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ORIGINAL ARTICLE

Effect of moisture on the physical properties of three varieties of kenaf seeds

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Abstract The physical properties of three kenaf varieties were evaluated as a function of moisture contents varying from 7.67 to 26.21, 7.35 to 25.96 and 7.27 to 25.53 % (dry basis) for cv. Everglades, Tainung and SF-459, respectively. The results showed that the increase in the moisture content of the kenaf seeds linearly decreased the bulk density, true density and rupture force, whereas it linearly increased the length, width, thickness, arithmetic mean diameter, geometric mean diameter, sphericity, surface area, seed volume, thousand seed mass, porosity, angle of repose and terminal velocity. Among the three varieties, maximum values for most selected physical properties of kenaf seeds were obtained for the Everglades seeds. At all moisture contents, the highest static coefficient of friction was found on the plywood surface followed by rubber, then galvanized iron, aluminum, glass and finally stainless steel. This study was conducted to investigate some moisture-dependent physical properties of kenaf seeds. These physical properties are necessary for the design of equipments for harvesting, processing, transportation, sorting, separating and packing.

Keywords Kenaf varieties · Physical properties · Moisture content · Static coefficient of friction

Introduction

Kenaf (*Hibiscus cannabinus* L.) from the family Malvaceae is a common warm season annual fiber plant native to India and Africa (Yazan et al. 2011). Although kenaf is a tropical plant, today its cultivars are well adapted to a wide geographical and climatic range (Danalatos and Archontoulis 2010). Kenaf plants have been widely used for the production of paper, biocomposites, fiber boards and bioplastics and in the textile industry. Depending on the variety and agroclimatic conditions, kenaf seed is an agricultural by-product of kenaf plantation, which yields up to 1,000 kg/ha (Chan et al. 2014). Kenaf seeds have potential uses in soap manufacturing and in linoleum, paints, varnishes, bio-diesel and industrial lubricants (Agbaje 2010). Kenaf seeds are also used as cooking (flour) and vegetable oils for human consumption. Kenaf seeds contain 9.6 % moisture, 6.4 % ash, 20.4 % oil, 21.4 % nitrogenous matter and 12.9 % crude fiber and can also be used as livestock due to their high protein content (more than 20 %) (Nyam et al. 2009). Kenaf seed oils contain healthy compounds: α-linolenic acid, β-sitosterol and vitamin E, and they have positive effects on human health such as anticancer, antioxidant and lipid-lowering cholesterol properties (Yazan et al. 2011).

Knowledge of the physical properties of agricultural products such as size dimensions, sphericity, surface area, seed volume, thousand seed mass, bulk density, true density, porosity, angle of repose, terminal velocity, rupture force and static coefficient of friction are the most important in designing grading, sorting, separating, cleaning, separation, transporting, handling, sizing, storing, processing and packaging systems (Altuntas and Demirtola 2007). In addition, those parameters are useful in determining the efficiency of machines and operations, evaluating the final product's quality, and classifying and distinguishing between different varieties. These results lead to a reduction in work efficiency and an increase in product loss. Therefore, the determination and consideration of these properties have important roles (Fathollahzadeh et al. 2008).

The physical properties of seeds are dependent on moisture content. The moisture-dependent characteristics of the physical properties of agricultural products have effects on the

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adjustment, performance efficiency and energy consumption of processing machines. In recent years, many researchers have reported the moisture dependence of the physical and mechanical properties of chosen agricultural materials, such as wheat (Tabatabaeefar 2003), linseed (Selvi et al. 2006), sorghum seed (Mwithiga and Sifuna 2006), tef seed (Zewdu and Solomon 2007), watermelon seed (Koocheki et al. 2007), red lentil seed (Gharibzahedi et al. 2011) and barley (Sologubik et al. 2013).

A literature review demonstrated that limited research has been conducted on the physical properties of kenaf seeds. Bakhtiari et al. (2011) determined some of the physical properties of kenaf seed (V36 variety) as a function of moisture content. However, detailed measurements of the principal dimensions and the variation of the physical properties of different varieties of kenaf seeds have not yet been investigated. The objective of this study was to determine some moisture-dependent physical properties of three varieties of kenaf seeds, including length, width, thickness, arithmetic mean diameter, geometric mean diameter, sphericity, surface area, seed volume, thousand seed mass, bulk density, true density, porosity, angle of repose, terminal velocity, rupture force and static coefficient of friction.

Materials and methods

The kenaf samples used in this study were obtained from fields at the Agricultural Faculty of Uludag University (Bursa, Turkey). The seeds were manually cleaned to remove all foreign matter such as dust, dirt, stones and chaff as well as immature, broken seeds. The initial moisture contents of the seeds were determined by oven (ED115 Binder, Tuttlingen, Germany) drying at 105 °C for 24 h (Cetin 2007) and were found to be 7.67, 7.35 and 7.27 % (dry basis (d.b.)) for the Everglades, Tainung and SF-459 varieties, respectively.

Kenaf samples at the desired moisture contents were prepared by adding the amount of distilled water calculated using the following equation (Yalcin 2007; Garnayak et al. 2008):

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

where Q is the mass of water added (kg), W_i the initial mass of the sample (kg), M_i the initial moisture content of the sample (% d.b.), and M_f is the final moisture content of the sample (% d.b.).

The samples were then poured into separate polyethylene bags, and the bags were sealed tightly. The samples were maintained at 5 °C in a refrigerator for a week to enable the moisture to distribute uniformly throughout the sample (Gharibzahedi et al. 2011). Prior to starting a test, the required quantity of the grain was taken out of the refrigerator and allowed to warm to room temperature for approximately 2 h. All the physical properties of the kenaf seeds were measured at moisture levels of 7.67, 13.88, 20.23 and 26.21 % (d.b.) for the Everglades; 7.35, 13.49, 19.71 and 25.96 % (d.b.) for the Tainung; and 7.27, 13.32, 19.34 and 25.53 % (d.b.) for the SF-459 (three replicates for each level) varieties.

