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Some physical properties of sugarbeet seed

İ. Dursun[a,*], K.M. Tuğrul[b], E. Dursun[a]

[a]Department of Agricultural Machinery, Faculty of Agriculture, Ankara University, 06110, Diskapi, Ankara, Turkey
[b]Turkish Sugar Factories Corporation Sugar Institute, 06790, Etimesgut, Ankara, Turkey

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Abstract

Various physical properties of sugarbeet seed were determined as a function of moisture content. The lengths of the major, medium and minor axes varied from 4.61 to 5.30, 3.82 to 4.36 and 2.20 to 2.38 mm, respectively, as the moisture content increased from 8.4 to 14.0% d.b. In the same moisture range, the arithmetic and geometric mean diameters increased from 3.54 to 4.02 and 3.38 to 3.80 mm, respectively. Studies on rewetted sugarbeet seed showed that the sphericity decreased from 0.734 to 0.717, whereas thousand seed mass and projected area increased from 12.60 to 13.41 g and 12.1 to 15.6 mm^2, respectively, with increase in moisture content from 8.4 to 14.0% d.b. The bulk density, true density and porosity decreased from 447 to 418 $kg\,m^{-3}$, 962 to 851 $kg\,m^{-3}$ and 53.6 to 50.9%, whereas terminal velocity and angle of repose increased from 5.6 to 6.6 ms^{-1} and 17.6 to 25.0°, respectively, as the moisture content increased from 8.39 to 14.00% d.b. The static coefficient of friction increased on four structural surfaces namely, rubber (0.687–0.790), plywood (0.480–0.608), galvanised metal (0.392–0.434) and aluminium (0.279–0.388) in the moisture range from 8.4 to 14.0% d.b.
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Keywords: Sugarbeet seed; Physical properties; Moisture content; Terminal velocity; Angle of repose; Static coefficient of friction

1. Introduction

Sugarbeet (*Beta vulgaris* L.) belongs to the family Chenopodiaceae. It is biennial plant which is essentially vegetative during the first year of growth and requires overwintering to induce reproductive development in the following year (Vandergeten et al., 2004).

Sugar is produced from sugar cane and sugarbeet in 120 countries in the world. White sugar production in the world was approximately 145 million tonnes in 2003 of which 26% was produced from sugarbeet and 74% from sugar cane.

White sugar is produced from sugarbeet in Turkey and sugarbeet was cultivated on 283,750 ha with a production of 13 million tonnes in 2003. Resulting white sugar production was 1.6 million tonnes (Anonymous, 2003).

Since sugarbeet seed used today is almost exclusively a monogerm seed, the seed provided for growers needs to be of the highest biological quality and uniformity. Most of the processing methods employed are still traditional. There is the need to develop appropriate technologies for its processing. In order to design equipment for handling, aeration, storing and processing sugarbeet seed, it is necessary to determine its physical properties as a function of moisture content. However, no published literature was found on the detailed physical properties of sugarbeet seed and their relationship with moisture content. The object of this study was to investigate some moisture-dependent physical properties of sugarbeet seed, namely size, sphericity, projected area, thousand seed mass, bulk density, true density, porosity, terminal velocity, angle of repose, and static coefficient of friction, in the moisture range from 8.4 to 14.0% d.b.

2. Materials and methods

2.1. Sample preparation

The sugarbeet seeds, variety Kassandra, were procured from the Sugarbeet Seed Processing Factory in Ankara, Turkey. The seeds were cleaned manually to remove foreign matter, broken and immature seeds. The initial

*Corresponding author. Tel.: +90 312 5961609; fax: +90 312 3183888.
E-mail address: dursun@agri.ankara.edu.tr (İ. Dursun).

