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Full Length Research Paper

Some physical properties of spinach (*Spinacia oleracea* L.) seed

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The physical properties of spinach seed were evaluated as a function of moisture content. Average length, width and thickness were 4.03, 3.51 and 2.44 mm, respectively, at 11.93% dry basis (d.b). moisture content. In the moisture range from 11.93 to 21.52% d.b. studies on rewetted spinach seed showed that the thousand seed mass increased from 11.55 to 13.53 g, the projected area from 6.28 to 7.81 mm^2, the sphericity from 0.807 to 0.821 and the terminal velocity from 6.10 to 6.58 m s^{-1}. The static coefficient of friction of spinach seed increased linearly against surfaces of four structural materials, namely, rubber (0.341 to 0.470), wood (0.318 to 0.391), stainless steel (0.271 to 0.364) and galvanised iron (0.321 to 0.388) as the moisture content increased from 11.93 to 21.52% d.b. The bulk density decreased from 538.9 to 893.1 kg m^{-3}, the true density from 893.1 to 784.6 kg m^{-3} and the porosity from 39.65 to 36.67% respectively, with an increase in moisture content from 11.93 to 21.52% d.b.

Key words: Spinach seed, physical properties, moisture content.

INTRODUCTION

Spinach (*Spinacia oleracea* L.) is an annual cool season crop in temperate areas. It can be grown all year around. It is a green, leafy vegetable and can be eaten boiled, baked and raw and even as a baby leaf. Spinach leaves contain relatively high levels of bioactive compounds such as vitamin C, vitamin A and minerals (USDA, 2005), but they accumulate compounds unwanted for human health (nitrate and oxalate) (Jaworska, 2005). Spinach is a common food plant in Turkey grown for fresh consumption and as raw material for canned food industry. Spinach is grown on 24000 ha areas in Turkey with a production rate of 235000 t (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 is known about the basic physical characteristics of biomaterials. 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).

Physical properties of spinach seeds are essential for the design of equipment and facilities for the harvesting, handling, conveying, separation, drying, aeration, storing and processing of spinach seeds. Various types of cleaning grading and separation equipment are designed on the basis of their physical properties as a function of moisture content. It seems that there is not much published work relating to moisture dependent physical properties of spinach seed.

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) and Çarman (1996) for lentil seed, Ogunjimi et al. (2002) for locust bean seed, Yalçın et al. (2007) for pea seed and Konak et al. (2002) for chickpea seeds. The objective of this study was to investigate some moisture-dependent physical properties of spinach seed namely, linear dimensions, thousand seed mass, projected area, sphericity, bulk density, true density, porosity, terminal velocity, and static coefficient of friction

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against different materials.

MATERIALS AND METHODS

The dry seeds of spinach 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 (Suthar and Das, 1996; Gupta and Das, 1997; Özarslan, 2002). The initial moisture content of the seeds was 12.01% dry basis (d.b.).

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

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

The samples were then poured in to separate polyethylene bags and the bags were 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 (Singh and Goswami, 1996; Yalçın and Özarslan, 2004; Baümler et al., 2006).

All the physical properties of the seeds were assessed at moisture levels of 11.93, 14.89, 17.67 and 21.52% 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; Vilche et al., 2003).

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; Coşkun et al., 2006).

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 spinach 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 spinach 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 spinach seed in the toluene (Singh and Goswami, 1996; Sacilik et al., 2003).

The porosity of spinach seed at various moisture contents was calculated from the 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 = porosity in %; ρ_b = bulk density in kg m^{-3}; ρ_t = 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, through 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 the least count of 0.01 m s^{-1}.

The static coefficient of friction of spinach 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 (Suthar and Das, 1996; Singh and Goswami, 1996; Dutta et al., 1988; Baryeh, 2002; Yalçın et al., 2007). The coefficient of friction was calculated from the following relationship:

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

Where, μ = coefficient of friction; α = angle of tilt in degrees.

RESULTS AND DISCUSSION

Seed dimensions and size distribution

The mean dimensions of 100 seeds measured at 11.93% d.b. moisture content were: length 4.03 ± 0.36 mm, width 3.51 ± 0.29 mm and thickness 2.44 ± 0.23 mm. About 82% of the seeds have a length ranging from 3.5 to 4.5 mm; about 80%, a width ranging from 3.2 to 3.8 mm and about 84%, a thickness ranging from 2.2 to 2.8 mm at 12.01% d.b. moisture content.

