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Physical properties characteristic of Polish and Canadian lentil seeds

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A b s t r a c t. The physical properties of the Polish variety of lentil seed, Tina and the Canadian variety, Laird Lentil (the most popular variety imported into Poland) were compared. The parameters of individual seeds (size distribution, mass per 1000 seeds) and the parameters of bulk seed (the bulk density, the porosity, the angle of internal friction, the wall friction coefficient and the pressure ratio) of both varieties were compared for the moisture content of the seed within the range 9 to 21%. The seeds of the Canadian variety were found to be shapelier than the seeds of the Polish variety. The different swelling characteristics observed between the two varieties can be attributed to the different anatomical structures of the seed coating /husk/ in the two varieties. The seed coating of the Polish variety is rougher than that of the Canadian variety. Microscope photos of cross-sections of the seeds indicated that the seed coat of the Canadian variety is approximately twice as thin as the Polish variety. The concentration of papillary cells on the surface of the seed coat is higher in the case of the Canadian variety which produces a smoother surface than does the Polish variety. The mechanical properties of bulk seed were similar for both varieties.

K e y w o r d s: lentil seeds, geometrical parameters, bulk density, porosity, friction coefficient, pressure ratio

INTRODUCTION

The lentil (*Lens culinaris* Medic.) is one of the oldest plants to be cultivated by man. Its high nutritional value was known in ancient times. It is also the oldest plant – besides the pea – with high protein content to be cultivated in Poland (Chorąży, 1988; Piróg, 1995). As agricultural intensification occurred, the lentil was systematically ignored. Negligence in growing it was additionally a negative factor. The last two decades can be called the New Age of the lentil on a world scale; witness the high increase in production, the development of fundamental and applied research in the most famous research centres in Canada (University of Saskatchewan), the USA (Washington State University) and other countries as well as breeding new fruitful varieties. Biochemical and applied research have confirmed the high nutritional and taste quality of lentil seeds. These advantages have resulted in placing the lentil on the world's list of healthy foods. Some medicinal properties of the lentil have also been demonstrated (Bhatty, 1980; Chorąży, 1988; Piróg, 1995). The lentil has been promoted as a leading leguminous crop. Lentil seeds are rich in cellulose, carbohydrate compounds and folic acid, are low in calories, low in fat and are cholesterol free (Troszczyńska *et al*., 1993). Recently, the lentil has been the focus of interest in Poland. Fundamental breeding research (Milczak *et al*., 1991; Milczak, 1996) and culinary studies have been published (Carper, 1995; 1996; Dębski and Dębska, 1989). The first Polish lentil variety, the Tina was registered in 1998, the second one, the Anita in 1999.

The revival of the lentil leads to an extension of the study of the other properties of the lentil which can be useful in characterizing seeds for technological processes. One of them is the physical property which is strongly influenced by moisture content. Therefore, it seems useful to supplement knowledge about the physical properties of this plant. Such a study of the Polish varieties of lentil seeds was started by Szot *et al*. (1998). The study was later extended to some other properties by Szot and Rudko (2000), Dobrzański and Szot (2001), and Szot and Stępniewski (2001a, 2001b).

The object of this study was to determine the characteristics of the physical properties of the most popular Polish and Canadian varieties of lentil seed to support engineers engaged in storage, handling and processing in the basic parameters of the material.

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MATERIALS AND METHOD

Tests were performed on the Polish and Canadian varieties of lentil seeds. The variety Tina is the first Polish variety registered in 1998. This variety was cultivated in an experimental field of the Institute of Agrophysics in Lublin and originated from qualified seed produced by the Horticulture Breeding and Seed Production Company, Nochowo. The variety, Laird Lentil is the most popular imported variety in Poland and originates from Canada.

The physical properties of the selected seeds were performed for moisture contents of 9, 12, 15, 18 and 21± 0.2% w.b. For obtaining higher levels of moisture content, samples of seed were moistened according to the procedure elaborated in the Institute of Agrophysics in Lublin (Szot and Woźniak, 1980). Frictional properties and the pressure ratio were determined for the moisture content of the seed at 9% w.b.