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Nomenclature

a	major axis, mm
A, B	intercept and regression coefficient
A_p	projected area, mm^2
b	minor axis, mm
c	medium axis, mm
D_a	arithmetic mean diameter, mm
D_g	geometric mean diameter, mm
H	vertical depth at the centre of sample, mm
m_{1000}	thousand seed mass, g
M	moisture content of sample, % d.b.
M_f	final moisture content of sample, % d.b.
M_i	initial moisture content of sample, % d.b.
Q	mass of water to be added, kg
R	radius of spread of the sample, mm
R^2	coefficient of determination
V_t	terminal velocity, $m\,s^{-1}$
W_i	initial mass of sample, kg
α	angle of tilt, deg
ε	porosity, %
θ	angle of repose, deg
μ	coefficient of friction
ρ_b	bulk density, $kg\,m^{-3}$
ρ_t	true density, $kg\,m^{-3}$
ϕ	sphericity, decimal

moisture content of the seeds was determined by using a standard hot air oven method on samples of at least 15 g at 105 ± 1 °C for 24 h (USDA, 1970; Gupta and Das, 2000). The average moisture content of the seeds was found to be 8.4% d.b.

Seed samples of the desired moisture levels were prepared by adding the amount of distilled water calculated from the following relationship (Balasubramanian, 2001):

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

where Q is the mass of water to be added in kg; W_i is the initial mass of the sample in kg; M_i is the initial moisture content of the sample in % d.b. and M_f is the final moisture content of the sample in % d.b.

The samples were sealed in separate polythene bags and kept in a refrigerator at 5 °C for 15 days for the moisture to distribute uniformly throughout the sample. Before starting a test, the required quantity of seed was taken out of the refrigerator and allowed to warm up to room temperature for about 2 h (Shepherd and Bhardwaj, 1986; Nimkar and Chattopadhyay, 2001).

The physical properties of the seeds were investigated at four moisture levels of 8.4, 9.8, 11.9 and 14.0% d.b. These values are within the range of moisture contents encountered for sugarbeet seed from harvest to storage. It is recommended that for storage the moisture content for sugarbeet seed should be under 13% (Adıyaman, 2000; Er and Uranbey, 2000).

2.2. Seed dimensions, sphericity and projected area measurement

To determine the average size of the seed, a sample of 100 seeds was randomly picked and the three principal dimensions namely, major, medium and minor axes were measured using a micrometer with an accuracy of 0.01 mm.

The average diameter of seed was calculated by using the arithmetic mean and geometric mean of the three axial dimensions. The arithmetic mean diameter D_a and geometric mean diameter D_g of the seed were calculated by using the following relationships (Mohsenin, 1970):

$$D_a = (a + b + c)/3, \tag{2}$$

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

where a is the major axis, b is the medium axis and c is the minor axis in mm.

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

$$\phi = \frac{(abc)^{1/3}}{a}. \tag{4}$$

The projected area of the seed was measured by the image analysis method (Dursun, 2001; Sahoo and Srivastava, 2002).

2.3. Thousand seed mass, bulk density, true density and porosity measurement

The thousand seed mass was determined by means of a digital electronic balance having an accuracy of 0.001 g. Five samples, each consisting of 1000 seeds, were randomly taken for each moisture content and weighed.

The bulk density of the sugarbeet seed at four different moisture levels was determined by filling a circular container of 500 ml in volume with the seed from a height of 150 mm at a constant rate and then weighing the contents. No separate manual compaction of seeds was performed (Singh and Goswami, 1996; Sacilik et al., 2003). The bulk density was calculated from the mass of the seeds and the volume of the container.

The true density, as a function of moisture content, was determined using the toluene displacement method. Toluene (C_7H_8) 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

sugarbeet seed in the toluene (Singh and Goswami, 1996; Konak et al., 2002). The experiments were replicated five times.

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

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right)100, \quad (5)$$

where ε is the porosity in %; ρ_b is the bulk density in $kg\,m^{-3}$ and ρ_t is the true density in $kg\,m^{-3}$.

2.4. Terminal velocity measurement

The terminal velocities of seeds at different moisture contents were measured using an air column device (Joshi et al., 1993; Gupta and Das, 1997; Sacilik et al., 2003). For each experiment, a sample was dropped into an air stream from the top of the air column. Then air-flow rate was gradually increased until the seed became suspended in the air stream. The air velocity near the location of the seed suspension was measured using a vane anemometer having at least $0.01\,m\,s^{-1}$ accuracy. Each sample consisted of 20 seeds selected randomly from a batch at each moisture content.