One thousand seed mass

The one thousand seed mass m_{1000} increased linearly from 11.55 to 13.53 g as the moisture content increased from 11.93 to 21.52% d.b. (Figure 1). An increase of 17.14% 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:

$$m_{1000} = 8.9643 + 0.2111 M_c \quad (R^2 = 0.9925) \quad (5)$$

A linear increase in the one thousand spinach seed mass as the seed moisture content increases has been noted by Sacilik et al. (2003) for hemp, Solomon and Zewdu (2009) for niger, Singh and Goswami (1996) for cumin, Vilche et al. (2003) for quinoa and Ixtaina et al. (2008) for chia.

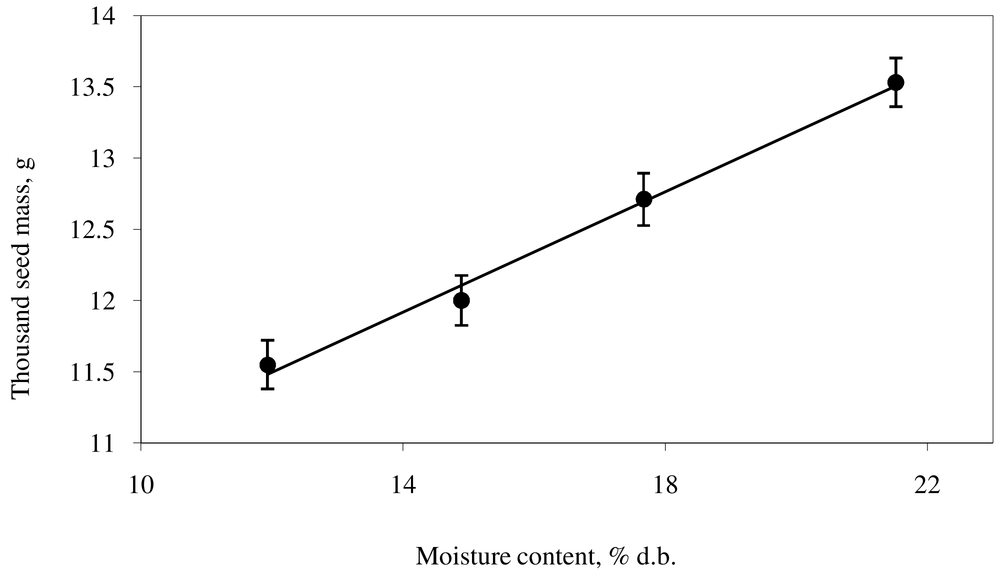

Figure 1. Effect of moisture content on thousand spinach seed mass.

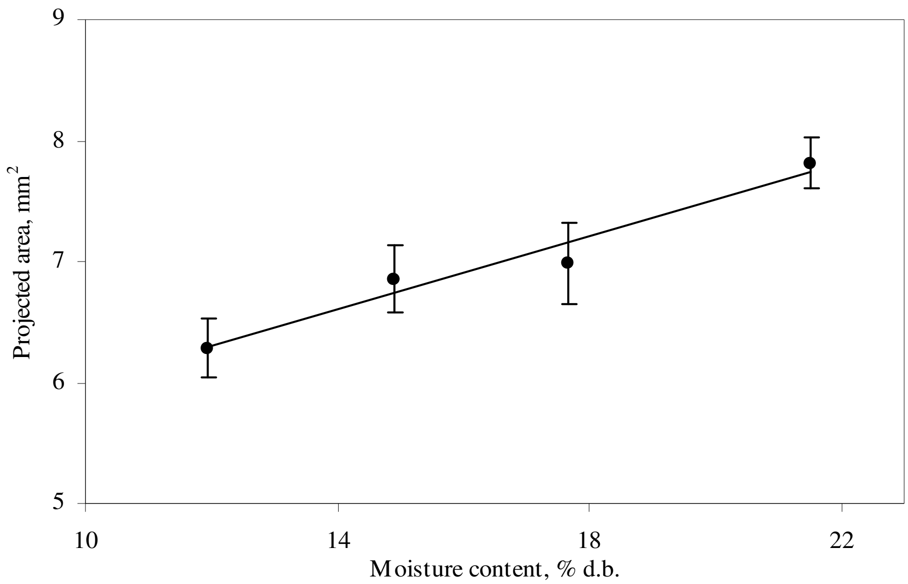

Figure 2. Effect of moisture content on projected area of spinach seed.