To determine the average size of the kenaf varieties, 100 seeds were randomly picked, and their three principal dimensions, namely length (L), width (W) and thickness (T), were measured at each moisture level using a digital slide clipper (Mitutoyo, Japan) with an accuracy of 0.01 mm. The arithmetic mean diameter (D_a) and the geometric mean diameter (D_g) were calculated by using the following relationships (Mohsenin 1986):

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

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

The sphericity (ϕ) of kenaf seeds was calculated as follows (Mohsenin 1986):

$$\phi = D_g/L \tag{4}$$

The surface area (S) and seed volume (V) were calculated using the following relationships (Karababa and Coşkuner 2013):

$$S = \pi D_g^2 \tag{5}$$

$$V = \frac{\pi B^2 L^2}{6(2B - L)} \tag{6}$$

Where $B=(WT)^{1/2}$

The thousand seed mass (M_{1000}) was determined by means of a digital electronic balance (Chyo, MP-300, Japan) having an accuracy of 0.001 g.

The bulk density (ρ_b) was determined by filling a circular container (500 ml volume) with the grain from a height of 150 mm at a constant rate and then weighing the contents. The bulk density was calculated from the mass of the grains and the volume of the container (Sacilik et al. 2003).

The true density (ρ_t) was determined using the toluene displacement method. The volume of toluene displaced was found by immersing a weighed quantity of kenaf seeds in toluene (Nimkar and Chattopadhyay 2001).

The porosity (ε) of the kenaf samples at various moisture contents was calculated from bulk and true densities using the relationship given by Mohsenin (1986) as follows:

$$\varepsilon = \left(\frac{\rho_t - \rho_b}{\rho_t}\right) \times 100 \tag{7}$$

The angle of repose (θ) was determined by using a topless and bottomless cylinder (10 cm diameter, 15 cm height). The cylinder was placed on a table, filled with the grains and raised slowly until it formed a cone. The diameter and height of the cone were recorded. The angle of repose was calculated by using the formula as (Dursun and Dursun 2005):

$$\theta = \tan^{-1}(2H/D) \tag{8}$$

where H is the height of the cone (cm) and D is the diameter of cone (cm).

The terminal velocity (V_t) that maintained the grain in suspension was recorded using a digital anemometer (Thies clima, Germany) having a least count of 0.1 m s^{-1} (Shirkole et al. 2011).

To determine the rupture force (F_r) of the kenaf seeds, a biological material test device (Sundoo, SH-500, Digital Force Gauge, China) with a load cell of 500 N capacities was used.

The coefficient of static friction on the six different surfaces, including plywood (μ_{pw}), rubber (μ_{ru}), galvanized iron (μ_{gi}), aluminum (μ_{al}), glass (μ_{gl}) and stainless steel (μ_{ss}), were determined. A polyvinylchloride cylindrical pipe (50 mm diameter, 100 mm height) was placed on an adjustable tilting plate, faced with the test surface and filled with the grain sample. The cylinder was raised slightly to not touch the surface. The structural surface with the cylinder resting on it was gradually raised with a screw device until the cylinder just started to slide down, and the angle of tilt was read from a graduated scale. The coefficient of friction was calculated from the following relationship (Garnayak et al. 2008):

$$\mu = \tan\alpha \tag{9}$$

where μ is the coefficient of friction and α is the angle of tilt (°).

The results were processed using MINITAB (Version 14, University of Texas, Austin, Texas, USA) and MS-Excel software programs. A one-way analysis of variance was used to analyze the results. Differences were considered significant at P<0.05 unless otherwise specified.

Results and discussion

The values for the principal dimensions, arithmetic mean diameter and geometric mean diameter of the kenaf varieties