The thickness and width of the seeds was determined applying the specially adopted slide caliper with an accuracy of 0.01 mm. Samples of 300 dry seeds were tested to obtain size distribution. For higher moisture content, samples of 60 seeds were tested.

The 1000 seed mass was determined using the LN-S-50A seed counter. The non-compacted bulk density was determined according to Polish Standard PN R-74007.

Porosity was determined with the prototype air picnometer (Szot and Woźniak, 1974). Ten replications of porosity measurement were performed for each level of moisture content.

The angle of internal friction was determined in a Jenike (1961) shear tester with a diameter of 210 mm. The sample was consolidated under normal stress reference σ_n of 100 kPa. The standardized twisting of the top plate of the shear box was applied to consolidate the sample (Eurocode 1, 1996). Next, the samples were sheared at normal stress σ_n of 20, 40, 60, 80 and 100 kPa after pre-loading to the reference stress. Maximum shear stress τ (developed before the horizontal displacement of 10% of the shear box diameter had been attained) was used to calculate the angle of internal friction. The displacement velocity was equal to 0.35 mm s^{-1}. The angle of internal friction φ and cohesion c was determined from the relationship:

$$\tau = \sigma_n tg\varphi + c. \quad (1)$$

The pressure ratio was determined in a uniaxial compression tester 0.21 m having a diameter according to the general guideline of the Eurocode 1 standard (1996). The height of the seed layer to the chamber diameter was 0.4. The experimental set allowed the mean lateral pressure σ_x to be determined, the mean vertical pressure σ_z on the bottom, and the mean vertical pressure σ_{zo} on the top plate (Horabik and Molenda, 2000). The sample was poured into the test chamber through a centrally located spout, without vibration or other compacting action. The specimen was loaded to the reference normal stress of 100 kPa using a universal loading frame with a constant displacement rate of 0.35 mm min^{-1}. The top plate was rotated backwards and forwards three times through an angle of 10 to consolidate the sample. Next the sample was reloaded to the reference vertical stress, and slope of the lateral to the vertical pressure increase was determined. Pressure ratio k_s appropriate for filling and storing was determined as (Eurocode 1, 1996):

$$k_s = 1.1\ k_{so}, \quad (2)$$

where:

$$k_{so}=\Delta\sigma_x/\Delta\sigma_{zm} \quad (3)$$

at the reference vertical stress $\sigma_{zm} = (\sigma_z + \sigma_{zo})/2 =$ 100 kPa.

The pressure ratio was determined also from empirical formula relating pressure ratio k_φ to the angle of internal friction φ Eurocode 1 (1996):

$$k_\varphi = 1.1\ (1 - \sin\varphi). \quad (4)$$

The coefficient of wall friction μ (for pressures evaluation in the silo) was determined for three wall materials: smooth galvanized steel, smooth stainless steel and concrete B 30 treated as the reference silo wall materials (Eurocode 1, 1996). Tests were performed in a Jenike shear tester substituting the lower part of the measuring cell with the wall materials tested. Tests were performed under normal stress equal to 20, 30, 40, 50 and 60 kPa corresponding to the average horizontal pressure in the silo.

The angle of wall friction φ_w (for flow evaluation) against three tested wall materials was measured with the tilting table method (Molenda *et al*., 2000). A square 20 cm seed compartment was placed on the test surface, filled with seeds and a loaded plate was placed on the free surface of the seed. The clearance between the frame and the test surface was maintained throughout the tests to eliminate frictional interaction. The table was tilted slowly using a screw mechanism and the angle at which the samples started sliding was treated as the angle of wall friction φ_w. Test were performed at low pressure (in the range 0–2.5 kPa) corresponding to the pressures occurring during discharge near the outlet of the silo.

Three replications of the friction and the pressure ratio tests were performed.

RESULTS

Lentil seeds have a characteristic shape similar to a biconvex lens. Therefore, two characteristic dimensions were considered: thickness and width (diameter) to describe the shape of the seeds. For a moisture content of about 9% (the air dry state of the seeds) both varieties had the same thickness 2.47 mm (Table 1). The range of variability of the thickness was 1.91–2.98 and 1.77–2.99 mm for the Laird Lentil and the Tina variety, respectively. The width of the two tested varieties was different. The Laird Lentil variety had a mean width of 6.15 mm (min. 5.1 and max. 7.04 mm) while the Tina variety had a mean width of 5.6 mm (min. 4.46 and max. 6.45 mm). Distributions of the thickness and width (300 replications of measurement) confirmed the difference in dimensions of both varieties (Figs 1 and 2).