Projected area of seed

The projected area of spinach seed (Figure 2) increased from 6.28 to 7.81 mm^2, while the moisture content of seed increased from 11.93 to 21.52% d.b. The variation in projected area A_p in mm^2 with moisture content of spinach seed can be represented by the following equation:

$$A_p = 4.4873 + 0.1511 M_c \quad (R^2 = 0.9583) \tag{6}$$

Similar trends have been reported by Paksoy and Aydin (2004) for edible squash, Abalone et al. (2004) for amaranth, Öğüt (1998) for white lupin, Işik (2008) for sira bean grains and Tang and Sokhansanj (1993) for lentil.

Sphericity

The sphericity of spinach seed increased from 0.807 to 0.821 with the increase in moisture content (Figure 3). The relationship between sphericity and moisture content

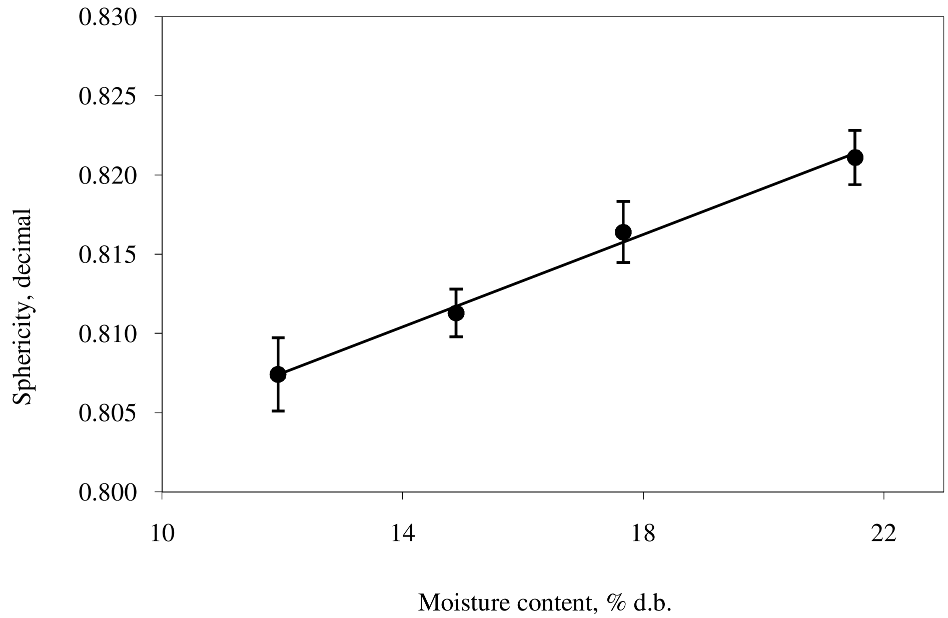

Figure 3. Effect of moisture content on sphericity of spinach seed.

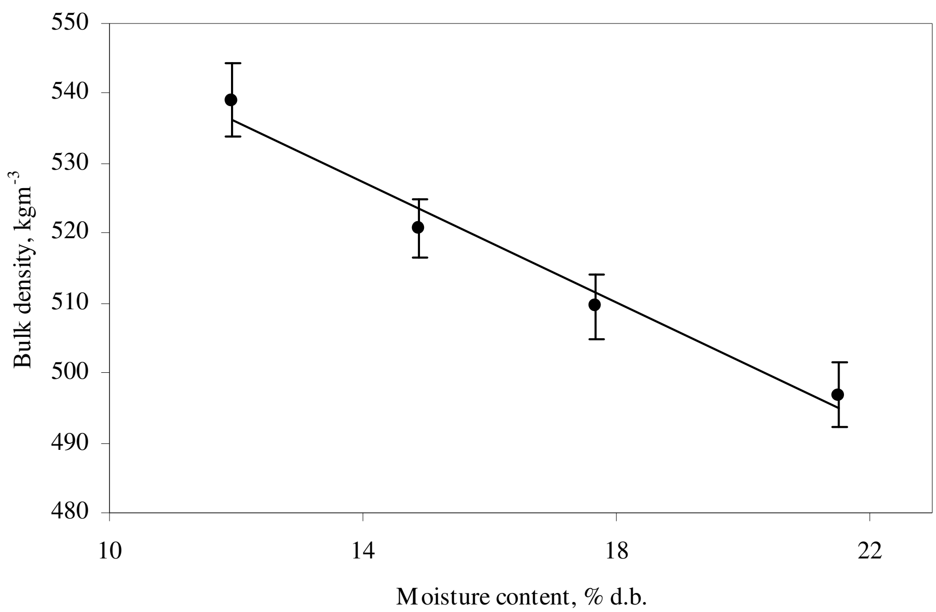

Figure 4. Effect of moisture content on bulk density of spinach seed.