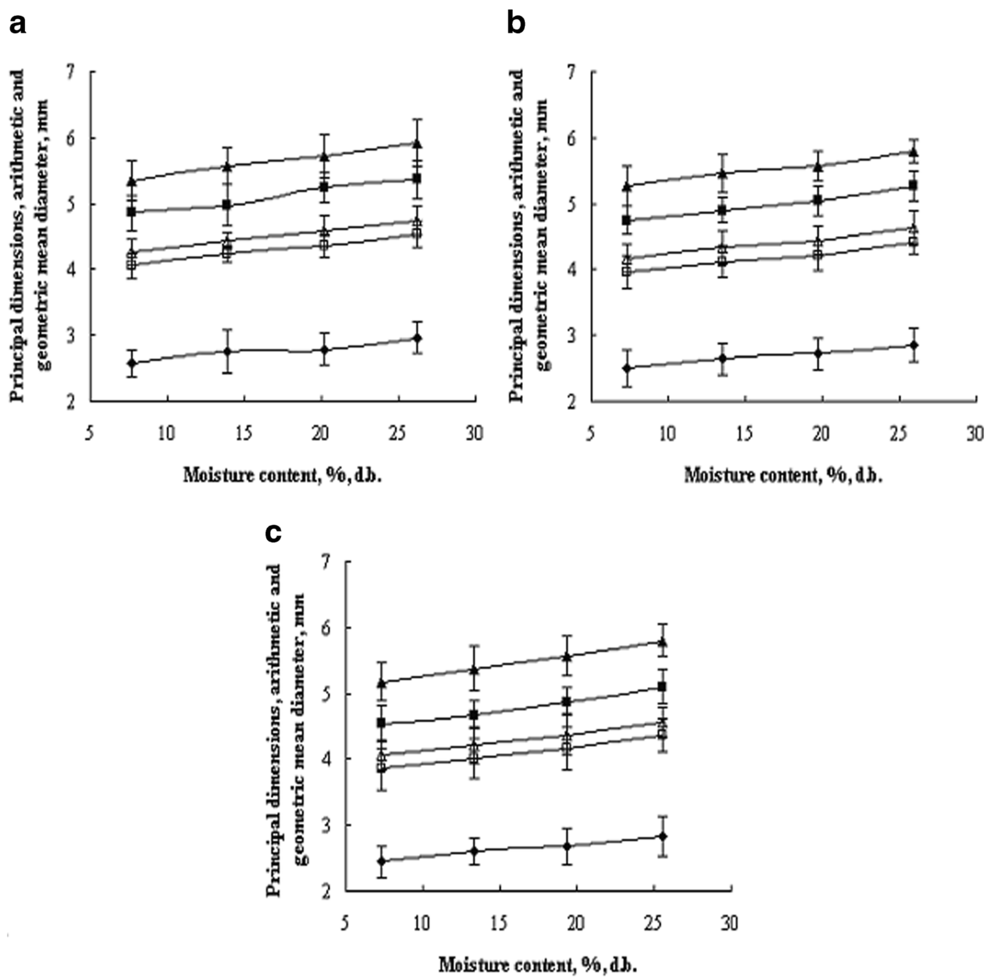

Fig. 1 Variation of the principal dimensions, arithmetic and geometric mean diameter of the Everglades **a**, Tainung **b** and SF-459 **c** varieties with different moisture contents: (▲) length, L; (■) width, W; (◆) thickness, T; (△) arithmetic mean diameter, D_a and (□) geometric mean diameter, D_g

Table 1 Equations representing the relationship between principal dimensions, the arithmetic mean diameter and the geometric mean diameter of the kenaf seed varieties and moisture content

Variety	M_c (%, d.b.)	Equation	R^2
Everglades	7.67−26.21	L=5.1249+0.0303 M_c	0.9948
		W=4.6183+0.0288 M_c	0.9791
		T=2.4428+0.0194 M_c	0.9428
		D_a=4.0622+0.0261 M_c	0.9988
		D_g=3.8551+0.026 M_c	0.9968
Tainung	7.35−25.96	L=5.0716+0.0269 M_c	0.9846
		W=4.5359+0.027 M_c	0.9873
		T=2.3695+0.0186 M_c	0.9857
		D_a=3.9923+0.0242 M_c	0.9892
		D_g=3.7856+0.0233 M_c	0.9889
SF-459	7.27−25.53	L=4.9238+0.034 M_c	0.9971
		W=4.294+0.0307 M_c	0.9889
		T=2.3104+0.0198 M_c	0.9856
		D_a=3.8427+0.0282 M_c	0.9967
		D_g=3.647+0.0274 M_c	0.9971

at the different moisture contents are provided in Fig. 1a-c. For the Everglades, with an increase in moisture content from 7.67 to 26.21 % (d.b.), the length, width, thickness, arithmetic mean diameter, and geometric mean diameter values increased 10.65 %, 10.52 %, 14.73 %, 11.5 % and 12.1 %, respectively. For the increase in moisture content of the Tainung from 7.35 to 25.96 % (d.b.), increases were observed for the length 9.87 %, the width 10.74 %, the thickness 14.46 %, the arithmetic mean diameter 11.03 % and the geometric mean diameter 11.39 %. Increasing the moisture content from 7.27 to 25.53 % (d.b.) increased the length, width, thickness, the arithmetic mean diameter and the geometric mean diameter of the SF-459 seeds 12.16 %, 12.33 %, 15.57 %, 12.84 % and 13.25 %, respectively. The effect of the moisture content on the principal dimensions of the kenaf varieties displayed a significant linear increase (P<0.05) with an increasing moisture content, and the regression equations and coefficients of determination (R^2) values are provided in Table 1. Furthermore, the values for the principal dimensions of the Everglades variety were higher compared to those of the Tainung and SF-459 varieties. The results of this study are in agreement with previous studies. Bakhtiari et al. (2011) found that the length, width, thickness, arithmetic mean diameter and

