Int. Agrophysics, 2009, 23, 137-145

INTERNATIONAL
Agrophysics
www.international-agrophysics.org

Physical and mechanical properties of rapeseed at different moisture content

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Received December 4, 2008; accepted February 10, 2009

A b s t r a c t. Physical and mechanical properties of three common varieties of rapeseed have been evaluated as a function of seed moisture content varying from 8.3 to 25.9%, from 7.7 to 27.4%, and from 7.3 to 26.4% (d.b.) for cv. Capitol, Jetneuf and Samurai, respectively. Increasing moisture content was found to increase the length, diameter, geometric mean diameter, sphericity, seed volume, surface area, thousand grain weight, porosity, angle of repose and terminal velocity, and static friction coefficient on six structural surfaces, while decreasing bulk density, true density and rupture strength. Among the varieties, Capitol had the highest values of geometric properties, at all moisture contents studied. An increase of sphericity with moisture content was observed. The maximum values of seed volume and surface area among the varieties were obtained for Capitol seeds. Jetneuf seed had the highest porosity which increased with increase in moisture content. While thousand seed weight, angle of repose and terminal velocity increased as the moisture contents increased for all three varieties, bulk density, true density and rupture force decreased as the moisture contents increased for all three varieties. At all moisture contents, rubber showed the highest friction coefficient, followed by plywood, then galvanized iron, glass, aluminium, and finally stainless steel. Capitol variety had the highest friction on all frictional surfaces at all moisture levels.

K e y w o r d s: rapeseed, physical and mechanical properties, moisture content, variety

INTRODUCTION

Rapeseed (*Brassica napus* L.), also known as rape, oilseed rape, rapa, rapaseed and canola, is a bright yellow flowering member of the family Brassicaceae (mustard or cabbage family). Rapeseed is very widely cultivated throughout the world for the production of animal feed, vegetable fat for human consumption, and biodiesel. Leading producers include the European Union, Canada, the United States, Australia, China and India (Anonymous, 2007a). World production is growing rapidly, with FAO reporting that 48.97 mln t of rapeseed was produced. Turkey has about 6000 ha of rapeseed harvesting 31 area, with 12 615 t of rapeseed production annually (FAO, 2006).

Rapeseed is an important fat plant since its seed contains 38-50% fat, 16-24% protein, and rich in oleic and linoleic acids and high boiling point of its fat (238°C) (Anonymous, 2007b). In Europe, rapeseed is primarily cultivated for animal feed, due to its very high lipid and medium protein content, and is a leading option for Europeans to avoid importation of GMO products. Rapeseed fat (or canola fat) contains both omega-6 and omega-3 fatty acids in a ratio of 2:1 and is only second to flax fat in omega-3 fatty acid content. It is one of the most heart-healthy fats and has been reported to reduce cholesterol levels, lower serum triglyceride levels, and keep platelets from sticking together (Anonymous, 2007a).

The physical properties of rapeseeds, like those of other grains, are essential for the design of equipment for handling, harvesting, aeration, drying, storing, dehulling and processing. These properties are affected by numerous factors such as size, form, superficial characteristics and moisture content of the seed. Moreover, knowledge of fracture characteristics of the seed hull is imperative for rational design of efficient dehulling systems, as well as for the optimisation of the process and product parameters.

Research results on physical and engineering properties are reported for different types of seeds, such as African nutmeg (Burubai *et al*., 2007), gram (Chowdhury *et al*., 2001), hemp seed (Sacilik *et al*., 2003), karingda seed

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(Suthar and Das, 1996), moth gram (Nimkar *et al*., 2005), oilbean (Oje and Ugbor, 1991), quinoa seed (Vilche *et al*., 2003), safflower (Baümler *et al*., 2006), sheanut (Aviara *et al*., 2005) and wheat (Tabatabaeefar, 2003). Limited research has been conducted on the physical properties and fracture resistance of rapeseed. Çalışır *et al*. (2005) reported some of those properties for rapeseed (not variety). However, surface area, true density, angle of repose and fracture characteristics of rapeseed and their variations at various levels of moisture content have not been investigated. Knowing the moisture dependence is useful for further investigation on drying the seeds. Thus, the objective of this study was to investigate some moisture-dependent physical properties and fracture resistance of three varieties of rapeseeds (Capitol, Jetneuf, Samurai) typically cultivated in Turkey. The parameters measured at different moisture content were axial dimensions, mean diameters, sphericity, surface area, volume, thousand seed mass, bulk density, true density, porosity, terminal velocity, angle of repose, rupture strength and the static coefficients of friction on various surfaces as a function of moisture content. These data will determine the behaviour of the rapeseeds during processing.