M_c in % d.b. can be represented by the following equation:

$$\phi = 0.79 + 0.0015 M_c \quad (R^2 = 0.9939) \tag{7}$$

Similar trends have been reported by Aydin et al. (2002) for Turkish mahaleb, Gupta and Das (1997) for sunflower, 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 538.9 to 496.9 kg m^{-3} (Figure 4). The bulk density of seed was found to bear the following relationship with moisture content:

$$\rho_b = 587.7 - 4.3137 M_c \quad (R^2 = 0.9759) \tag{8}$$

A similar decreasing trend in bulk density has been reported

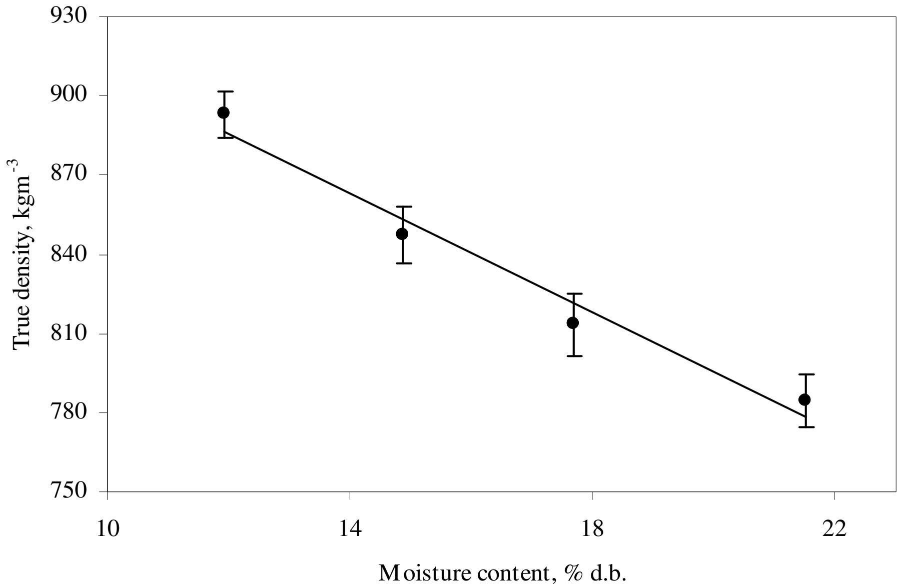

Figure 5. Effect of moisture content on true density of spinach seed.

by Zewdu and Solomon (2007) for tef, Dursun and Dursun (2005) for caper, Abalone et al. (2004) for amaranth, Pradhan et al. (2008) for Karanja kernel, Kiani et al. (2008) for red bean and Gupta and Das (1997) for sunflower seed.

True density

The true density varied from 893.1 to 784.6 kg m^{-3} when the moisture level increased from 11.93 to 21.52% d.b. (Figure 5). The true density and the moisture content of seed can be correlated as follows:

$$\rho_t = 1020.5 - 11.264M_c \quad (R^2 = 0.9718) \tag{9}$$

The results were similar to those reported by Özarslan (2002) for cotton seed, Abalone et al. (2004) for amaranth, Shepherd and Bhardwaj (1986) for pigeon pea, Deshpande et al. (1993) for soybean, Karababa (2006) for popcorn, Nimkar et al. (2006) for horse gram and Sacilik et al. (2003) for hemp seed.

Porosity

The porosity of spinach seed decreased from 39.65 to 36.67% with the increase in moisture content from 11.93 to 21.52% d.b. (Figure 6). The relationship between porosity and moisture content can be represented by the following equation:

$$P_f = 43.295 - 0.3175M_c \quad (R^2 = 0.9651) \tag{10}$$

Dursun and Dursun (2005) and Nimkar et al. (2006) reported similar trends in the case of caper seed and horse gram, 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 spinach seed at various moisture levels are shown in Figure 7. The terminal velocity was found to increase linearly from 6.10 to 6.58 m s^{-1} as the moisture content increased from 11.93 to 21.52% d.b. The relationship between terminal velocity and moisture content can be represented by the following equation:

$$V_t = 5.5621 + 0.0485M_c \quad (R^2 = 0.9583) \tag{11}$$

Similar results were reported by Gupta and Das (1997), Suthar and Das (1996), Singh and Goswami (1996), Çarman (1996), Yalçın et al. (2007) , Nimkar et al. (2005) and Ramakrishna (1986) in the case of sunflower, karingda, cumin, lentil, onion, moth gram and melon seeds, respectively.