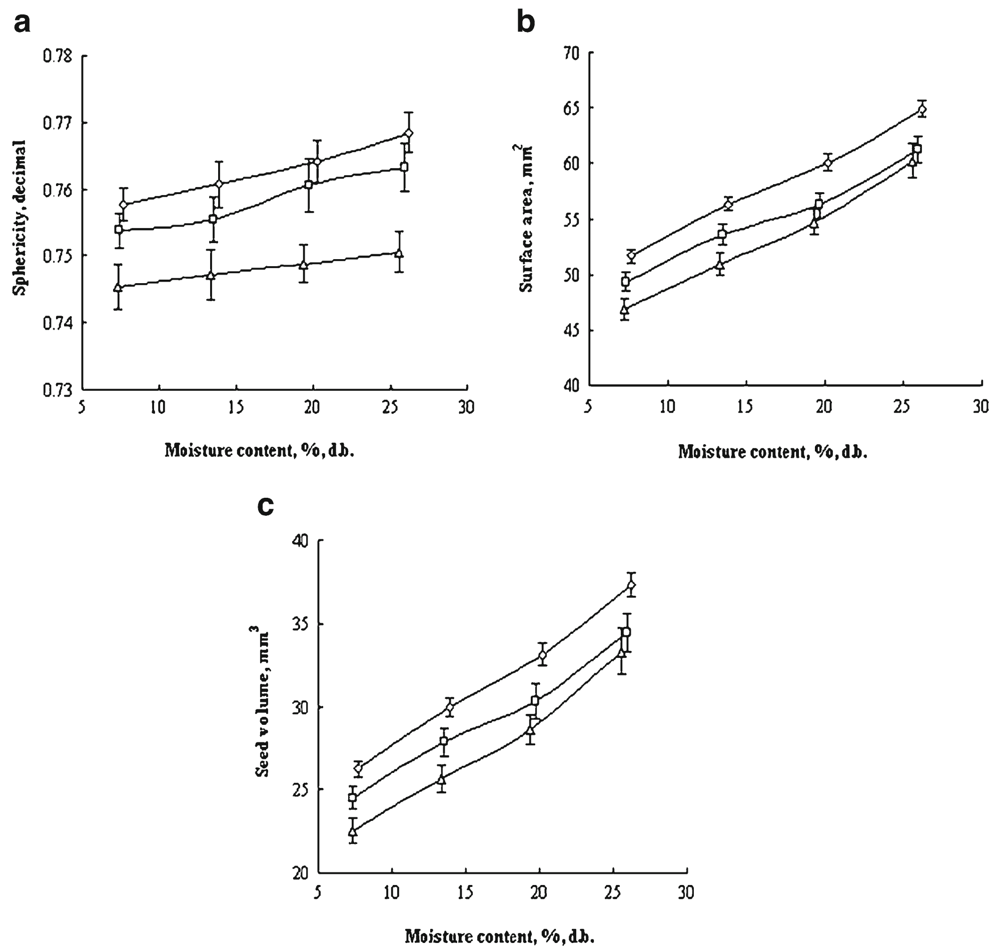

Fig. 2 Sphericity **a**, surface area **b** and seed volume **c** of the kenaf seeds as a function of variety and moisture content: (◇) Everglades, (□) Tainung and (△) SF-459

Table 2 Regression relationships between the sphericity, the surface area, and seed volume of the kenaf seed varieties and moisture content

Variety	M_c (%, d.b.)	Equation	R^2
		ϕ=0.7529+0.0006 M_c	0.9936
Everglades	7.67−26.21	S=46.288+0.7031 M_c	0.9968
		V=21.686+0.5865 M_c	0.9959
		ϕ=0.7493+0.0005 M_c	0.9681
Tainung	7.35−25.96	S=44.81+0.6186 M_c	0.9883
		V=20.629+0.5204 M_c	0.9906
		ϕ=0.7433+0.0003 M_c	0.9997
SF-459	7.27−25.53	S=41.366+0.7223 M_c	0.9933
		V=18.041+0.5797 M_c	0.9884

geometric mean diameter increased 8.44 %, 6.56 %, 6.02 %, 7.59 % and 6.99 % for kenaf seeds (V36 variety) with an increase in moisture content from 6.8 to 25.2 % (d.b.), respectively. In addition, the length, width and thickness of different varieties of melon seeds (Koocheki et al. 2007), arithmetic mean diameter of coriander seeds (Coşkuner and Karababa 2007) and the geometric mean diameter of three varieties of sorghum seeds (Mwithiga and Sifuna 2006) have been reported to increase linearly with increases in moisture content.

The sphericities of kenaf varieties with different moisture levels are shown in Fig. 2a. The sphericity values of the Everglades, Tainung and SF-459 were 0.759–0.769, 0.754–0.763, and 0.745–0.751, respectively. The results demonstrate that the Everglades variety had a higher sphericity compared to the other varieties. The sphericities of the kenaf varieties were compared with those of the other seeds, and it was observed that the sphericity of the grain at given moisture levels was lower compared to those of hemp seed (Sacilik et al. 2003) and higher than those of caper seed (Dursun and Dursun 2005). The sphericity increased linearly with the increasing moisture content for all three varieties. These linear behaviors are in accordance with similar reported results for maize (Barnwal et al. 2012). The regression equation for the relationship between sphericity and moisture content is represented in Table 2.

The variation of the surface area for the kenaf varieties with different moisture contents is plotted in Fig. 2b. The surface area of the Everglades, Tainung and SF-459 varieties increased from 51.64 to 64.92, 49.35 to 61.24 and 46.87 to 60.24 mm^2, respectively. The highest surface area values were obtained for the Everglades variety in comparison to the Tainung and SF-459 varieties. According to the results obtained for all three varieties, increases in the moisture level led

