (Joshi et al., 1993; Baryeh, 2002; Yalçın, 2007). For each experiment, a sample was dropped into the air stream from the top of the air column, up which air was blown to suspend the material in the air stream. The air velocity near the location of the seed suspension was measured by a hot wire anemometer having a least count of 0.01 m s^{-1}.

The static coefficient of friction of red pepper seed against four different structural materials, namely rubber, aluminium, stainless steel and galvanised iron was determined. These are common material used for handling and processing of grains and construction of storage and drying bins. A polyvinylchloride cylindrical pipe of 50 mm diameter and 50 mm height was placed on an adjustable tilting plate, faced with the test surface and filled with the seed sample. The cylinder was raised slightly so as not to touch the surface. The structural surface with the cylinder resting on it was raised gradually with a screw device until the cylinder just started to slide down and the angle of tilt α was read from a graduated scale. Other researchers have used this method for other grains and seeds (Singh and Goswami, 1996; Dutta et al., 1988; Baryeh, 2002). The coefficient of friction was calculated from the following relationship:

$$\mu = \tan \alpha \quad (4)$$

Where, μ is the coefficient of friction and α is the angle of tilt in degrees.

RESULTS AND DISCUSSION

Seed dimensions and size distribution

The mean dimensions of 100 seeds measured at 7.27% d.b. moisture content are: length 4.46 ± 0.23 mm, width 3.66 ± 0.26 mm and thickness 0.79 ± 0.08 mm. About 88% of the seeds have a length ranging from 4.2 to 4.8 mm; about 84%, a width ranging from 3.4 to 4.0 mm; and about 86%, a thickness ranging from 0.7 to 0.9 mm at 7.27% d.b. moisture content.

One thousand seed mass

The one thousand seed mass m_{1000} increased linearly

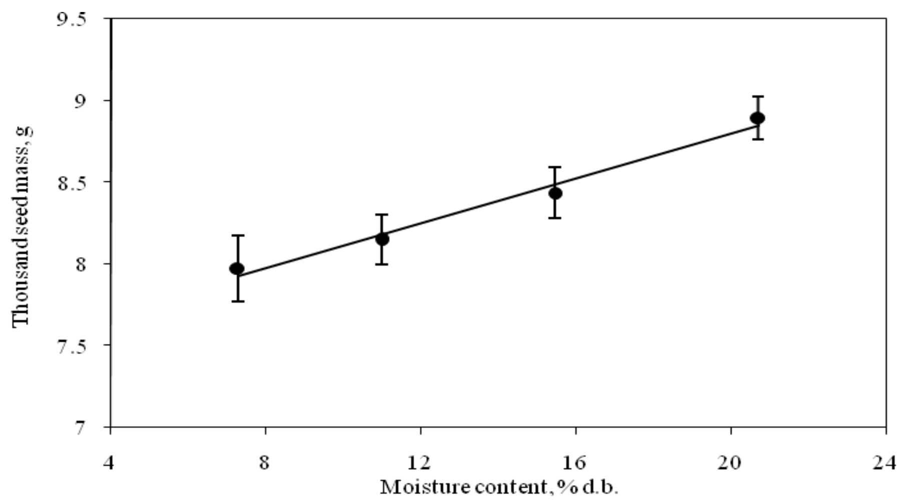

Figure1. Effect of moisture content on thousand seed mass.