Static coefficient of friction

The static coefficient of friction of spinach seed on four surfaces (rubber, wood, stainless steel and galvanised iron) against moisture content in the range 11.93 to 21.52% d.b. are presented in Figure 8. It was observed that the static coefficient of friction increased with

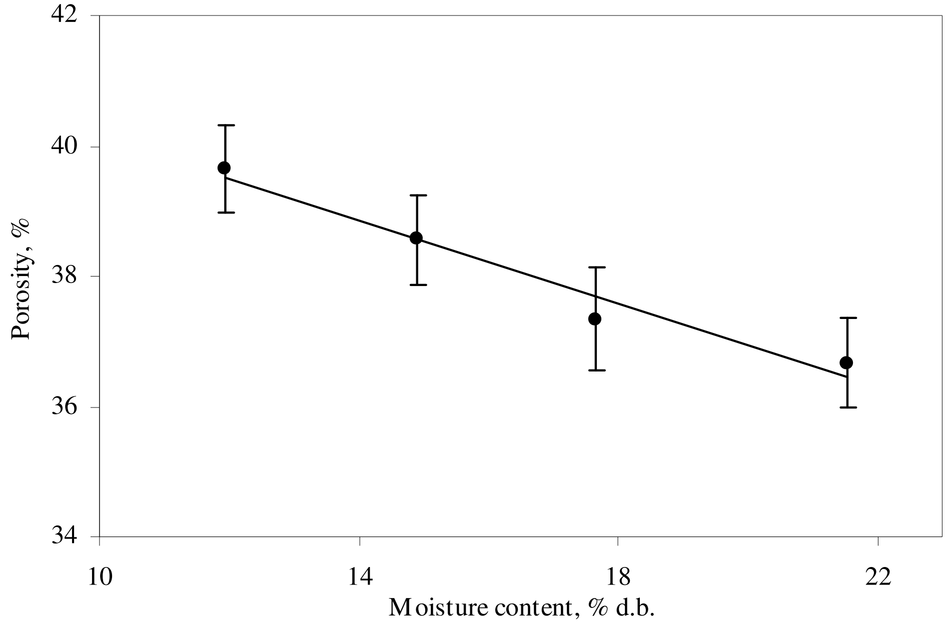

Figure 6. Effect of moisture content on porosity of spinach seed.

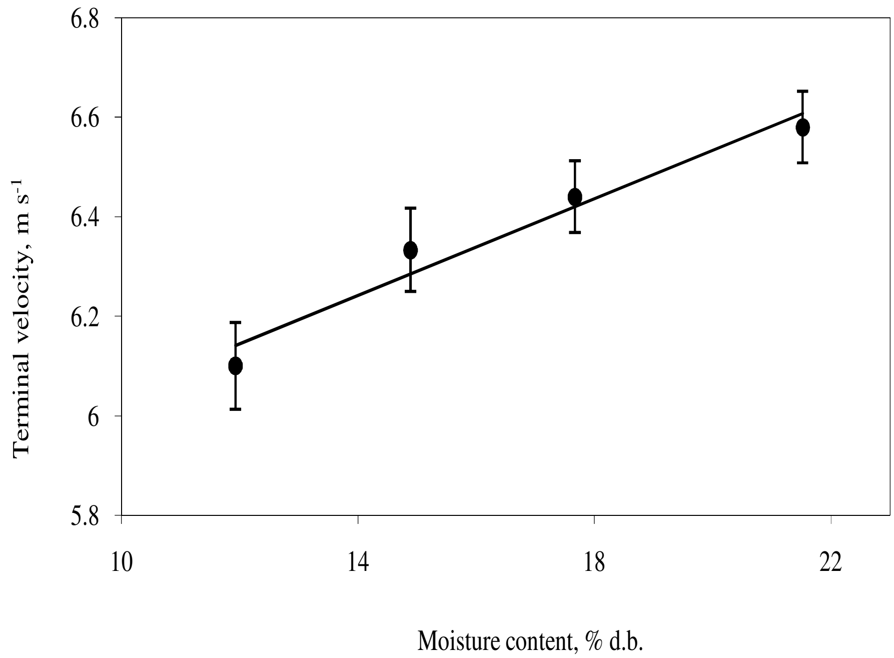

Figure 7. Effect of moisture content on terminal velocity of spinach seed.