MATERIALS AND METHODS

Dry mature rapeseeds (*Brassica napus oleifera* L. Cvs. Capitol, Jetneuf and Samurai) were used for all the experiments in this study. The seeds were grown in 2006-2007 growing season at the experimental farm of the Department of Field Crops in Agriculture Faculty of Uludag University. The seeds were cleaned in an air screen cleaner where all foreign matter such as dust, dirt, stones and chaff as well as immature and broken seeds was removed. The rapeseeds were transported in polypropylene bags and held at room temperature (20 to 25°C). The initial moisture content of the seeds was determined by following a standard oven method (ASAE, 1997) and was found to be 8.3, 7.7 and 7.3% d.b. for Capitol, Jetneuf and Samurai varieties, respectively.

The rapeseed samples at the desired moisture levels were prepared by adding calculating amounts of distilled water, through mixing and then sealing in separate plastic bags.

The samples were kept at 5°C in a refrigerator for at least a week to enable the moisture to distribute uniformly throughout the sample. Before starting a test, the required quantities of the seed were allowed to warm up to room temperature (Deshpande *et al*., 1993). All the physical properties of rapeseeds were measured at moisture levels (M_c) of 8.3, 15.9, 20.4 and 25.9% (d.b.) for Capitol; 7.7, 15.6, 21.3 and 27.4% for Jetneuf; and 7.3, 15.5, 21.7 and 26.4% for Samurai, with three replications at each level.

In order to determine the size of the seeds, three subsamples, each weighing 50 g, were randomly drawn from the bulk samples; from each of three 50 g sub-samples, 100 seeds were picked out and the 300 seeds thus obtained were mixed thoroughly. Finally, 100 seeds were randomly selected and labelled for easy identification. This method of random sampling was similar to the one followed by Gupta and Das (1997). For each individual seed, two principal dimensions, namely length (L) and diameter (D), were measured using a digital vernier calliper to an accuracy of 0.01 mm. The geometric mean diameter (D_g), sphericity (ϕ), surface area (A_s) and volume of seeds (V) were computed at different moisture content according to Kingsly *et al*. (2006) and Mohsenin (1970).

The mass of individual and thousand seed for cvs. Capitol, Jetneuf and Samurai were determined by using an electronic balance (MP-300 Chyo) weighing to an accuracy of 0.001 g.

Bulk density was obtained from formulas given by Akaaimo and Raji (2006) and Mohsenin (1970). A true density whereas according to Singh and Goswami (1996). The porosity and angle of repose were obtained from formulas given by Moshenin (1970) and Chowdhury *et al*. (2001), respectively.

The terminal velocity which kept the grain in suspension was recorded by a digital anemometer (Thies clima, Germany) having a least count of 0.1 m s^{-1} (Singh and Goswami, 1996; Suthar and Das, 1996).

To determine the rupture strength of rapeseeds, a biological material test device was used. The device was equipped with a load cell of 50 N capacities (Sundoo 50 SH Digital Push Pull Gauge).

The static coefficient of friction was obtained through the use of an inclinometer and 6 friction plates (aluminium, galvanized iron, glass, plywood, rubber and stainless steel) (Nimkar *et al*., 2005).

The results were processed by the MINITAB (Version 14, University of Texas, Austin, USA) and MS-Excel software programs. One way analysis of variance and LSD test MSTAT_C (Version 2.1., Michigan State University, MI, USA) software program were used to analyse the results. Differences were considered significant at $P<0.05$, unless otherwise specified.

RESULTS AND DISCUSSION

Average values of the length, diameter and geometric diameter sizes for three rapeseed varieties at different moisture contents are presented in Table 1. It shows that average length and diameter sizes increased with the increase in moisture content. For Capitol it increased from 2.46 to 2.57 mm and from 1.96 to 2.08 mm with an increase in moisture content from 8.3 to 25.9% d.b., for Jetneuf it increased from 2.26 to 2.36 mm and from 1.85 to 2.00 mm with an increase in moisture content from 7.7 to 27.4% d.b., and for Samurai it increased from 2.25 to 2.33 mm and from 1.82 to 1.98 mm with an increase in moisture content from 7.3 to 26.4% d.b., respectively. Differences between values are statistically

T a b l e 1. Geometric properties of three rape seed varieties (n=100) at various moisture contents