With a moisture content increase from 9 to 21% the thickness of the lentil seed variety Laird Lentil increased from 2.47 to 2.80 mm (13%) while the thickness of the Tina variety increased only 4% (from 2.47 to 2.57 mm). Increase in the width of the both varieties was similar: 6% – for the Tina and 8% for the Laird Lentil variety (Table 1). The difference in the swelling characteristics observed in the two varieties can be attributed to the different anatomical structure of the seed coat of the two varieties. The relatively low level of coefficients of variability (4.6–8.9%) indicates the good equalization of seed size.

The seeds of the Canadian variety (Laird Lentil) are shapelier than those of the Polish variety Tina. With a moisture content equal to 9%, the mass of 1000 seeds of the Canadian variety was considerably higher (64.27 g) than the mass of the Polish variety (46.52 g). The mass of 1000 seeds, increased linearly with the moisture content increase and with a moisture content of 21% reached 72.73 g for the Canadian variety and 58.48 g for the Polish variety (Table 2).

With a moisture content of 9%, the bulk density of the Laird Lentil variety equal to 791.0 kg m^{-3} was 1% higher than that of the Tina variety. With the moisture content increase the bulk density decreased faster in the case of the Laird Lentil variety. Consequently, for a moisture content of 21% the bulk density of the Laird Lentil variety was 2.2% less than that of the Tina variety.

T a b l e 1. Geometrical characteristics of the Polish (Tina) and the Canadian (Laird Lentil) varieties of lentil seeds as influenced by moisture content

Variety	Moisture content w.b. (%)	Thickness (mm)				Width (mm)			
		Mean	Min.	Max.	Variability (%)	Mean	Min.	Max.	Variability (%)
Tina	9	2.47	1.77	2.99	8.91	5.60	4.46	6.45	6.64
	12	2.51	1.95	2.86	7.41	5.64	4.92	6.27	5.96
	15	2.60	2.05	2.92	8.09	5.77	5.00	6.62	6.93
	18	2.61	2.15	2.75	5.78	5.76	5.33	6.67	5.01
	21	2.57	2.25	2.80	4.88	5.93	5.46	6.56	4.63
Laird Lentil	9	2.47	1.91	2.98	8.62	6.15	5.10	7.04	6.37
	12	2.58	2.10	3.00	7.27	6.46	5.63	7.31	6.39
	15	2.60	2.13	2.96	7.49	6.62	5.67	7.56	5.72
	18	2.66	2.20	3.18	8.31	6.61	5.55	7.55	7.31
	21	2.80	2.25	3.28	7.92	6.63	5.70	7.50	6.14

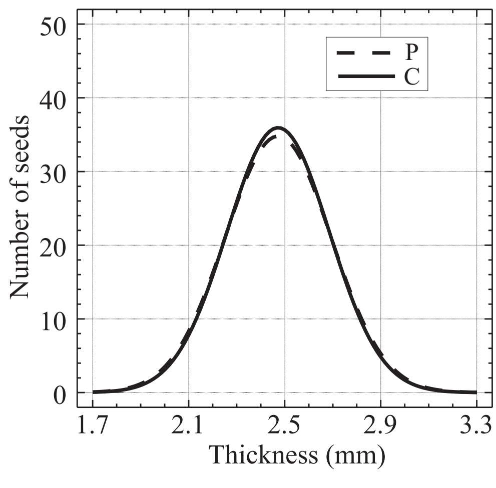


Fig. 1. Thickness of distribution of the Polish (P) and the Canadian (C) varieties of lentil seeds.