2.5. Angle of repose measurement

To determine the emptying or dynamic angle of repose, a plywood box of $300 \times 300 \times 300$ mm, with a removable front panel, was used. The box was filled with the sample and the front panel was then quickly removed, allowing the seeds to flow and assume a natural slope (Joshi et al., 1993). The angle of repose was calculated from the measurements of the vertical depth at the centre and radius of spread of the sample, using the following relationship (Jha, 1999):

$$\theta = \tan^{-1}(H/R), \quad (6)$$

where θ is the angle of repose in degree; H is the vertical depth at the centre of sample in mm and R is the radius of spread of the sample in mm.

2.6. Static coefficient of friction measurement

The static coefficient of friction of seed at different moisture contents was measured for four structural materials, namely rubber, plywood, galvanised metal and aluminium. A plastic cylinder of 100 mm diameter and 50 mm height was placed on an adjustable tilting plate, faced with the test surface and filled with the sample. The cylinder was raised slightly so as not to touch the surface. The structural surface with the cylinder resting on it was inclined gradually with a screw device until the box just started to slide down. The angle of tilt was read from a graduated scale (Shepherd and Bhardwaj, 1986; Joshi et al., 1993; Gupta and Das, 1997; Dutta et al., 1998; Nimkar and Chattopadhyay, 2001; Owolarafe and Shotonde, 2004). The experiments were replicated five times for each structural material at different moisture contents. The coefficient of friction was calculated from the following relationship:

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

where μ is the coefficient of friction and α is the angle of tilt in degree.

2.7. Data analysis

All the experiments were replicated five times, unless stated otherwise, and the average values were calculated. The data were statistically analysed for each parameter of study at different moisture contents. The effect of moisture content on different physical properties of sugarbeet seed was determined using the analysis of variance.

3. Results and discussion

3.1. Seed dimensions

The three axial dimensions increased with moisture content. The major axis, medium axis and minor axis of seeds ranged from 4.61 to 5.30, 3.82 to 4.36, and 2.20 to 2.38 mm respectively as the moisture content increased from 8.4 to 14.0% d.b. (Table 1). The increases in major axis, medium axis and minor axis were 14.97, 14.14 and 8.18%, respectively.

The average diameters increased with moisture content. The arithmetic and geometric mean diameters increased from 3.54 to 4.02 and 3.38 to 3.80 mm as the moisture content increased from 8.4 to 14.0% d.b., respectively (Table 1).

Table 1
Means and standard errors of the axial dimensions of sugarbeet seeds

Moisture content, % d.b.	Axial dimension (mm)			Average diameter (mm)	
	Major axis (a)	Medium axis (b)	Minor axis (c)	Arithmetic mean (D_a)	Geometric mean (D_g)
8.4	4.61 ± 0.043	3.82 ± 0.050	2.20 ± 0.028	3.54	3.38
9.8	4.84 ± 0.056	4.10 ± 0.051	2.21 ± 0.039	3.72	3.53
11.9	5.17 ± 0.048	4.30 ± 0.043	2.24 ± 0.036	3.90	3.68
14.0	5.30 ± 0.037	4.36 ± 0.033	2.27 ± 0.040	3.98	3.75

3.2. Sphericity

The sphericity of the sugarbeet seed decreased linearly from 0.734 to 0.717 with the increase in moisture content (Fig. 1). Similar trends have been reported by Kulkarni et al. (1993) for soyabean and Nimkar and Chattopadhyay (2001) for green gram. The relationship between sphericity and moisture content can be represented by the following regression equation:

$$\phi = 0.757 - 0.003M \quad (8)$$

with a value for R^2 of 0.98. The relationship between sphericity and moisture content was found to be significant at $P<0.05$.