Varieties	M_c (% d.b.)	L (mm)	D (mm)	D_g (mm)	ϕ (%)	A_s (mm^2)	V (mm^3)
Capitol	8.3	2.46±0.20 b	1.96±0.11 c	2.11±0.13 c	86.1±2.86 ns	14.1±1.73 c	5.66±1.13 c
	15.9	2.50±0.21 ab	2.00±0.13 bc	2.16±0.14 bc	86.4±3.31 ns	14.7±1.94 bc	6.03±1.23 bc
	20.4	2.54±0.20 ab	2.04±0.12 ab	2.19±0.13 ab	86.5±3.15 ns	15.1±1.85 ab	6.27±1.21 ab
	25.9	2.57±0.21 a	2.08±0.12 a	2.23±0.13 a	86.8±3.97 ns	15.7±1.83 a	6.60±1.26 a
Jetneuf	7.7	2.26±0.16 b	1.85±0.13 c	1.98±0.12 c	87.4±3.48 b	12.3±1.53 c	4.56±0.84 c
	15.6	2.29±0.17 b	1.91±0.14 b	2.03±0.14 bc	88.7±2.77 ab	13.0±1.82 b	4.89±1.01 bc
	21.3	2.32±0.19 ab	1.96±0.11 a	2.07±0.12 ab	89.6±3.22 a	13.6±1.64 b	5.17±1.04 ab
	27.4	2.36±0.19 a	2.00±0.13 a	2.12±0.14 a	89.8±3.05 a	14.1±1.86 a	5.48±1.15 a
Samurai	7.3	2.25±0.16 b	1.82±0.13 c	1.96±0.13 c	86.8±3.61 b	12.1±1.58 c	4.45±0.88 c
	15.5	2.28±0.17 ab	1.91±0.14 b	2.03±0.14 b	89.1±3.13 a	12.9±1.75 b	4.85±0.98 b
	21.7	2.31±0.18 ab	1.95±0.12 ab	2.07±0.13 ab	89.6±2.74 a	13.5±1.70 ab	5.11±1.02 ab
	26.4	2.33±0.16 a	1.98±0.15 a	2.09±0.15 a	89.6±3.22 a	13.8±1.91 a	5.28±1.09 a

a, b, c, d – means superscript with different letters in the same column differ significantly (P<0.05), ns – not significant.

significant at P<0.05. The geometric mean diameters increased with the increase in moisture contents. In the case of Capitol, the geometric mean diameter increased from 2.11 to 2.23 with an increase in moisture content from 8.3 to 25.9% d.b., for Jetneuf it increased from 1.98 to 2.12 mm with an increase in moisture content from 7.7 to 27.4% d.b., and for Samurai it increased from 1.96 to 2.09 mm with an increase in moisture content from 7.3 to 26.4% d.b., respectively (P<0.05). According to Çalışır *et al*. (2005), the diameter and geometric diameter of rapeseed showed less association with its length.

The values of sphericity, surface area and seed volume of rapeseed varieties were calculated individually with Eqs (3), (4) and (5) by using the data on diameter and length of the seeds, and results obtained are presented in Table 1. The sphericity increased with the increase in moisture content for all other varieties except for Capitol (P<0.05). The results indicated that the values of sphericity for different moisture contents varied from 86.1 to 86.8% , 87.4 to 89.8% and 86.8 to 89.6% for Capitol, Jetneuf and Samurai seeds, respectively. The sphericity of the Capitol seed was found the lower than other varieties. As shown in the table, Capitol has a lower tendency to have its shape towards a sphere than cvs. Jetneuf and Samurai. At comparable moisture contents, the sphericity of Samurai with an increase in moisture content from 15.5 to 26.4% d.b was higher than at the moisture content of 7.3% d.b. The relationship between sphericity and moisture content of all the varieties is shown in Table 2. Similar trends have been reported by Deshpande *et al.* (1993) for soybean, Baryeh (2002) for millet, Sacilik *et al.* (2003) for hemp seed, and Baümler *et al*. (2006) for safflower. At comparable moisture contents, the sphericity of rapeseeds is higher than those of soybean and hemp seed, whereas, it is lower than that of millet.

T a b l e 2. Equation representing relationship between sphericity, surface area, seed volume and moisture content for different varieties of rape seed

Variety	M_c (% d.b.)	Equation	R^2
Capitol	8.3-25.9	ϕ = 85.686 + 0.0422 M_c	0.991
		A_s = 13.277 + 0.0907 M_c	0.997
		V = 5.2037 + 0.0532 M_c	0.997
Jetneuf	7.7-27.4	ϕ = 86.583 + 0.1263 M_c	0.930
		A_s = 11.581 + 0.0919 M_c	0.999
		V = 4.1846 + 0.0467 M_c	0.997
Samurai	7.3-26.4	ϕ = 86.158 + 0.1460 M_c	0.844
		A_s = 11.467 + 0.0893 M_c	0.988
		V = 4.1535 + 0.0433 M_c	0.996

The seed surface area increased linearly with increasing seed moisture content for all three varieties (Table 1). It increased from 14.1 to 15.7 mm^2 for Capitol, 12.3 to 14.1 mm^2 for Jetneuf, and 12.1 to 13.8 mm^2 for Samurai. The relationships between surface area and moisture content were significant (P<0.05) and were found to be as in Table 2. Similar trends have been reported by Deshpande *et al.* (1993) for soybean and by Sacilik *et al*. (2003) for hemp

