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Moisture-dependent physical properties and biochemical composition of red lentil seeds

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Abstract. Determination of the physical and chemical properties of red lentil seed showed that the physical properties of red lentil were significantly affected by moisture content. The red lentil seeds were especially rich in protein (25.9%) and starch (40.51%). The amount of K, P, Ca and Na were 1 024, 341, 170.3 and 65 mg 100 g^{-1} of dry matter, respectively. The major fatty acids in the red lentil oil were linoleic, followed by oleic, palmitic and linolenic acids.

Keywords: lentil seeds, physical properties, nutritional properties, post-harvest processing

INTRODUCTION

Lentil (*Lens culinaris* Medic.) is one of the oldest cultivated plants. Its high nutritional value was known in ancient times. It is also the oldest high-protein-content plant – besides the pea – to be cultivated in Iran. Lentils are an important cool-season legume crop grown extensively in Canada, India, Turkey, the USA and Australia. World lentil production was 4.15 mln t in 2005-2006 onsisting of 70% red, 25% green and 5% brown or other colours. Canada is the largest lentil producer (1.3 mln t), followed by India (1 mln t). Also, after Turkey, Canada is the second-largest lentil-exporting country (70% of its total lentil production), sending its production to Europe, the Middle East, Africa, South and North America as well as Asia. Canada and the USA are the main producers of green lentils, whereas other countries mainly produce red lentils. The nutritional and cooking quality characteristics of food legumes are very important from the consumer point of view. In terms of nutritional quality, proteins, limiting amino acids, calcium, iron and vitamins, food legumes are of great significance because of their complementary effects on 80 cereal-based diets. Lentils comparatively shorter cooking time and lower anti-nutritional factors than the most other food legumes make them more suitable for human consumption (Wang and Daun, 2006).

The knowledge of morphology and size distribution and their dependence on the moisture content of lentil seeds is essential for accurate design of the equipment for cleaning, grading and separation. Gravimetric properties are important in the design of equipment related to aeration, drying, storage and transport. Bulk density determines the capacity of storage and transport systems, while true density is useful for separation equipment; porosity of the mass of seeds determines the resistance to air flow during aeration and drying of seeds. The frictional properties such as the angle of repose and the coefficient of external friction are recognized by engineers as important properties concerned with rational design of seed bins and other storage structures, including the compressibility and flow behaviour of materials (Gharibzahedi *et al*., 2010).

The aim of this work was to study the effects of moisture content on some physical properties of red lentil seeds and their biochemical compositions.

MATERIALS AND METHODS

The red lentil seeds were obtained during June-July, 2008, and kept in cooled bags during transportation to the laboratory. They were cleaned in an air screen cleaner to remove all foreign materials such as dust, dirt and chaff, as well as immature and damaged seeds. The initial moisture content of the seeds, as brought from the market, was determined by drying samples in a hot air oven set at 105°C

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(±1°C) for 24 h and was found to be 9.5% w.b. The drying conditions were decided based on preliminary studies and in reference to ASAE standards S352.3 (ASAE, 1994). The lentil samples at the desired moisture levels were prepared by adding calculated amounts of distilled water, through mixing and then sealing in separate plastic bags. The samples were kept at 5°C (±1°C) in a refrigerator for 7 days 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 (Gharibzahedi *et al.,* 2010). All the physical properties of red lentil were investigated at moisture levels of 9.5, 13.2, 16.8, 19.17 and 21.1% w.b. Every test was repeated ten times to determine mean values.