3.3. Projected area of seed

The projected area of sugarbeet seed (Fig. 2) increased from 12.1 to 15.6 mm^2, while the moisture content of seed increased from 8.4 to 14.0% d.b. Similar trends have been reported for many other seeds (Deshpande et al., 1993; Tang and Sokhansanj, 1993; Çarman, 1996; Öğüt, 1998; Konak et al., 2002). The relationship between projected area and moisture content was found to be significant ($P<0.05$) and can be represented by the following equation:

$$A_p = 7.17 + 0.617M \quad (9)$$

with a value of R^2 of 0.97.

3.4. Thousand seed mass

Thousand seed mass of sugarbeet seed (m_{1000}) increased linearly from 12.60 to 13.41 g ($P<0.01$) when the moisture content was increased from 8.4 to 14.0% d.b. (Fig. 3). The relationship between thousand grain mass and moisture content can be represented by the following regression equation:

$$m_{1000} = 11.5 + 0.138M \quad (10)$$

with a value of R^2 of 0.98.

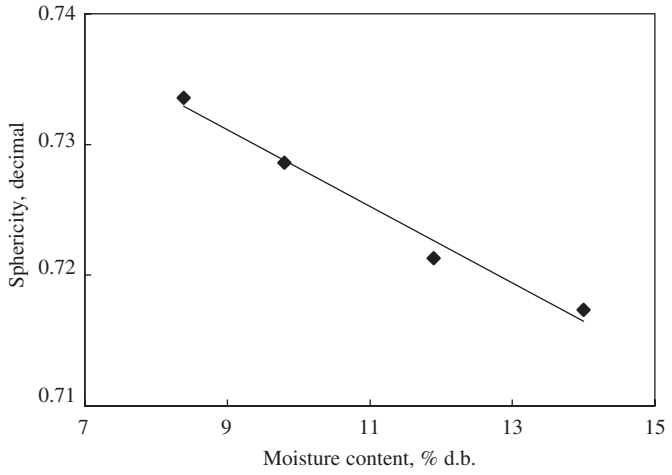

Fig. 1. Effect of moisture content on sphericity of sugarbeet seeds.

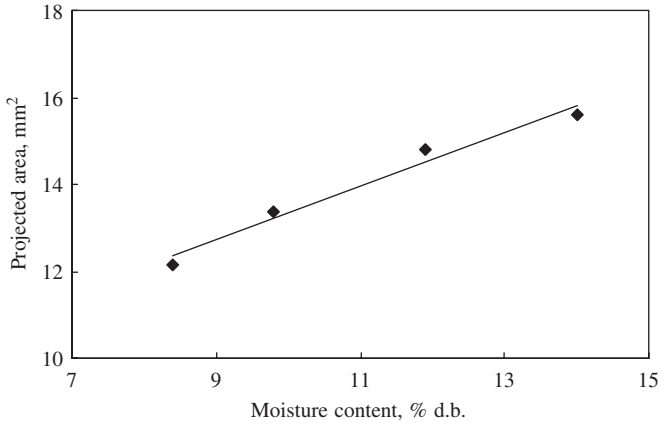

Fig. 2. Effect of moisture content on projected area of sugarbeet seeds.

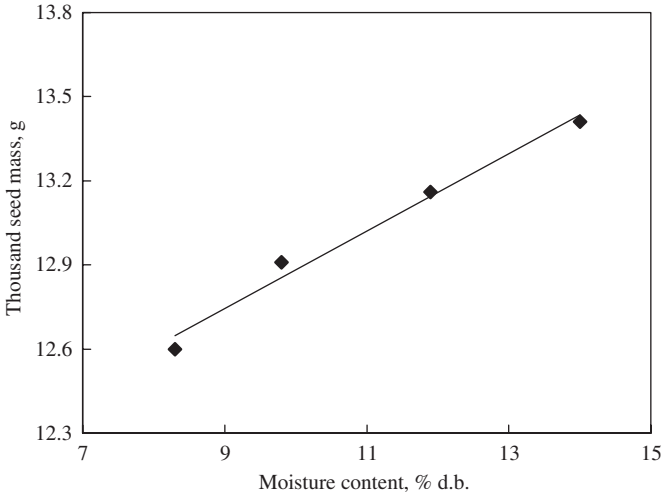

Fig. 3. Effect of moisture content on thousand seed mass of sugarbeet seeds.