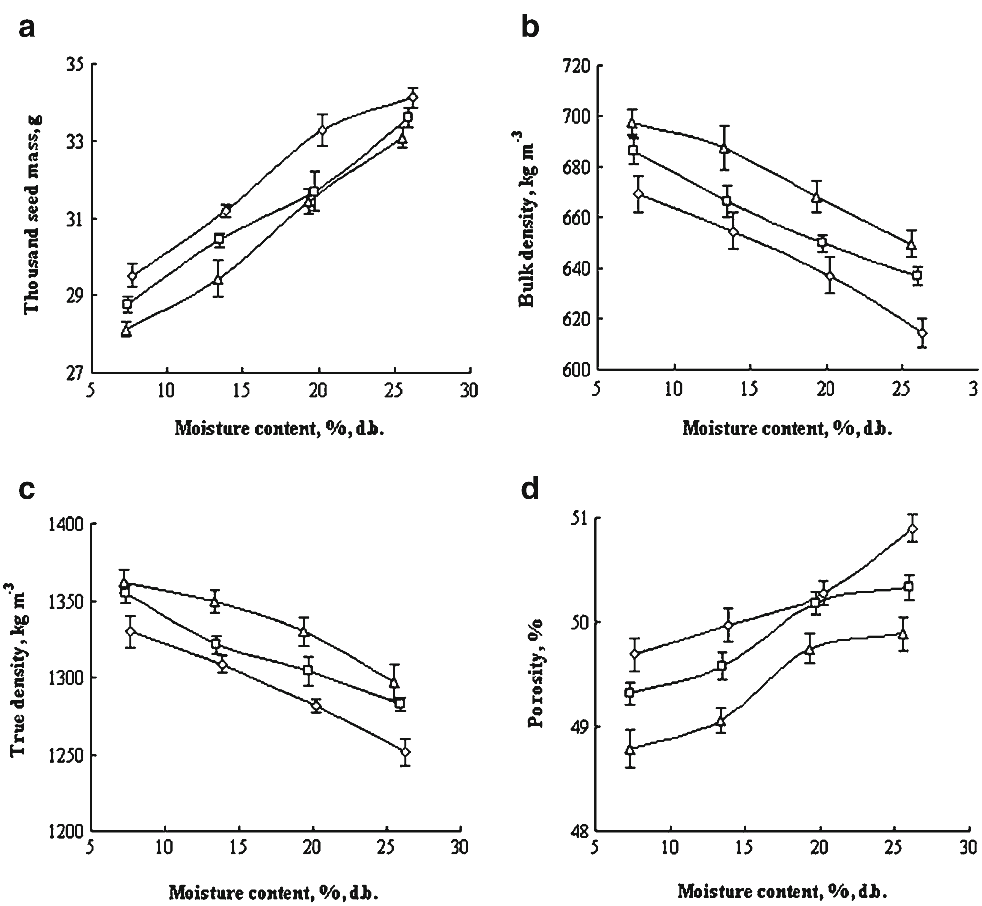

Fig. 3 Thousand seed mass **a**, bulk density **b**, true density **c** and porosity **d** of the kenaf seeds as a function of the variety and moisture content: (◇) Everglades, (□) Tainung and (△) SF-459

Table 3 Equations representing the relationship for the thousand seed mass, bulk density, true density and porosity of the kenaf seeds as a function of the variety and moisture content

Variety	M_c (%, d.b.)	Equation	R^2
Everglades	7.67−26.21	M_{1000}=27.667+0.2567 M_c	0.9794
		ρ_b=693.54−2.9244 M_c	0.9877
		ρ_t=1364.9−4.2388 M_c	0.9934
		ε=49.136+0.0633 M_c	0.9540
Tainung	7.35−25.96	M_{1000}=26.897+0.2540 M_c	0.9940
		ρ_b=703.78−2.6477 M_c	0.9893
		ρ_t=1377.6−3.7350 M_c	0.9795
		ε=48.880+0.0588 M_c	0.9532
SF-459	7.27−25.53	M_{1000}=25.977+0.2776 M_c	0.9944
		ρ_b=719.61−2.6829 M_c	0.9849
		ρ_t=1393.1−3.5799 M_c	0.9597
		ε=48.305+0.0653 M_c	0.9389

to a linear increase in the surface area (P<0.05). Similar trends have been reported by Milani et al. (2007) for cucurbit seeds and by Koocheki et al. (2007) for watermelon seeds. The relationship between surface area and the moisture content for all the varieties is shown in Table 2.

Figure 2c shows the seed volume variation for the kenaf varieties at different moisture levels. The seed volumes of the varieties were: lowest for SF-459 (22.55-33.30 mm^3), then Tainung (24.50-34.45 mm^3), and highest for the Everglades (26.24-37.31 mm^3) as the moisture contents increased from 7.27 to 25.53, 7.35 to 25.96 and 7.67 to 26.21 % (d.b.), respectively. The results demonstrate that the seed volume increased linearly with the increasing moisture content for all kenaf varieties (P<0.05). The equations representing the relationship between the seed volume and moisture content for each kenaf variety are presented in Table 2. These linear behaviors are in agreement with similar reported results for millet (Baryeh 2002) and legume seeds (Altuntas and Demirtola 2007).

The variation of thousand seed masses for the kenaf varieties with different moisture contents is depicted in Fig. 3a. The values for the Everglades, Tainung and SF-459 varieties ranged from 29.52 to 34.12, 28.76 to 33.60 and 28.12 to 33.08 g at moisture contents ranging from 7.67 to 26.21, 7.35 to 25.96 and 7.27 to 25.53 % (d.b.), respectively. The thousand seed masses for the kenaf samples were greater than the reported values for tef seed (Zewdu and Solomon 2007)