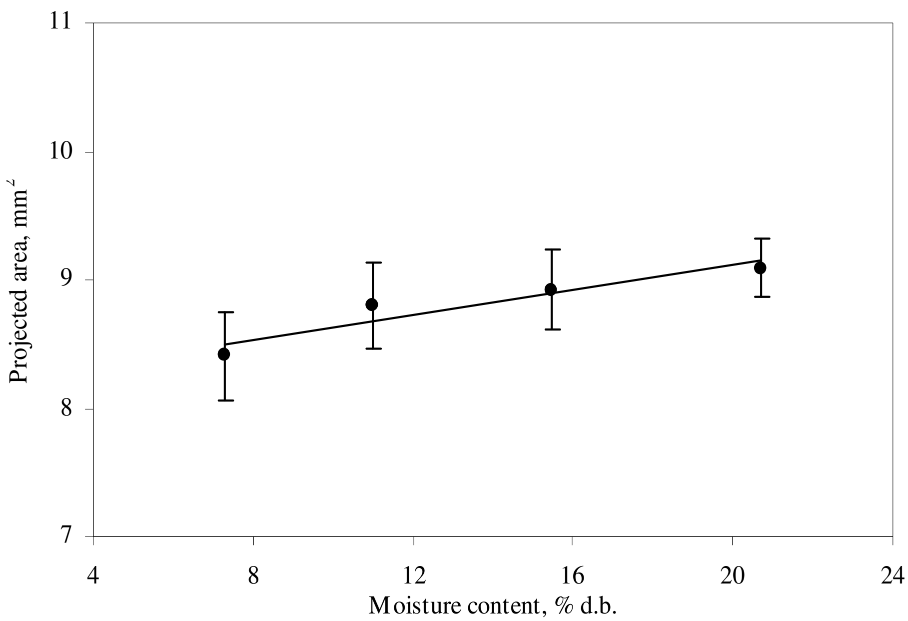

Figure 2. Effect of moisture content on projected area.

from 7.97 to 8.89 g as the moisture content increased from 7.27 to 20.69% d.b. (Figure 1). An increase of 11.54% in the one thousand seed mass was recorded within the above moisture range. The linear equation for one thousand seed mass can be formulated to be:

$$m_{1000} = 7.4275 + 0.687 M_c \quad (R^2 = 0.9834) \tag{5}$$

A linear increase in the one thousand red pepper seed mass as the seed moisture content increases has been noted by Sacilik et al. (2003) for hemp, Singh and Goswami (1996) for cumin and Ixtaina et al. (2008) for chia.

Projected area of seed

The projected area of red pepper seed (Figure 2) increased from 8.40 to 9.09 mm^2, while the moisture content of seed increased from 7.27 to 20.69% d.b. The variation in projected area A_p in mm^2 with moisture content of red pepper seed can be represented by the following equation

$$A_p = 8.1548 + 0.0478 M_c \quad (R^2 = 0.8953) \tag{6}$$

Similar trends have been reported by Abalone et al. (2004) for amaranth, Işik (2008) for sira bean grains and Tang

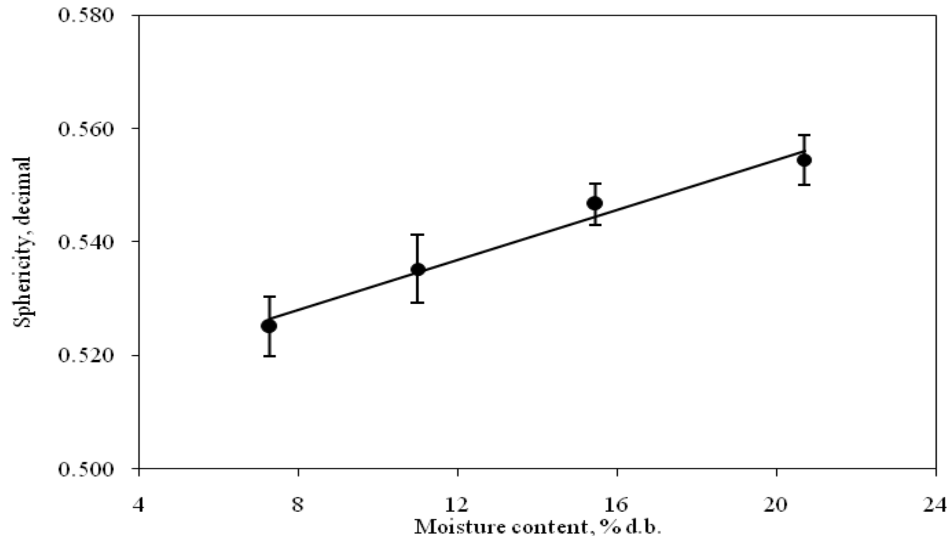

Figure 3. Effect of moisture content on sphericity.