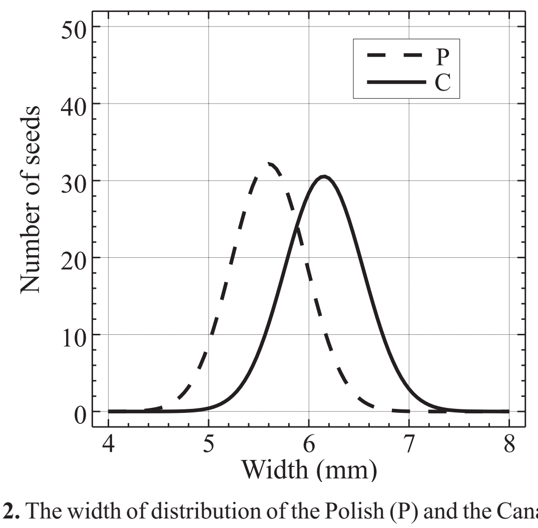


Fig. 2. The width of distribution of the Polish (P) and the Canadian (C) varieties of lentil seeds.

Table 2. Characteristics of the basic physical properties of the Polish (Tina) and the Canadian (Laird Lentil) varieties of lentil seeds as influenced by moisture content

Moisture content w.b. (%)	Tina				Laird Lentil			
	Mass of 1000 seeds (g)	Bulk density (kg m^{-3})	Porosity (%)	Angle of repose (°)	Mass of 1000 seeds (g)	Bulk density (kg m^{-3})	Porosity (%)	Angle of repose (°)
9	46.52	783.0	45.7	31	64.27	791.0	50.3	28
12	51.62	784.0	46.9	28	68.39	779.0	47.9	27
15	53.89	762.0	46.9	28	68.96	775.0	48.0	28
18	57.69	752.5	47.3	26	71.29	754.5	49.6	26
21	58.48	747.0	47.8	26	72.73	731.0	50.2	26

The influence of the moisture content on porosity was different for both varieties. Porosity in the Tina variety was equal to 45.7% at a moisture content of 9%. With the increase in moisture content, porosity increased to 47.8%, with a moisture content of 21%. In the case of the Laird Lentil variety, initial porosity (50.3%) determined at a moisture content of 9% decreased to 48% with a moisture content of 12 and 15% and then increased again to 50.2% with a moisture content of 21%. At all levels of moisture content, the porosity of the Laird Lentil variety was higher than the Tina variety.

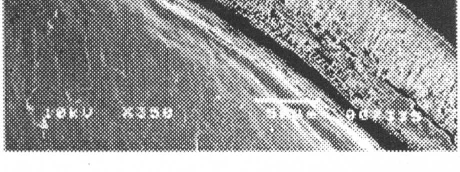
The seed coat of the Polish variety is rougher than that of the Canadian variety. The difference is more visible for lower levels of moisture contents. The reason is the difference in the thickness of the seed coat and the different anatomical structure. The scanning microscope photos of the cross-sections of the seeds indicated that the seed coat of the Canadian variety is approximately twice as thin as the Polish variety (Figs 3a and b). The concentration of the papillary cells on the seed coat surface is bigger in the case of the Canadian variety which produces a smoother surface than does the Polish variety (Figs 4a and b). Dobrzański and Szot (2001) analysing microscopy photographs of lentil seed coats indicated that the concentration of the papillary cells influences the ability to absorb moisture.

The angle of natural repose of the Tina variety was 31° and of the Laird Lentil variety 28°. With the increase in the moisture content of the seed, the angle of natural repose decreased to 26° in both varieties.

The values of the pressure ratio were similar for both varieties (Table 3). The values of pressure ratio k_s determined in the uniaxial compression test (0.56–0.57) belong to the region typical for cereal grain (Eurocode 1, 1996). Pressure ratio k_φ calculated from the empirical formula (0.8–0.82) recommended is significantly larger than the experimental values as a result of the relatively low values of the angle of internal friction of the lentil seed (14–15°) as compared to the angle of internal friction of cereal grain (20–25°) (Horabik and Molenda 2002).

The wall friction coefficient obtained in the Jenike shear tester was influenced by the wall material and normal stress. The values of friction against the concrete ranged from 0.26 to 0.28 and were larger than the friction coefficient against the galvanized and stainless steel by about 25%. The wall friction coefficient decreased with the normal stress increase in the case of the galvanized and stainless steel and increased in the case of the concrete (Fig. 5). The friction coefficient against the galvanized and stainless steel was larger for the Canadian variety than for the Polish variety.

a



b

Fig. 3. Microscope photographs of cross-sections of the Polish (a) and Canadian (b) varieties of lentil seeds.