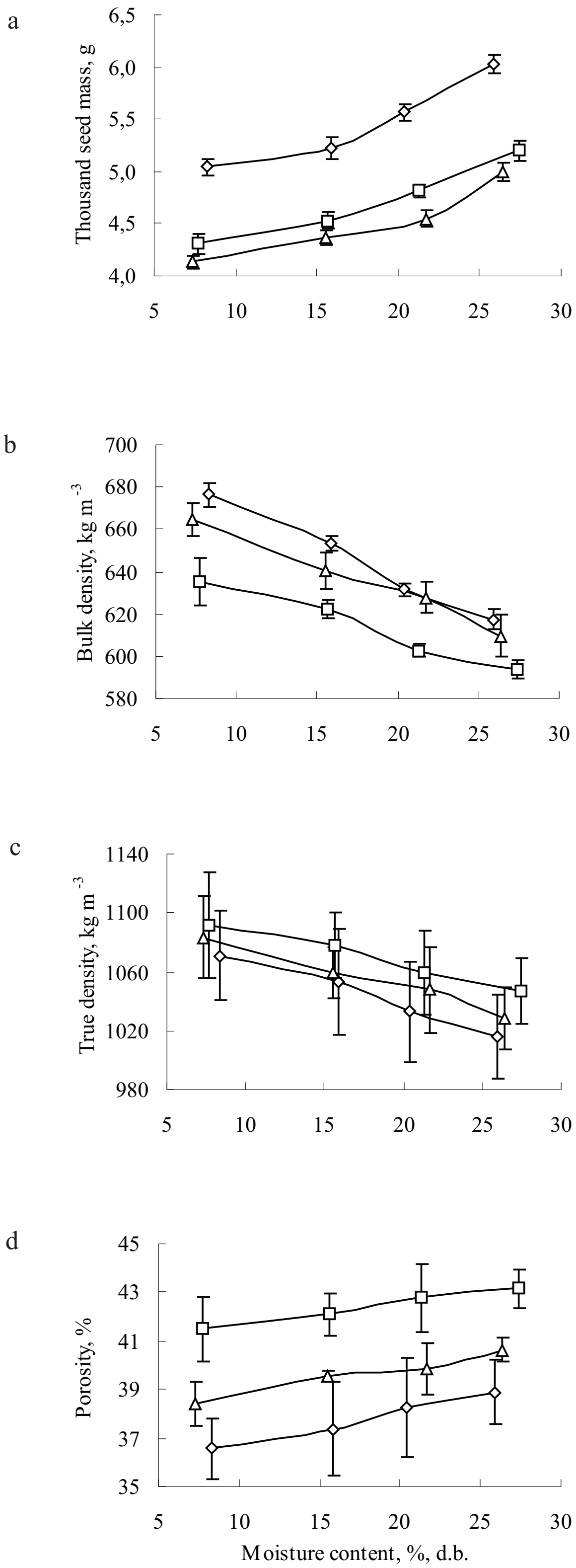

Fig. 1. Thousand seed mass (a), bulk density (b), true density (c) and porosity (d) of rapeseeds as a function of variety and moisture content: ◇ Capitol, □ Jetneuf, △ Samurai.

seed. In comparison with the above mentioned seeds, surface areas of rapeseed varieties were lower than those of soybean but higher than those of hemp seed.

The mean volumes for Capitol, Jetneuf and Samurai with moisture contents ranging from 8.3 to 25.9% d.b., from 7.7 to 27.4% d.b. and from 7.3 to 26.4% d.b., respectively, are presented in Table 1. Differences between the values are statistically significant at $P<0.05$. The volume of seeds increased linearly with the increase in moisture content. The volume of Capitol seed was from 5.66 to 6.60 mm^3 and it was higher than those of the Jetneuf and Samurai seeds which recorded from 4.56 to 5.48 and 4.45 to 5.28 mm^3, respectively. Increasing relationships were found between seed volumes and moisture contents. Seed volume was significantly correlated to moisture content of seeds (Table 2). Similar results have been observed by Deshpande *et al.* (1993) for soybean and by Nimkar *et al.*, (2005) for moth gram. At a moisture content of 8.3% d.b., the volume of Capitol (5.66 mm^3) was found to be smaller than moth gram (23.34 mm^3) and soybean (91 mm^3), whereas, it was found to be similar to that of millet (5.59 mm^3).