A linear increase in the thousand seed mass as the seed moisture content increases has been reported by Deshpande et al. (1993) for soybean, Jha (1999) for makhana, Nimkar and Chattopadhyay (2001) for green gram and Özarslan (2002) for cotton seed.

3.5. Bulk density

The bulk density decreased from 447 to 418 kg m^{-3} as the moisture content increased from 8.4 to 14.0% d.b. (Fig. 4). The negative linear relationship of bulk density with moisture content has been observed with other products by various research workers (Shepherd and Bhardwaj, 1986; Deshpande et al., 1993; Gupta and Das, 1997; Dutta et al., 1998, Bart-Plange and Baryeh, 2003). The decrease in bulk density with increase in moisture content shows that the increase in mass resulting from the moisture gain of the sample is lower than the accompanying volumetric expansion of the bulk. The relationship between bulk density and moisture content can be

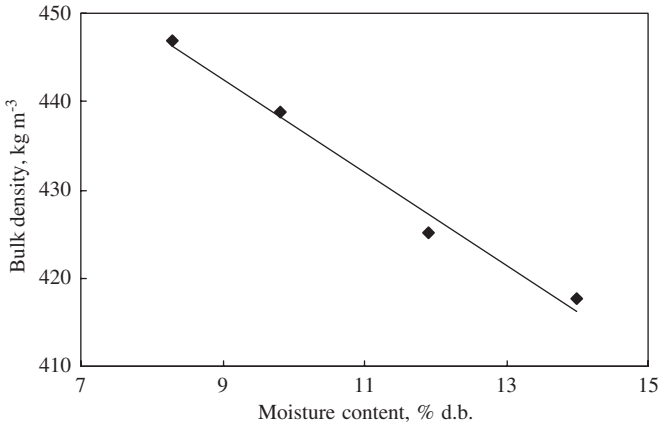

Fig. 4. Effect of moisture content on bulk density of sugarbeet seeds.

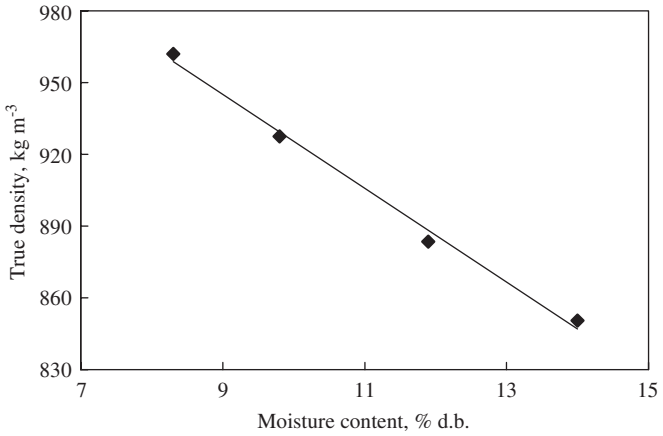

Fig. 5. Effect of moisture content on true density of sugarbeet seeds.

represented by the following regression equation:

$$\rho_b = 490.1 - 5.27M \quad (11)$$

with a value for R^2 of 0.99. This relationship was significant at $P<0.05$.

3.6. True density

The true density of the seed varied from 962 to 851 kg m^{-3} when the moisture content increased from 8.4 to 14.0% d.b. (Fig. 5). The variation in true density with moisture content was significant ($P<0.01$). The decrease in true density values with increase in moisture content may be due to a lower weight increase of seed in comparison with its volume expansion on moisture gain. A similar decreasing trend in true density has been observed by Shepherd and Bhardwaj (1986) for pigeon pea, Dutta et al. (1998) for gram, Deshpande et al. (1993) for soybean, Nimkar and Chattopadhyay (2001) for green gram and Kaleemullah and Gunasekar (2002) for arecanut kernel. The relationship between true density and moisture content of the sugarbeet seed can be expressed as follows:

$$\rho_t = 1121.6 - 19.60M \quad (12)$$

with a value for R^2 of 0.99.