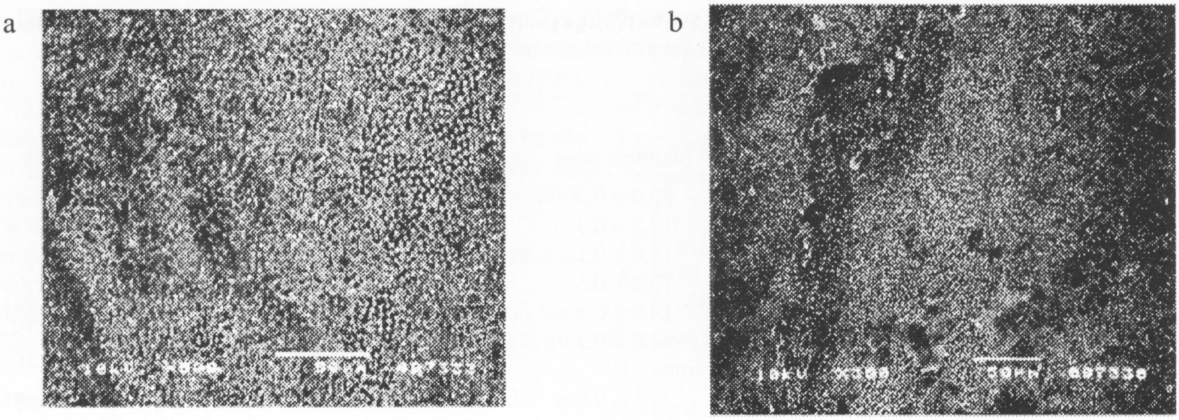


Fig. 4. Microscope photograph of the seed coat of the Polish (a) and Canadian (b) varieties of lentil seeds.

T a b l e 3. Measured (k_s) and calculated (k_φ) values of the pressure ratio, the angle of internal friction φ and cohesion c (mean ± st.dev.) of the Polish (Tina) and the Canadian (Laird Lentil) varieties of lentil seeds with a moisture content of 9% w.b.

Variety	Pressure ratio		Angle of internal friction φ (°)	Cohesion c (kPa)
	k_s	k_φ		
Tina	0.56±0.01	0.82±0.02	14.3±0.4	2.1±0.6
Laird Lentil	0.57±0.01	0.80±0.02	15.5±0.6	2.3±0.8

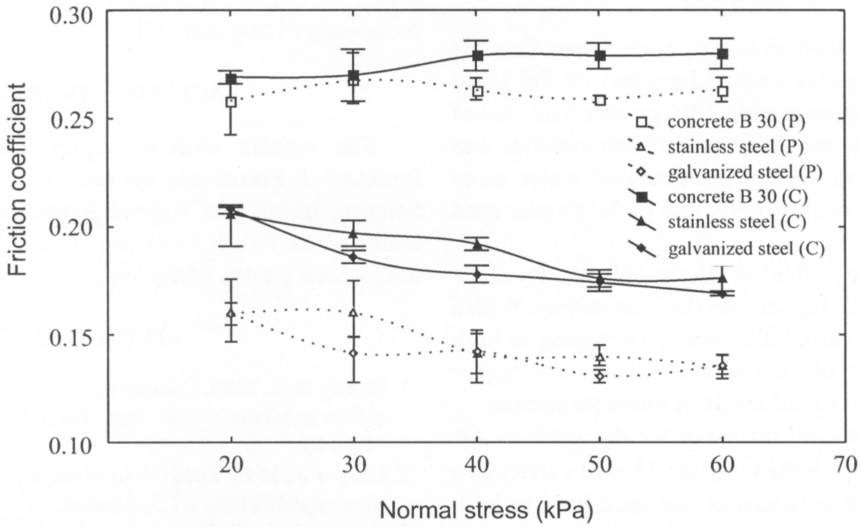


Fig. 5. The wall friction coefficient of the Polish (P) and Canadian (C) varieties of lentil seeds against concrete B 30, stainless steel and galvanized steel under the influence of normal stress.