The thousand seed mass values of three rapeseed varieties at different moisture contents are presented in Fig. 1a. The thousand seed mass increased with the increase in moisture content for the three rapeseed varieties ($P<0.05$). The results indicated that thousand seed mass of the seeds increased from 5.04 to 6.03 g for Capitol, 4.31 to 5.20 g for Jetneuf, and 4.13 to 4.99 g for Samurai. Increasing relationships were found between thousand seed mass and moisture content. The change in thousand seed mass with moisture content can be represented by the equations shown in Table 3. Similar results of the effect of seed moisture on thousand seed mass have been reported for soybean (Deshpande *et al.*, 1993), guna seed (Aviara *et al.*, 1999), millet (Baryeh, 2002) and hemp seed (Sacilik *et al.*, 2003).

The variation of bulk density of different varieties of rapeseeds with moisture content is depicted in Fig. 1b. It can be seen that the bulk density decreased with increase in

T a b l e 3. Equation representing relationship between sphericity, surface area, seed volume and moisture content for different varieties of rape seed

Variety	M_c (% d.b.)	Equation	R^2
Capitol	8.3-25.9	$\phi = 85.686 + 0.0422\, M_c$	0.991
		$A_s = 13.277 + 0.0907\, M_c$	0.997
		$V = 5.2037 + 0.0532\, M_c$	0.997
Jetneuf	7.7-27.4	$\phi = 86.583 + 0.1263\, M_c$	0.930
		$A_s = 11.581 + 0.0919\, M_c$	0.999
		$V = 4.1846 + 0.0467\, M_c$	0.997
Samurai	7.3-26.4	$\phi = 86.158 + 0.1460\, M_c$	0.844
		$A_s = 11.467 + 0.0893\, M_c$	0.988
		$V = 4.1535 + 0.0433\, M_c$	0.996

moisture content. The variations in bulk densities with moisture content between varieties were significant (P<0.05). For Capitol it decreased from 676.3 to 617.4 kg m^{-3}, for Jetneuf it decreased from 635.0 to 593.6 kg m^{-3}, and for Samurai it increased from 664.8 to 609.7 kg m^{-3}. The decrease in bulk densities of rapeseed varieties may have resulted from increase in sizes with moisture content which gives rise to decrease in quantity of seeds occupying the same bulk volume. Also, the resistance of seeds to consolidation may have increased with moisture content as a result of increase in internal pressure. The bulk density decreased linearly as the seed moisture content increased for all three varieties, and it can be expressed by the relations shown in Table 3. A negative linear relationship of bulk density with moisture content was also observed by various research workers (Deshpande *et al*., 1993; Nimkar *et al*., 2005). Bulk densities of rapeseed varieties were compared with those of above literature and it was observed that the bulk densities of this study seeds at given moisture levels were lower than those of soybean (Deshpande *et al*., 1993), hemp seed (Sacilik *et al*., 2003) and moth gram (Nimkar *et al*., 2005), whereas, they were almost the same as those of safflower seed (Baümler *et al*., 2006) and guna seed (Aviara *et al*., 1999), and higher than rapeseed (Çalışır *et al*., 2005). These changes are probably due to the structural properties of the seeds.

The experimental results of the true density for rapeseed varieties at different moisture contents are also presented in Fig. 1c. For Capitol it decreased from 1 071.2 to 1 015.8 kg m^{-3}, for Jetneuf it decreased from 1 091.3 to 1 047.1 kg m^{-3} and for Samurai it increased from 1 083.1 to 1 028.4 kg m^{-3}. The true densities were not significantly different (P>0.05) among the rape seed varieties at different moisture contents. The decrease in true density values with increase in moisture content may be due to lower weight increase of seed in comparison with its volume expansion with moisture gain. Similar decreasing trends in true density have been observed by Sacilik *et al*., (2003) for hemp seed, Nimkar *et al*., (2005) for moth gram and Deshpande *et al*. (1993) for soybean. In comparison with the above mentioned seeds, for instance, at moisture content of 7.7% d.b., true densities of rape seed varieties were found to be lower than those of soybean (1 214.3 kg m^{-3}) and moth gram (1 372.2 kg m^{-3}), whereas, they were almost the same as those of hemp seed (1 054.3 kg m^{-3}) and higher than guna seed (854.9 kg m^{-3}). The relationships between true density and moisture content of all the varieties are shown in Table 3.

The porosities of rape seed varieties were found to increase linearly with the increase at different moisture contents as presented in Fig. 1d. Porosity increased with the increase in moisture content for all three rape seed varieties. It increased for Capitol from 36.6 to 38.9%, for Jetneuf it increased from 41.5 to 43.2%, and for Samurai it increased from 38.4 to 40.6%. While porosity of the Samurai variety was significantly different (P<0.05), the porosities of Capitol and Jetneuf varieties were not significantly different (P>0.05). The porosity of Jetneuf seed was found higher compared with Samurai and Capitol. Increase in moisture content may have caused a decrease in the cohesion of the bulk seed as a result of resistance to consolidation. Similar results of the effect of seed moisture on bulk porosity have been reported for gram (Chowdhury *et al*., 2001), guna seed (Aviara *et al*., 1999) and rape seed (Çalışır *et al*., 2005). Average bulk porosities of rape seed varieties (36.6% for Capitol, 41.5% for Jetneuf and 38.4% for Samurai) at initial moisture contents were found to be lower than rape seed (49.8%) while it was higher than gram (32.7%) and it was almost same as those of moth gram (37.1%) and guna seed (37.8%). Since the porosity depends on the bulk and true densities, the magnitude of variation in porosity depends on these densities only. The regression equations of porosity with moisture contents and R^2 are presented in Table 3.