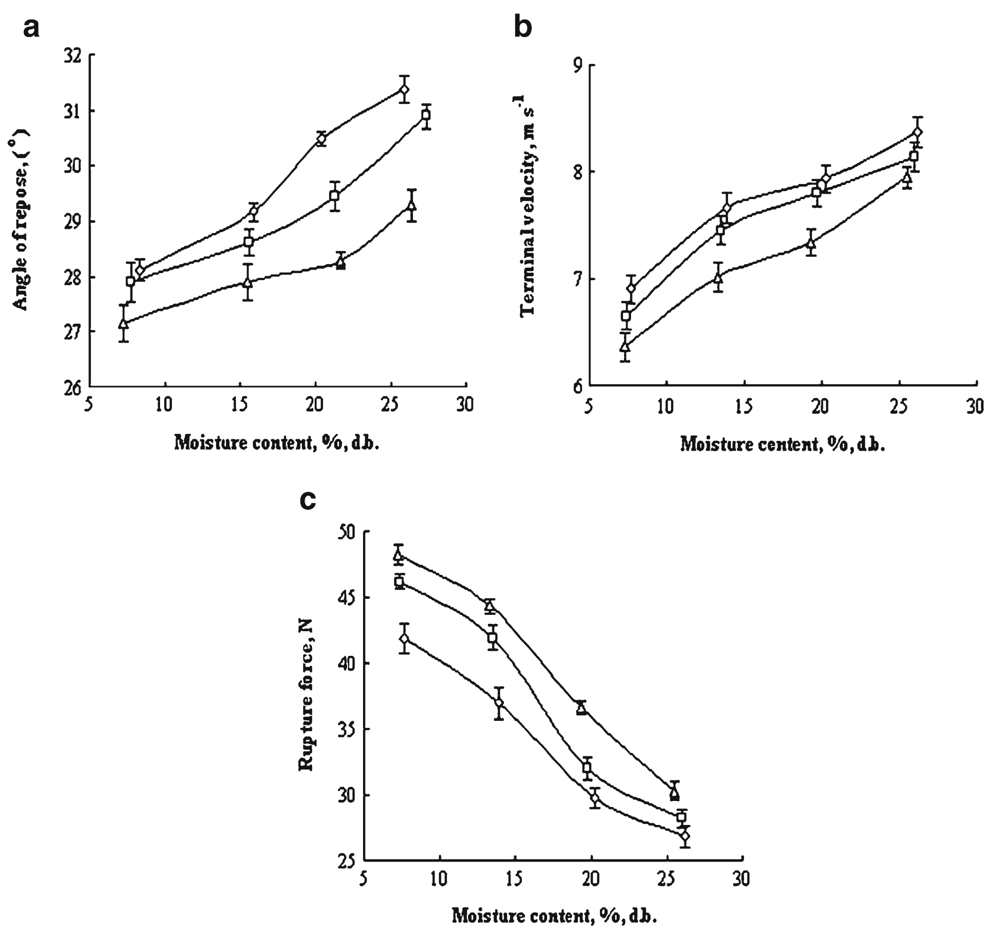

Fig. 4 Angle of repose **a**, terminal velocity **b**, rupture force **c** and porosity **d** of the kenaf seeds as a function of the variety and moisture content: (◇) Everglades, (□) Tainung and (△) SF-459

Table 4 Regression relationships between the angle of repose, terminal velocity, rupture force and porosity of the kenaf seed varieties and moisture content

Variety	M_c (%, d.b.)	Equation	R^2
		θ=26.417+0.191 M_c	0.9800
Everglades	7.67−26.21	V_t=6.4366+0.0753 M_c	0.9563
		F_r=48.24−0.8461 M_c	0.9806
		θ=26.522+0.1493 M_c	0.9498
Tainung	7.35−25.96	V_t=6.2233+0.0773 M_c	0.9457
		F_r=54.137−1.0273 M_c	0.9661
		θ=26.308+0.1045 M_c	0.9409
SF-459	7.27−25.53	V_t=5.799+0.0835 M_c	0.9861
		F_r=56.456−1.0139 M_c	0.9858

and lower than those for vetch seed (Yalçın and Özarslan 2004). Furthermore, the results indicate that the thousand seed mass increased with increases in the moisture content for all kenaf varieties (P<0.05). These results are similar to those reported by Nimkar and Chattopadhyay (2001) for green gram and by Baryeh (2002) for millet. The regression equations and the R^2 values obtained for the thousand seed masses of the kenaf varieties as a function of the moisture content are presented in Table 3.

The experimental results for the bulk densities of the kenaf varieties with moisture contents are shown in Fig. 3b. The bulk density values varied from 669.08 to 614.46 kg m^{-3} in the moisture range 7.67–26.21 % (d.b.) for the Everglades variety, from 686.25 to 636.94 kg m^{-3} as the moisture content increased from 7.35 to 25.96 % (d.b.) for the Tainung variety, and from 697.64 to 649.68 kg m^{-3} in the moisture range 7.27–25.53 % (d.b.) for the SF-459 variety. The results indicate that the bulk density decreased with the increasing moisture content. The variation in bulk density with the moisture content was found to be significant (P<0.05). The decrease in the bulk density of the kenaf varieties with the increasing moisture content may be due to the increase in mass, owing to the moisture gain in the sample being lower than the corresponding volumetric expansion of the bulk (Sologubik et al. 2013). The relationship of the bulk density of the kenaf varieties with respect to the moisture content can be represented by the equations provided in Table 3. The negative linear relationship existing between the bulk density and moisture content has also been demonstrated by Dursun and Dursun (2005) for caper seeds and by Milani et al. (2007) for cucurbit seeds.