The angle of wall friction was largest for the stainless steel surface (21°) in the case of the lowest normal stress (Table 4) and then decreased and was almost constant with the increase in pressure. Additionally in the case of the rough surface of the concrete, the angle of friction was largest for the lowest normal stress but then increased with an increase in normal stress. The friction coefficient corresponding to the angle of wall friction determined by tilting the table ($\mu = \tan \varphi_w$) was significantly higher than the friction coefficient determined in the Jenike shear tester for the galvanized steel and the stainless steel and similar for the concrete. The relation between the friction coefficient and

T a b l e 4. The angle of wall friction φ_w (mean ± st.dev.) of the Polish (Tina) and the Canadian (Laird Lentil) varieties of lentil seeds against stainless steel, galvanized steel and concrete B 30 determined at a moisture content of 9 % w.b.

Variety	Normal stress (kPa)	Angle of wall friction φ_w (°)		
		Stainless steel	Galvanized steel	Concrete B 30
Tina	0	20.9 ± 0.3	16.7 ± 0.3	19.5 ± 0.3
	0.5	14.2 ± 0.3	15.5 ± 0.3	15.3 ± 0.3
	1.0	13.6 ± 0.1	15.0 ± 0.1	16.7 ± 0.3
	1.5	13.9 ± 0.3	15.7 ± 0.3	16.8 ± 0.1
	2.1	14.0 ± 0.1	15.4 ± 0.1	18.7 ± 0.5
	2.5	14.0 ± 0.1	15.4 ± 0.1	19.0 ± 0.3
Laird Lentil	0	20.3 ± 0.3	16.2 ± 0.3	19.8 ±0.3
	0.5	15.4 ± 0.1	14.5 ± 0.1	14.2 ± 0.6
	1.0	13.6 ± 0.1	13.6 ± 0.1	14.4 ± 0.1
	1.5	14.5 ± 0.5	14.0 ± 0.1	14.5 ± 0.5
	2.1	15.4 ± 0.1	13.9 ± 0.3	15.6 ± 1.0
	2.5	15.4 ± 0.1	14.6 ± 0.1	17.0 ± 0.6

normal stress is attributed to the less than proportional increase in the normal and tangent stresses at any single contact area of the grain with the wall surface with an increase in normal load. To explain the influence of the range of normal stress and the roughness of the surfaces tested on the friction coefficient, two components of friction resistance should be taken into account: adhesion and the deformation of asperities (Molenda *et al*., 1995).

CONCLUSIONS

1. Seeds of the Canadian variety were larger than the Polish variety. The mean width (diameter) of the Laird Lentil variety was approximately 10% greater than that of the Tina variety while the thickness of both varieties was similar. The Canadian variety accumulated water more readily than did the Polish variety, due to the thinner seed coat.

2. With a moisture content of 9%, the bulk density of the Laird Lentil variety was higher than the Tina variety. With a moisture content increase, bulk density decreased in both varieties. The porosity of the Canadian variety was higher than the Polish variety for all levels of moisture content.

3. The angle of natural repose of the dry seeds of the Tina variety was 3 higher than the Laird Lentil variety as a result of the different structure of the seed coat in both varieties.

4. The pressure ratio, the angle of internal friction and cohesion was similar in both varieties. The pressure ratio calculated from the recommended empirical formula was significantly higher than had been determined in the uniaxial compression test.

5. The friction coefficient against the concrete was higher than for that against the galvanized and stainless steel plates for both varieties. In the case of the galvanized and stainless steel, the friction coefficient decreased with normal stress increase and was higher for the Laird Lentil seeds. Consequently, the friction coefficient against galvanized and stainless steel determined in the tilting table was higher than had been determined in the Jenike tester.

6. Values of physical parameters were similar for both varieties (the pressure ratio, the angle of internal friction, the wall friction coefficient) and different for both varieties (seed dimensions, the mass of 1000 seeds, the porosity, the density, the angle of natural repose) and provide information useful for engineers engaged in the storage, handling and processing of this material.

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