3.7. Porosity

As the moisture content increased from 8.4 to 14.0% d.b., the porosity decreased from 53.6 to 50.9% (Fig. 6). The variation in porosity with moisture content was significant ($P<0.01$). Deshpande et al. (1993), Joshi et al. (1993), Tang and Sokhansanj (1993), Suthar and Das (1996) and Sacilik et al. (2003) reported a similar decrease in porosity when the moisture content was increased for soybean seed, pumpkin seed, lentil seed, karingda seed and hemp seed, respectively. The relationship between porosity and the moisture content of the sugarbeet seed can be

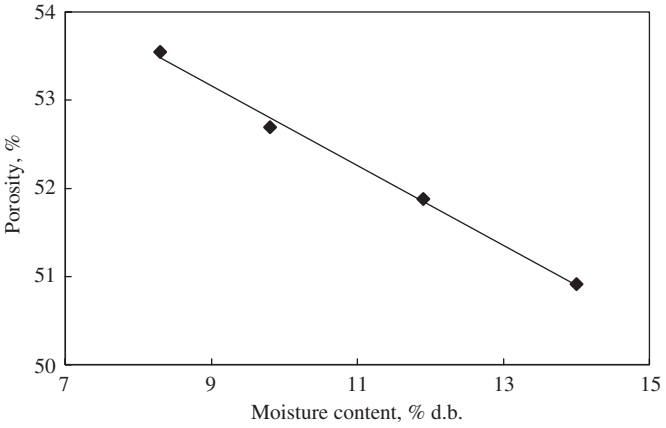

Fig. 6. Effect of moisture content on porosity of sugarbeet seeds.

represented by the following equation:

$$\varepsilon = 57.24 - 0.453M \quad (13)$$

with a value for R^2 of 0.99.

3.8. Terminal velocity

As the moisture content increased, the terminal velocity was found to increase linearly from 5.6 to 6.6 m s^{-1} in the specified moisture range (Fig. 7). The variation in terminal velocity with moisture content was significant ($P<0.01$). The relationship between moisture content and terminal velocity can be represented by the following equation:

$$V_t = 4.32 + 0.163M \quad (14)$$

with a value for R^2 of 0.97.

Singh and Goswami (1996), Suthar and Das (1996), Nimkar and Chattopadhyay (2001), Gezer et al. (2002), Konak et al. (2002) and Sacilik et al. (2003) have reported a linear increase in terminal velocity with increase in the moisture content for cumin seed, karingda seed, green gram, apricot kernel, chick pea seed and hemp seed, respectively. The increase in terminal velocity with increase in moisture content within the range studied can be

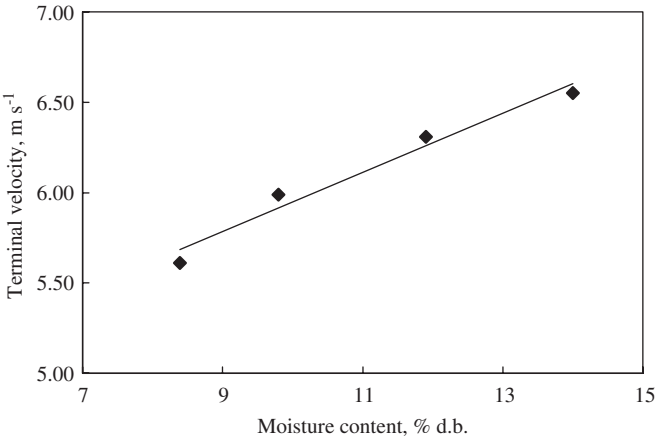

Fig. 7. Effect of moisture content on terminal velocity of sugarbeet seeds.