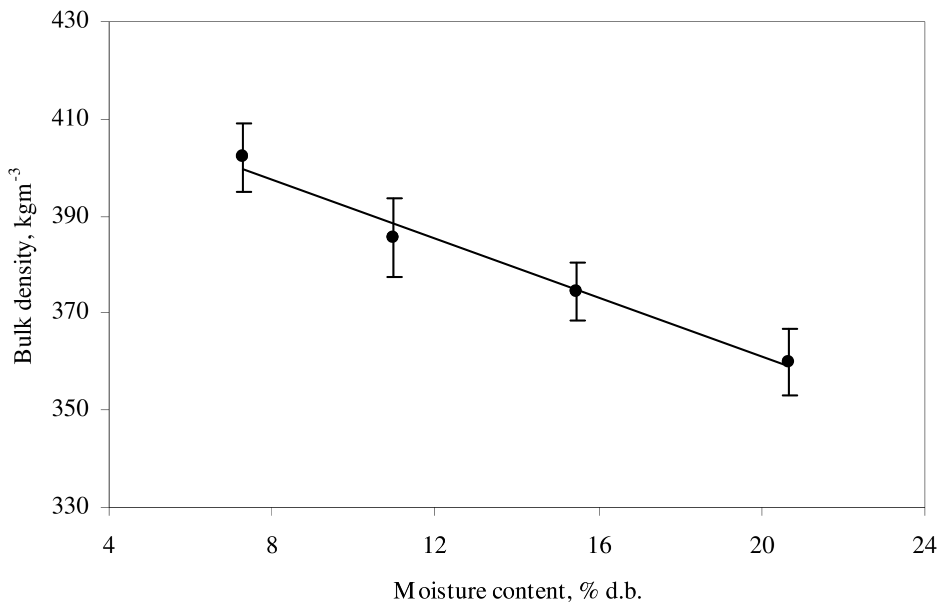

Figure 4. Effect of moisture content on bulk density.

and Sokhansanj (1993) for lentil.

Sphericity

The sphericity of red pepper seed increased from 0.525 to 0.555 with the increase in moisture content (Figure 3). The relationship between sphericity and moisture content M_c in % d.b. can be represented by the equation

$$\phi = 0.5104 + 0.0022M_c \ (R^2 = 0.9808) \quad (7)$$

Similar trends have been reported by Altuntaş et al. (2005) for fenugreek seed, Baümler et al. (2006) for safflower and Solomon and Zewdu (2009) for niger seed.

Bulk density

The values of the bulk density for different moisture levels varied from 402.1 to 360.0 kg m^{-3} (Figure 4). The bulk density of seed was found to bear the following relationship with moisture content.

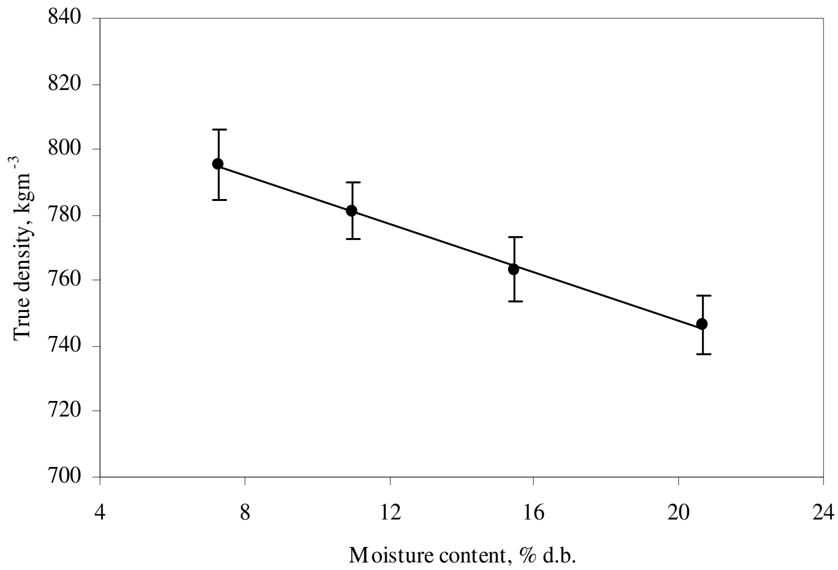

Figure 5. Effect of moisture content on true density.