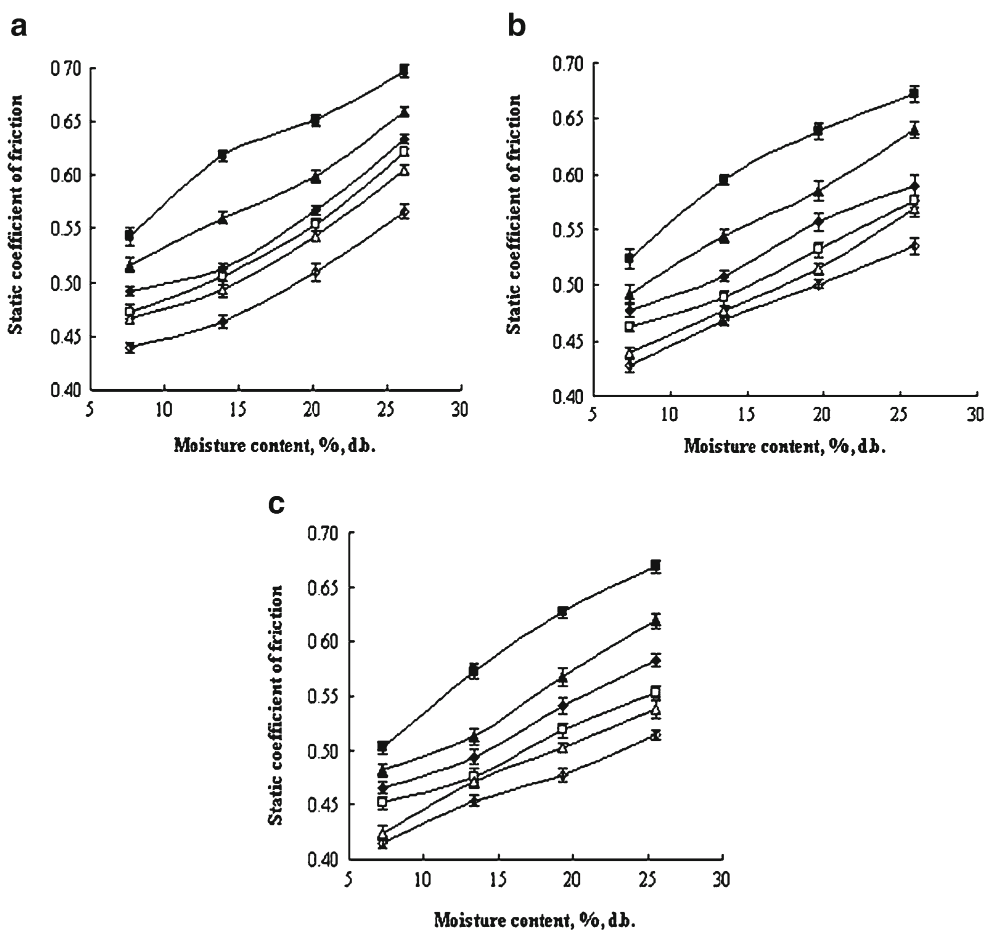

Fig. 5 Static coefficients of friction for the Everglades **a**, Tainung **b** and SF-459 **c** varieties with different moisture contents for various surfaces: (■) plywood, μ_{pw}; (▲) rubber, μ_{ru}; (◆) galvanized iron, μ_{gi}; (□) aluminum, μ_{al}; (△) glass, μ_{gl} and (◇) stainless steel, μ_{ss}

The values for the true densities for the Everglades, Tainung and SF-459 seeds at different moisture contents decreased from 1330.01 to 1251.47, 1354.19 to 1282.60 and 1362.33 to 1296.49 kg m^{-3}, respectively. It was observed that the true density decreased linearly with the moisture content, as can be observed in Fig. 3c. The effect of the moisture content on the true density of the kenaf varieties was statistically significant ($P<0.05$). The true density values for the kenaf varieties were found to be lower than those of roselle seed (Bamgboye and Adejumo 2009) and higher than those of wheat (Tabatabaeefar 2003). The relationship between true density and moisture content for all the varieties is shown in Table 3. The negative linear relationship of the true density with the moisture content has also been observed by Sacilik et al. (2003) for hemp seed.

The results of the porosity for the kenaf varieties are presented in Fig. 3d and increased from 49.69 to 50.90 % for the Everglades, 49.32 to 50.34 % for the Tainung, and 48.79 to 49.89 % for the SF-459. The porosity increased linearly with the increase in moisture content for all three varieties. The relationships between the porosity and moisture content were significant ($P<0.05$). A similar increasing trend in porosity has been reported by Gharibzahedi et al. (2011) for red lentil seeds. In addition, the porosity values for the kenaf varieties were lower compared to those for faba bean (Altuntas and Yildiz 2007) but higher than those for tef seed (Zewdu and Solomon 2007). The equations representing the relationship between the porosity and moisture content for each kenaf variety are presented in Table 3.

The experimental values for the angle of repose for kenaf varieties at various moisture content levels are provided in Fig. 4a. The angles of repose for the Everglades, Tainung and SF-459 varieties ranged from 28.12 to 31.38, 27.90 to 30.89 and 27.16 to 29.29° for moisture contents ranging from 7.67–26.21, 7.35 to 25.96 and 7.27–25.53 % (d.b.), respectively. The angle of repose increased linearly as the seed moisture content increased for all three varieties and can be expressed by the relationships shown in Table 4. Increasing trends have also been reported by Barnwal et al. (2012) for maize. The angles of repose for the kenaf varieties are greater than those reported for linseed (Selvi et al. 2006) and lower than those for bean seed (Firouzi et al. 2012). The greatest angle of repose value was for the Everglades and then the Tainung, whereas the lowest was obtained for SF-459. The results for the angle of repose indicate that the moisture content had a significant effect on all three seed varieties at a 5 % level of significance.

The values obtained for the terminal velocity of the kenaf varieties at different moisture contents are graphically shown in Fig. 4b. As the moisture content increased, the terminal velocity increased linearly from 6.90 to 8.37, 6.65 to 8.13 and 6.37 to 7.95 m s^{-1} for the Everglades, Tainung and SF-459 varieties, respectively. The moisture content effect on the terminal velocity of the kenaf varieties was significant ($P<0.05$). A linear increase in terminal velocity with an increase in moisture content has been observed by Rajabipour et al. (2006) for three different varieties (Pishtaz, Mahdavi and Marvdasht) of wheat. The terminal velocity values for the kenaf varieties were determined to be lower than those of soybean varieties (*cv.* TAMS-38 and JS-335) (Shirkole et al. 2011) and higher than those of linseed (Selvi et al. 2006). The results demonstrate that for the Everglades variety, the terminal velocity is greater compared to the Tainung and SF-459 varieties at all moisture content levels. The relationships between the terminal velocity and moisture contents of all kenaf varieties are presented in Table 4.