The variation of the angle of repose of rape seeds with moisture content is presented in Table 4. As it can be seen, the angle of repose for Capitol, Jetneuf and Samurai varieties ranged from 21.37 to 26.81, 18.11 to 22.11 and 18.91 to 24.56° at moisture contents ranging from 8.3 to 25.9, 7.7 to 27.4 and 7.3 to 26.4% (d.b.), respectively. The greatest value of angle of repose was for Capitol, and then Samurai, while the lowest was obtained for Jetneuf. The lowest value for Jetneuf could be attributed to the higher sphericity allowing this to slide and roll over easily. The results of this research indicated that the angle of repose of varieties increased as the moisture content increased in the range studied. It can be stated that the angle of repose increased linearly with seed moisture content. Differences between values are statistically important at P<0.05. The volume of seeds increased linearly with the increase in moisture content. The regression constants for the linear regression are also presented in Table 5, together with the coefficient of determination for all three varieties. As it can be concluded, there were positive linear relationships with very high correlation (R^2) between the angle repose and moisture content for all rape seed varieties. The values for rape seed varieties are lower than those for cumin seed (Singh and Goswami, 1996) and millet (Baryeh, 2002), while higher than these for oilbean seed (Oje and Ugbor, 1991). Furthermore, the angles of repose of the seeds were found to be similar to those of hemp seed (Sacilik *et al*., 2003) and Prosopis africana seed (Akaaimo and Raji, 2006).

The experimental results for the terminal velocity of rape seed varieties were found to increase linearly with the increase in moisture contents as seen in Table 4. The terminal velocity increased with the increase in moisture content for the three rape seed varieties. It increased for Capitol from 3.61 to 3.77 m s^{-1}, for Jetneuf it increased from 3.49 to 3.66 m s^{-1} and for Samurai it increased from 3.44 to 3.52 m s^{-1}. The variations in terminal velocity of Capitol and

T a b l e 4. Angle repose, velocity and rupture properties of rape seeds (n=15) at different moisture contents

Varieties	M_c (% d.b.)	Angle of repose (°)	Terminal velocity (m s^{-1})	Rupture force (N)
Capitol	8.3	21.97 ± 0.62 d	3.61 ± 0.13 b	14.94 ± 2.31 a
	15.9	23.34 ± 0.53 c	3.66 ± 0.15 b	13.99 ± 2.32 ab
	20.4	24.76 ± 0.40 b	3.70 ± 0.11 ab	12.68 ± 2.06 bc
	25.9	26.81 ± 1.42 a	3.77 ± 0.16 a	11.61 ± 2.86 c
Jetneuf	7.7	18.22 ± 1.15 c	3.49 ± 0.12 c	13.21 ± 2.17 a
	15.6	19.73 ± 1.67 b	3.56 ± 0.11 bc	12.08 ± 3.67 ab
	21.3	20.17 ± 0.89 b	3.59 ± 0.11 ab	10.51 ± 3.34 b
	27.4	22.11 ± 0.71 a	3.66 ± 0.14 a	8.17 ± 2.82 c
Samurai	7.3	18.91 ± 1.05 d	3.44 ± 0.13 ns	11.71 ± 2.87 a
	15.5	20.26 ± 0.99 c	3.47 ± 0.15 ns	10.37 ± 1.97 ab
	21.7	22.79 ± 0.46 b	3.50 ± 0.10 ns	9.50 ± 1.58 b
	26.4	24.56 ± 0.91 a	3.52 ± 0.16 ns	8.02 ± 1.12 c

Explanations as in Table 1.