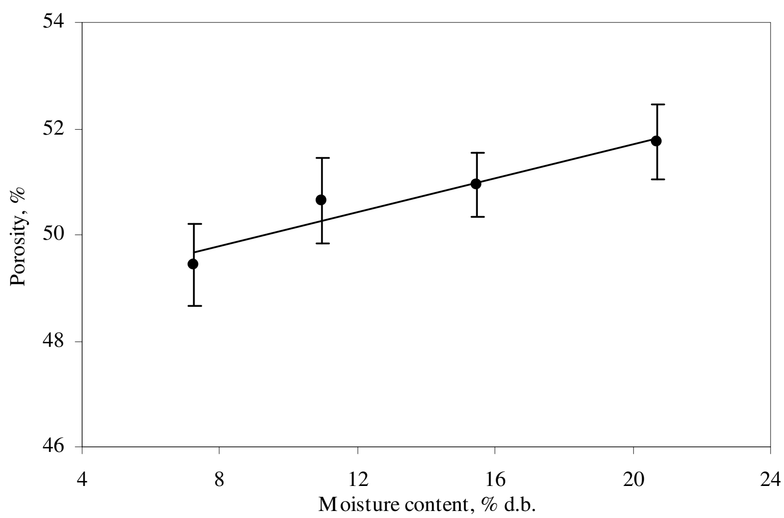

Figure 6. Effect of moisture content on porosity.

$$\rho_b = 421.98 - 3.0462 M_c \quad (R^2 = 0.9837) \tag{8}$$

A similar decreasing trend in bulk density has been reported by Dursun and Dursun (2005) for caper, Abalone et al. (2004) for amaranth, Kiani et al. (2008) for red bean seed.

True density

The true density varied from 795.2 to 746.3 kg m^{-3} when the moisture level increased from 7.27 to 20.69% d.b. (Figure 5). The true density and the moisture content of seed can be correlated as follows

$$\rho_t = 821.48 - 3.6736 M_c \quad (R^2 = 0.998) \tag{9}$$

The results were similar to those reported by Abalone et al. (2004) for amaranth, Shepherd and Bhardwaj (1986) for pigeon pea, Nimkar et al. (2006) for horse gram and Sacilik et al. (2003) for hemp seed.

Porosity

The porosity of red pepper seed increased from 49.43 to 51.76% with the increase in moisture content from 7.27 to 20.69% d.b. (Figure 6). The relationship between porosity and moisture content can be represented by the equation

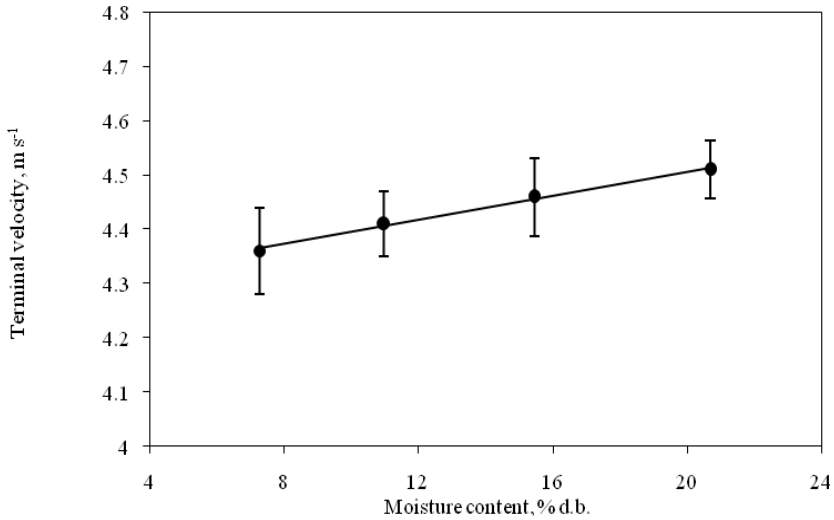

Figure 7. Effect of moisture content on terminal velocity.

$$P_f = 48.515 + 0.1601M_c \quad (R^2 = 0.924) \tag{10}$$

Singh and Goswami (1996), Gupta and Das (1997) and Yalçın and Özarslan (2004) reported similar trends in the case of cumin, sunflower and vetch, respectively. Since the porosity depends on the bulk and true densities, the magnitude of variation in porosity depends on these densities only.

Terminal velocity

The experimental results for the terminal velocity of red pepper seed at various moisture levels are shown in Figure 7. The terminal velocity was found to increase linearly from 4.36 to 4.51 m s^{-1} as the moisture content increased from 7.27 to 20.69% d.b. The relationship between terminal velocity and moisture content can be represented by

$$V_t = 4.2839 + 0.0111M_c \quad (R^2 = 0.9942) \tag{11}$$

Similar results were reported by Suthar and Das (1996), Singh and Goswami (1996), Yalçın et al. (2009), Nimkar et al. (2005) and Ramakrishna (1986) in the case of karingda, cumin, onion, moth gram and melon seeds, respectively.