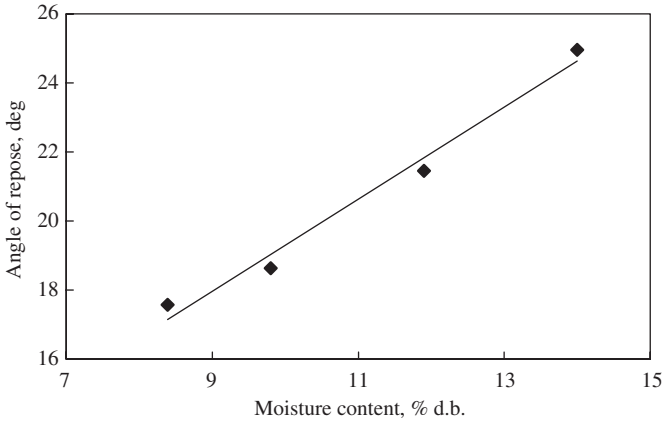

Fig. 8. Effect of moisture content on angle of repose of sugarbeet seeds.

attributed to the increase in mass of an individual seed per unit frontal area presented to the air stream.

3.9. Angle of repose

The angle of repose increased from 17.6° to 25.0° in the moisture range of 8.4–14.0% d.b. (Fig. 8). The results were similar to those reported by Singh and Goswami (1996) for cumin seed, Nimkar and Chattopadhyay (2001) for green gram, Baryeh (2002) for millet, Amin et al. (2004) for lentil.

3.10. Static coefficient of friction

The static coefficient of friction increased with increase in moisture content on all surfaces (Fig. 9). This is due to increased adhesion between the seed and the surface at higher moisture values. Similar results were found by other researchers (Shepherd and Bhardwaj, 1986; Dutta et al., 1998; Çarman, 1996; Suthar and Das, 1996). At all moisture contents, the static coefficient of friction was greatest against rubber (0.687–0.790), followed by plywood (0.480–0.608), galvanised metal (0.392–0.434) and least for

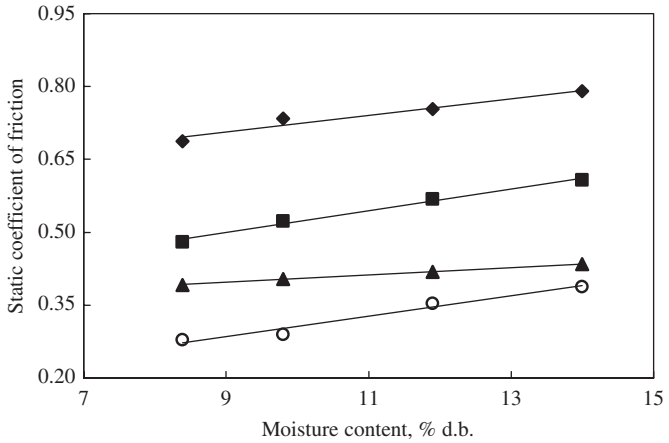

Fig. 9. Effect of moisture content on coefficient of static friction of sugarbeet seeds: ♦, rubber; ■, plywood; ▲, galvanised metal; ○, aluminium.

Table 2
Intercepts, regression coefficients and coefficients of determination of Eq. (15) for static coefficients of friction on various test surfaces

Surface	Intercept	Regression coefficient	Coefficient of determination (R^2)
	A	B	
Rubber	0.553	0.017	0.948
Plywood	0.297	0.022	0.990
Galvanised iron	0.331	0.007	0.998
Aluminium	0.097	0.021	0.966

aluminium (0.279–0.388). This may be due to the smoother and more polished surface of aluminium compared with the other test surfaces.

The linear equations for static coefficient of friction on all test surfaces can be represented as:

$$\mu = A + BM, \tag{15}$$

where μ is the coefficient of friction and A and B are the intercept and regression coefficient respectively. These values are given in Table 2.

4. Conclusions

Various physical properties of sugarbeet seed were evaluated as a function of moisture content. The following changes in physical properties were determined in the moisture range between 8.4 and 14.0%: the axial dimensions and average diameters increased as the moisture content increased. The thousand seed mass, projected area, terminal velocity, angle of repose and static coefficient of friction increased, whereas sphericity, bulk density, true density and porosity decreased with the increase in moisture content.

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