T a b l e 5. Equation representing relationship between angle of repose (θ, degree), terminal velocity (V_t, m s^{-1}), rupture force (F_r, N) and moisture content for different varieties of rape seed

Variety	M_c (% d.b.)	Equation	R^2
Capitol	8.3-25.9	$\theta = 19.401 + 0.2734\, M_c$	0.968
		$V_t = 3.5281 + 0.0088\, M_c$	0.972
		$F_r = 16.718 - 0.1937\, M_c$	0.974
Jetneuf	7.7-27.4	$\theta = 16.697 + 0.1866\, M_c$	0.954
		$V_t = 3.4170 + 0.0087\, M_c$	0.985
		$F_r = 15.567 - 0.2542\, M_c$	0.951
Samurai	7.3-26.4	$\theta = 16.308 + 0.3002\, M_c$	0.960
		$V_t = 3.3997 + 0.0046\, M_c$	0.996
		$F_r = 13.169 - 0.1845\, M_c$	0.972

Jetneuf seeds at the different moisture contents were significant at a significance level of 0.05, but it was not significant for Samurai. At any moisture level, the terminal velocities for three rape seed varieties were found to be greater than those of sunflower seed hulls (Gupta and Das, 1997) and much lower than those of cotton seed (Özarslan, 2002) and quinoa seed (Vilche *et al*., 2003). However, the values were found to be similar to rape seed (Çalışır *et al*., 2005) and cumin seed (Singh and Goswami, 1996). Therefore, pneumatic equipment should be designed to handle the seed at low moisture contents to reduce energy input. The increase in terminal velocity with increase in moisture content can be attributed to the increase in mass of an individual seed per unit frontal area presented to the air stream. The relationships between terminal velocity and moisture content of all the varieties are shown in Table 5.

The rupture forces decreased with an increase in moisture content for Capitol, Jetneuf and Samurai (Table 4). It decreased from 14.94 to 11.61 N for Capitol, 13.21 to 8.17 N for Jetneuf and 11.71 to 8.02 N for Samurai. The small rupturing forces at higher moisture content might have resulted from the fact that the seed tended to be very brittle at high moisture content. The differences between rupture strength values of rape seed varieties at different moisture contents have been found to be statistically significant (P<0.05). Also, applying forces in different varieties found to be statistically significant. In rape seed varieties, the force applied for Capitol was the highest and it was followed by the one applied for Jetneuf and Samurai. This difference may be attributed to the physical properties of the rape seed varieties. The results are similar to those reported by Özarslan (2002) for cotton seed and Baümler *et al*. (2006) for safflower seed. The regression equation obtained for predicting the rupture force for rape seed varieties as a function of moisture content are given in Table 5. It can be found that there were negative linear relotionships of rupture force with moisture content.

Experimental data of static coefficient of friction for rape seeds on frictional surfaces of stainless steel, aluminium, glass, galvanized iron, plywood and rubber at various moisture levels are presented against moisture content as shown in Table 6. It was observed that the static coeffecient of friction for each rape seed variety on the six structual surfaces increased as the moisture content increased. The highest static coefficient of friction was obtained on the rubber surface, followed by plywood, galvanized iron, glass, aluminium, and finally stainless steel surface. This

T a b l e 6. Mean coefficients of static friction of rapeseeds (n=10) at different moisture contents

Varieties	M_c (% d.b.)	Surface					
		Stainless steel	Aluminium	Glass	Galvanized iron	Plywood	Rubber
Capitol	8.3	0.285±0.014 D b	0.295±0.024 CD c	0.308±0.011 BC b	0.314±0.026 BC c	0.317±0.026 AB c	0.325±0.018 A b
	15.9	0.304±0.021 C b	0.308±0.017 BC bc	0.310±0.018 BC b	0.319±0.021 ABC bc	0.325±0.030 AB bc	0.339±0.029 A b
	20.4	0.310±0.025 B ab	0.315±0.014 B b	0.319±0.020 B b	0.339±0.018 A ab	0.348±0.024 A ab	0.354±0.027 A ab
	25.9	0.331±0.038 C a	0.335±0.026 BC a	0.337±0.031 BC a	0.358±0.035 AB a	0.360±0.020 AB a	0.370±0.025 A a
Jetneuf	7.7	0.246±0.024 B ns	0.248±0.020 B ns	0.249±0.015 B ns	0.251±0.014 B b	0.255±0.020 B b	0.257±0.013 A b
	15.6	0.248±0.025 B ns	0.251±0.014 B ns	0.253±0.017 B ns	0.257±0.016 AB ab	0.261±0.028 AB b	0.268±0.020 A b
	21.3	0.249±0.020 B ns	0.264±0.032 AB ns	0.255±0.027 AB ns	0.264±0.017 AB ab	0.272±0.032 AB b	0.277±0.018 A ab
	27.4	0.257±0.020 B ns	0.272±0.021 B ns	0.261±0.020 B ns	0.274±0.028 B a	0.295±0.034 A a	0.304±0.033 A a
Samurai	7.3	0.233±0.014 B b	0.237±0.025 AB b	0.242±0.013 AB b	0.244±0.023 AB b	0.248±0.014 A c	0.249±0.020 A b
	15.5	0.238±0.023 B ab	0.246±0.012 AB ab	0.257±0.025 A ab	0.246±0.017 AB ab	0.259±0.020 A bc	0.257±0.020 A ab
	21.7	0.240±0.022 A ab	0.248±0.014 AB ab	0.259±0.033 AB ab	0.270±0.022 A a	0.268±0.022 A ab	0.270±0.026 A ab
	26.4	0.251±0.016 B a	0.261±0.024 AB a	0.272±0.015 AB a	0.272±0.036 AB a	0.276±0.024 A a	0.278±0.029 A a

Means fallowed by the same letter between rows (a, b, c, d) and between columns (A, B, C, D) within each variety are not significantly different at 5% level, ns – not significant.