Static coefficient of friction

The static coefficient of friction of red pepper seed on four surfaces (rubber, aluminium, stainless steel and galvanised iron) against moisture content in the range 7.27 to 20.69% d.b. are presented in Figure 8. It was observed that the static coefficient of friction increased with increase in moisture content for all the surfaces. This is due to the increased adhesion between the seed and the material surfaces at higher moisture values. Increases of 21.06, 49.80, 39.59 and 23.82% were recorded in the case of rubber, aluminium, stainless steel and galvanised iron, respectively, as the moisture content increased from 7.27 to 20.69% d.b. As the moisture content of the seed increased, the static coefficients increased significantly. This is due to the increased adhesion between the product and the surface at higher moisture values. The relationships between static coefficients of friction and moisture content on rubber μ_{ru}, wood μ_{wo}, stainless steel μ_{ss} and galvanised iron μ_{gi}, can be represented by the following equations:

$$\mu_{ru} = 0.3448 + 0.0062M_c \quad (R^2 \text{ of } 0.9866) \tag{12}$$

$$\mu_{al} = 0.1994 + 0.009M_c \quad (R^2 \text{ of } 0.9645) \tag{13}$$

$$\mu_{ss} = 0.2331 + 0.009M_c \quad (R^2 \text{ of } 0.9948) \tag{14}$$

$$\mu_{gi} = 0.2875 + 0.0053M_c \quad (R^2 \text{ of } 0.9466) \tag{15}$$

Similar results were found by Sahoo and Srivastava (2002), Singh and Goswami (1996), Çarman (1996), Gurhan et al. (2009) and Garnayak et al. (2008) for okra, cumin, lentil, black kabuli chickpea and jatropha seeds, respectively.

Conclusions

From the study, it was found that the thousand seed mass

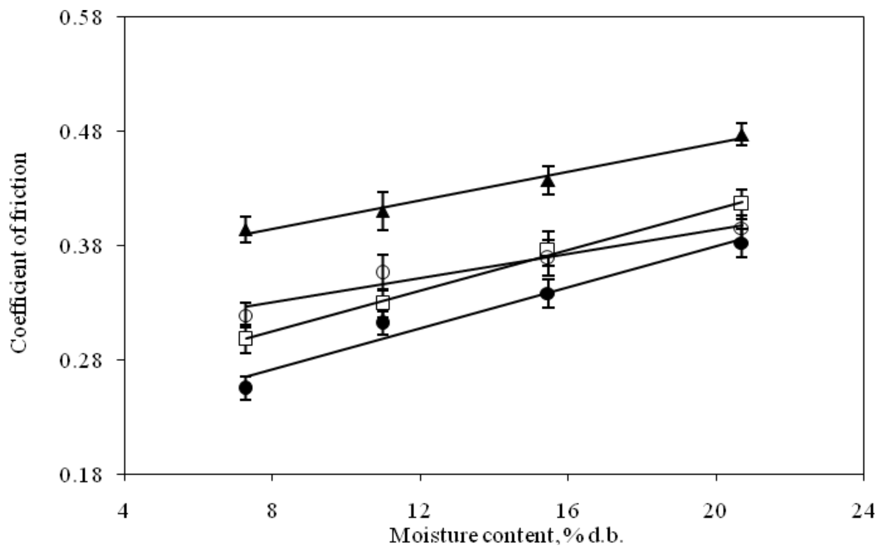

Figure 8. Effect of moisture content on static coefficient of friction; ▲, rubber; ●, aluminium; ○, galvanized iron; □, stainless steel.

increased from 7.97 to 8.89 g and the sphericity increased from 0.525 to 0.555 with increase in moisture content from 7.27 to 20.69% d.b. Also, the projected area increased from 8.40 to 9.09 mm^2. The bulk density decreased linearly from 402.1 to 360.0 kg m^{-3}, the true density decreased from 795.2 to 746.3 kg m^{-3} and the porosity increased from 49.43 to 51.76%. Finally, the terminal velocity increased from 4.36 to 4.51 m s^{-1} and static coefficient of friction increased for all four surfaces, namely, rubber (0.394 to 0.477), aluminium (0.255 to 0.382), stainless steel (0.298 to 0.416) and galvanised iron (0.319 to 0.395).

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