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 37.83, 22.96, 34.32 and 20.87% were recorded in the case of rubber, wood, stainless steel and galvanised iron, respectively as the moisture content increased from 11.93 to 21.52% 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:

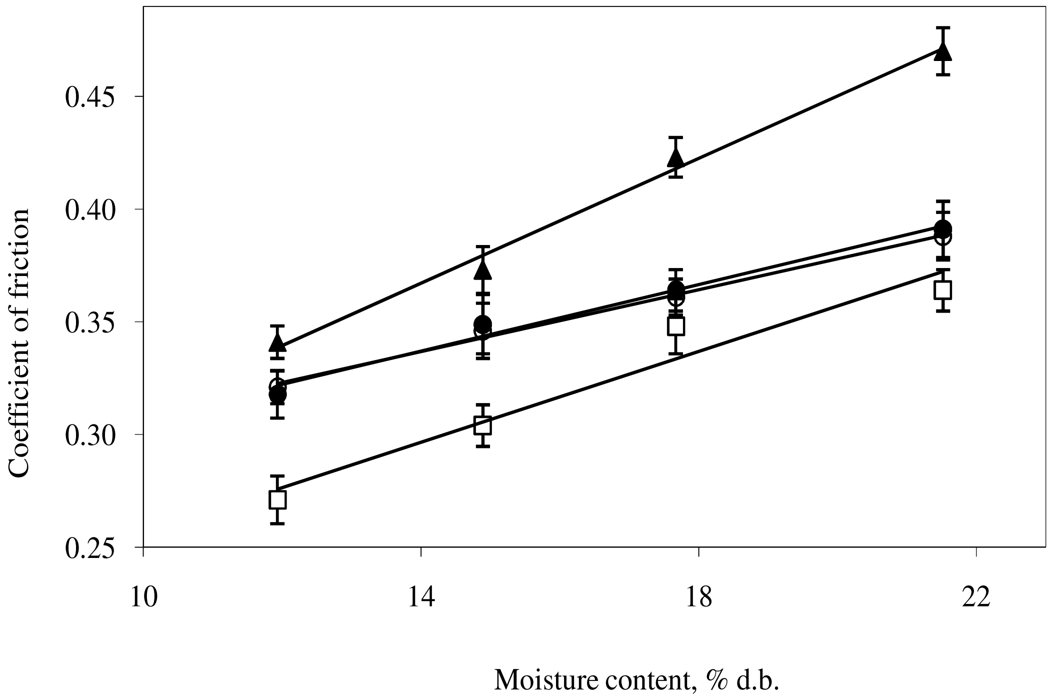

Figure 8. Effect of moisture content on static coefficient of friction. ▲ = rubber; ● = wood; ○ = galvanized iron; □ = stainless steel.

$\mu_{ru} = 0.1738 + 0.0138 M_c$ (R^2 of 0.9922) (12)

$\mu_{wo} = 0.2335 + 0.0074 M_c$ (R^2 of 0.9836) (13)

$\mu_{ss} = 0.1558 + 0.0101 M_c$ (R^2 of 0.9435) (14)

$\mu_{gi} = 0.241 + 0.0068 M_c$ (R^2 of 0.9944) (15)

Similar results were found by Özarslan (2002), Singh and Goswami (1996), Çarman (1996) and Yalçın and Özarslan (2004) for rapeseed, okra, cotton, cumin, lentil, black kabuli chickpea, jatropha and vetch seeds, respectively.

Conclusions

The present study showed that the thousand seed mass increased from 11.55 to 13.53 g and the sphericity increased from 0.807 to 0.821 with the increase in moisture content from 11.93 to 21.52% d.b. Also, the projectted area increased from 6.28 to 7.81 mm^2. The bulk density decreased linearly from 538.9 to 496.9 kg m^{-3}, the true density decreased from 893.1 to 784.6 kg m^{-3} and the porosity decreased from 39.65 to 36.67%. In addition, the terminal velocity increased from 6.10 to 6.58 m s^{-1}. The static coefficient of friction increased for all four surfaces, namely, rubber (0.341 to 0.470), wood (0.318 to 0.391), stainless steel (0.271 to 0.364) and galvanised iron (0.321 to 0.388).

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