T a b l e 7. Regression relationships between coefficient of static friction (μ) of rapeseed varieties and moisture content

Surface	Capitol	R^2	Jetneuf	R^2	Samurai	R^2
Stainless steel	$\mu = 0.2630 + 0.0025 M_c$	0.971	$\mu = 0.2404 + 0.0005 M_c$	0.836	$\mu = 0.2252 + 0.0009 M_c$	0.855
Aluminium	$\mu = 0.2739 + 0.0022 M_c$	0.961	$\mu = 0.2353 + 0.0013 M_c$	0.930	$\mu = 0.2274 + 0.0011 M_c$	0.892
Glass	$\mu = 0.2897 + 0.0016 M_c$	0.825	$\mu = 0.2447 + 0.0005 M_c$	0.959	$\mu = 0.2320 + 0.0140 M_c$	0.936
Galvanized iron	$\mu = 0.2867 + 0.0026 M_c$	0.899	$\mu = 0.2409 + 0.0011 M_c$	0.968	$\mu = 0.2281 + 0.0017 M_c$	0.836
Plywood	$\mu = 0.2925 + 0.0026 M_c$	0.921	$\mu = 0.2352 + 0.0020 M_c$	0.885	$\mu = 0.2365 + 0.0015 M_c$	0.999
Rubber	$\mu = 0.3013 + 0.0026 M_c$	0.981	$\mu = 0.2352 + 0.0023 Mc$	0.914	$\mu = 0.2367 + 0.0015 M_c$	0.970

trend is due to the roughness of the surfaces, which in the case of stainless steel, with its smoothness and polished surface, revealed the minimum friction value. As can be also seen from Table 6, the highest friction on all fictional surfaces at all moisture levels was offered by the Capitol variety. As the moisture content of three varieties increased, the static coefficient of friction increased linearly. The reason for the increased friction coefficient at higher moisture content may be owing to the water present in the varieties offering a cohesive force on the surface of contact. This variety was followed by Jetneuf and Samurai, in that order. As moisture content of Capitol increases, the surfaces of the samples become stickier. Water tends to adhere to surfaces and the water on the moist Jetneuf and Samurai surfaces would be attracted to the surface across which the sample is being moved. The regression constants for the linear regression are also presented in Table 7, together with the coefficient of determination for all three varieties. As it can be concluded, there were positive linear reletionships with very high correlation (R^2) between static coeffecient of friction and moisture content for all rape seed varieties. The static coeffecients of friction of the three varieties were found to be significant on the all structural surfaces according to moisture contents ($P<0.05$). In addition, while Capitol and Samurai varieties were found significant statically different as regards structural surfaces at each moisture content, Jetneuf was not found important for stainless stell, aluminium and glass surfaces. Other researchers found that as the moisture content increased, the static coefficient of friction increased also (Baryeh, 2002; Çalışır *et al*., 2005).

CONCLUSIONS

1. It is evidenced that the increase in moisture content of rape seeds linearly increased the axial dimensions, geometric mean diameters, surface areas, volumes, sphericities, porosity, terminal velocities, angles of repose and static frictions of coefficient on six structural surfaces, while it decreased the bulk and true densities and rupture forces.

2. The results also showed that these parameters vary from variety to variety. Among the varieties, Capitol had the highest values of geometric properties. The maximum values of true density and porosity among the varieties were obtained for Jetneuf seeds, while it had lowest bulk density. Samurai seed had the second highest bulk and true density, and porosity. The maximum and minimum values for angle of repose were obtained for Capitol and Jetneuf. Furthermore, maximum values for terminal velocity and rupture force among the varieties were obtained for Capitol, then Jetneuf, and finally Samurai seeds.

3. At all moisture contents, rubber showed the highest friction coefficient, followed by plywood, galvanized iron, glass, aluminium, and finally stainless steel. The friction coefficients of Capitol were significantly higher than those for the other two varieties. The increase in friction coefficient with moisture content was the largest for Capitol seed on rubber surface, followed by Jetneuf and Samurai on rubber surface, respectively. Samurai variety had the lowest friction on all frictional surfaces at all moisture levels. The lowest coefficient of friction (0.244) was at 26.4 % moisture content for the Samurai variety on the stainless steel surface.

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