The variation of the rupture force for the kenaf varieties at different moisture contents is presented in Fig. 4c. The values for the Everglades, Tainung and SF-459 varieties ranged from 41.89 to 26.84, 46.14 to 28.21 and 48.24 to 30.26 N at moisture contents ranging from 7.67–26.21, 7.35 to 25.96 and 7.27–25.53 % (d.b.), respectively. The data indicate that the rupture force decreased with the increasing moisture content ($P<0.05$). Furthermore, the largest angle of repose value was for the Capitol and then Samurai, whereas the lowest value was obtained for the Jetneuf. Thus, it can be concluded that there were negative linear relationships with very high correlations (R^2) between the rupture force and moisture contents for all kenaf varieties (Table 4). Similar results have been reported by Barnwal et al. (2012) for maize.

Table 5 Equations representing the relationship for static coefficients of friction on different surfaces of kenaf seeds as a function of the variety and moisture content

Variety	M_c (%, d.b.)	Equation	R^2
Everglades	7.67−26.21	μ_{pw}=0.4915+0.0080 M_c	0.9711
		μ_{ru}=0.4557+0.0075 M_c	0.9871
		μ_{gi}=0.4206+0.0077 M_c	0.9524
		μ_{al}=0.4036+0.0079 M_c	0.9724
		μ_{gl}= 0.3990+0.0075 M_c	0.9701
		μ_{ss}= 0.3768+0.0069 M_c	0.9697
Tainung	7.35−25.96	μ_{pw}=0.4765+0.0079 M_c	0.9674
		μ_{ru}=0.4355+0.0078 M_c	0.9965
		μ_{gi}=0.4285+0.0063 M_c	0.9929
		μ_{al}=0.4119+0.0062 M_c	0.9886
		μ_{gl}= 0.3859+0.0069 M_c	0.9913
		μ_{ss}= 0.3872+0.0058 M_c	0.9980
SF-459	7.27−25.53	μ_{pw}=0.4442+0.0091 M_c	0.9862
		μ_{ru}=0.4195+0.0077 M_c	0.9880
		μ_{gi}=0.4139+0.0065 M_c	0.9905
		μ_{al}=0.4070+0.0057 M_c	0.9907
		μ_{gl}= 0.3839+0.0061 M_c	0.9915
		μ_{ss}= 0.3782+0.0053 M_c	0.9916

The static coefficients of friction for the kenaf varieties with different moisture contents on six structural surfaces (plywood, rubber, galvanized iron, aluminum, glass and stainless steel) are provided in Fig. 5a-c. The experimental results demonstrate that the static coefficient of friction values for the three varieties significantly increased with the increasing moisture content on all surfaces ($P<0.05$). Similar studies have reported the effect of moisture content on the static coefficient of friction: Altuntas and Yildiz (2007), Milani et al. (2007) and Sologubik et al. (2013) for faba bean, cucurbit seeds and barley, respectively. The increase in the static coefficient of friction with the moisture content may be due to the increased adhesion between the seed and the material surface at higher moisture values. At all moisture contents, plywood (0.50–0.70) displayed the highest static coefficient of friction followed by rubber (0.48–0.66), galvanized iron (0.47–0.63), then aluminum sheet (0.45–0.62), glass (0.42–0.60) and finally stainless steel (0.41–0.57). Plywood has been suggested to possess the highest static coefficient of friction by Coşkuner and Karababa (2007) for coriander seeds and by Garnayak et al. (2008) for jatropha seeds. Furthermore, Cetin (2007) for barbunia bean and Yalcin (2007) for cowpea have reported the lowest friction values on a stainless steel surface. As can also be observed from Fig. 5a-c, the highest friction on all surfaces at all moisture levels was observed with the Everglades variety. This result could be due to the Everglades variety having a higher moisture content compared to the other varieties because the water present in the varieties offer a cohesive force on the surface of contact. Regression equations related to the static coefficient of friction for the kenaf varieties, and R^2 values are presented in Table 5.

Conclusions

The effect of the moisture content on most physical properties of the kenaf varieties with different moisture contents was investigated in this study. For all the kenaf varieties with different moisture contents, the bulk density decreased from 697.64 to 614.46 kg m^{-3}, the true density decreased from 1362.33 to 1251.42 kg m^{-3} and the rupture force decreased from 48.24 to 26.84 N, whereas increases were observed for the length from 5.18 to 5.92 mm, width from 4.54 to 5.36 mm, thickness from 2.44 to 2.96 mm, arithmetic mean diameter from 4.05 to 4.75 mm, geometric mean diameter from 3.85 to 4.54 mm, sphericity from 0.745 to 0.769, surface area from 46.87 to 64.92 mm^2, seed volume from 22.55 to 32.31 mm^3, thousand seed mass from 28.12 to 34.12 g, porosity from 48.79 to 50.90 %, angle of repose from 27.16 to 31.38°, and terminal velocity from 6.37 to 8.37 m s^{-1}. Among the three varieties, maximum values for the length, width, thickness, arithmetic mean diameter, geometric mean diameter, sphericity, surface area, seed volume, thousand seed mass, porosity, angle of repose, and terminal velocity were obtained for the Everglades seeds, whereas it had the lowest values for bulk density, true density, and rupture force. The highest static coefficient of friction was determined on the plywood surface. The static coefficient of friction increased from 0.50 to 0.70, 0.48 to 0.66, 0.47 to 0.63, 0.45 to 0.62, 0.42 to 0.60, and 0.41 to 0.57 for the plywood, rubber, galvanized iron, aluminum, glass and stainless steel surfaces, respectively. It can be observed that the static coefficient of friction for different varieties of kenaf seeds increased linearly with increases in the moisture content.

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