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 digital vernier caliper with an accuracy of 0.01 mm. The arithmetic (D_a) and geometric (D_g) mean diameter, sphericity (ϕ) and surface area (S) of red lentil seed were calculated according to Mohsenin (1986). Thousand seeds mass (m_{1000}) was determined by means of an electronic balance reading to an accuracy of 0.001 g. Bulk density (ρ_b) is the ratio of grain mass to the volume of the sample container. The true density (ρ_t) was determined using the toluene displacement method (Mohsenin, 1986). The porosity (ε) of the bulk grain was computed from the values of the true and bulk density of the seeds by using the relationship given by Mohsenin (1986). The angle of repose (α) was determined by the method applied by Tabatabaeefar (2003). The coefficients of static friction (μ) of the samples against three different surfaces, namely, plywood, glass and stainless steel, were determined according to the technique introduced by Gharibzahedi *et al.* (2010).

In order to determine total ash, samples were kept in an oven at 525°C until they became total ash, then weighed (AOAC, 1990). Total protein was determined by the Kjeldahl method. Protein was calculated using a nitrogen conversion factor of 6.25 (AOAC, 1990). Crude fat was determined by the Soxhlet method. The starch was determined colorimetrically (AACC, 2000). Acid detergent fibre (ADF) and neutral detergent fibre (NDF) were determined according to the Ankom Technology method (1998) using the Ankom fibre analyzer. Samples were wet-digested in a mixture of nitric and perchloride acids [(HNO_3: $HClO_4$ (4:1)]. Potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu) and sodium (Na) concentrations in the digest were determined using an atomic absorption spectrophotometer (Perkin-Elmer® Model 2380) (Gharibzahedi *et al*., 2009). The amounts of minerals were calculated with a standard curve. Phosphorus (P) was measured using a UV-visible spectrophotometer (Spectronic Genesys^{TM} 10, GENEQ Inc., Montreal, Canada) at 430 nm wavelength and comparing the results to the standard curve (Gharibzahedi *et al*., 2009).

In order to evaluate the fatty-acid composition of lentil oil, a 30 m × 0.22 mm, 0.25 μm film fused-silica capillary column DB-23 was connected to a Varian 3400 gas chromatograph (Palo Alto, CA, USA) equipped with a flame ionisation detector (FID) and a split/splitless injector. Helium was used as the carrier gas at a velocity of 23 cm s^{-1}, and as the make-up gas at a rate of 30 ml min^{-1}. The oven temperature was programmed from 140°C (0 min) at 7°C min^{-1}, to 215°C (81.29 min). The fatty acid methyl ester (FAME) dissolved in hexane was injected (1 μl) in a split mode of injection at a split ratio of 40:1. The injector and detector temperatures were 250 and 290°C, respectively (AOAC, 1997). A Varian 4270 integrator was used for recording the peak areas. No response factors were applied in calculating fatty-acid composition, since the GC temperature program showed almost equal responses for different FAME standard mixtures.

RESULTS AND DISCUSSION

The three axial dimensions increased with moisture content (Table 1). The increase is attributed to expansion or swelling as a result of moisture uptake in the intracellular spaces within the seeds. The length, width and thickness of seeds ranged from 4.07 to 4.13 mm (1.47%), 3.93 to 3.99 mm (1.50%) and 2.32 to 2.38 mm (2.58%), the arithmetic and geometric mean diameters increased from 3.44 to 3.50 and 3.33 to 3.39 mm, respectively.

Table 1. Means and standard errors of the axial dimensions of red lentil seeds at different moisture contents

Moisture (% w.b.)	Axial dimension (mm)			Average diameter (mm)	
	L	W	T	D_a	D_g
9.5	4.07 ± 0.052a	3.93 ± 0.013a	2.32 ± 0.031a	3.44a	3.33a
13.2	4.09 ± 0.053b	3.95 ± 0.022b	2.34 ± 0.063b	3.46b	3.35b
16.8	4.10 ± 0.049b	3.97 ± 0.049b	2.35 ± 0.042b	3.47b	3.37c
19.7	4.11 ± 0.057c	3.98 ± 0.029c	2.37 ± 0.030c	3.48c	3.38c
21.1	4.13 ± 0.057d	3.99 ± 0.091c	2.38 ± 0.016c	3.50d	3.39d

Values in the same columns followed by different letters (a-d) are significant ($p<0.05$).

Table 2 gives the mean values for each investigated physical property at the initial and final moisture content, the linear relationships between the physical characteristics of red lentil seed and moisture content and their coefficient of determination (R^2) values.

The one thousand seed mass increased linearly from 51.2 to 51.8 g (1.17%) as the moisture content increased from 9.5 to 21.1% w.b. ($p>0.05$). This parameter is useful in determining the equivalent diameter that can be used in the theoretical estimation of seed volume and in cleaning using aerodynamic forces. Similar to these observations, an increase in the m_{1000} as the seed moisture content increases has been noted by Sacilik *et al*. (2003) for hemp seed and Cagatay Selvi *et al*. (2006) for linseed. Lentil-seed sphericity increased from 81.85 to 82.16%. Similar trends have been reported by Sacilik *et al*. (2003) for hemp seed and Gharibzhedi *et al.* (2009) for sesame seed. The surface area of the lentil seed increased from 34.84 to 36.15 mm^2. Similar increases have been reported by Sacilik *et al*. (2003) and Gharibzahedi *et al.* (2010) for hemp seed and black cumin, respectively. The bulk density decreased from 822.2 to 718.5 kg m^{-3} as the moisture content increased. The decrease in bulk density with increase in moisture content shows that the increase in mass resulting from the moisture gain of the sample is lower than the accompanying volumetric expansion of the bulk. The negative linear relationship of bulk density with moisture content has been observed for other products (Gharibzahedi *et al*., 2009, 2010; Cagaty Selvi *et al.*, 2006). The true density varied from 1 320 to 1 223 kg m^{-3}. The increase in true density might be attributed to the relatively lower true volume as compared to the corresponding mass of the seed after adsorption of water. The results were similar to those reported by Sacilik *et al.* (2003) for hemp seed. The seed porosity increased from 37.71 to 41.86% with the increase in moisture content. This could be attributed to the expansion and swelling of seeds that might have resulted in more voids between the seeds and increased bulk volume. This is also exhibited in the reduction of bulk density with increase in moisture content. Similarly, for cumin seeds, Singh and Goswami (1996) stated that as the moisture content increased so did the porosity value. As the moisture content increased, the terminal velocity was found to increase linearly from 9.54 to 10.05 m s^{-1}. The increase in terminal velocity with an increase in moisture content within the range studied can be attributed to the increase in mass of an individual seed per unit frontal area presented to the air stream. Linear increases in terminal velocity with an increase in moisture content have been reported by Singh and Goswami (1996) for cumin seeds and by Sacilik *et al.* (2003) for hemp seeds. The angle of repose increased from 27.12 to 27.91° in the moisture range of 5.9 to 21.1% w.b. ($p<0.05$). At higher moisture content seeds might tend to stick together due to the plasticity effect (stickiness) over the surface of the seeds, resulting in better stability and less flowability, thereby increasing the angle of repose. The angle of repose is of paramount importance in designing hopper openings, sidewall slopes of storage bins and chutes for bulk transporting of seeds (Gharibzahedi *et al.,* 2009). Therefore, seed moisture content should be taken into account while designing transport and storage equipment. Singh and Goswami

T a b l e 2. Linear relationships between the physical parameters of red lentil seed and moisture content, their coefficient of determination (R^2) values and their mean value at the initial and final moisture content

Physical properties	Value[a]		Equations	R^2
	A	B		
One thousand seed mass (g)	51.2	51.8	$m_{1000}=50.72 + 0.050\ Mc$	0.994
Sphericity (%)	81.85	82.16	$\phi = 81.57 + 0.031\ Mc$	0.976
Surface area (mm^2)	34.84	36.15	$S = 33.83 + 0.106\ Mc$	0.986
Bulk density (kg m^{-3})	822.25	718.5	$\rho_b = 907.9 - 8.812\ Mc$	0.987
True density (kg m^{-3})	1320	1223	$\rho_t = 1368 - 6.292\ Mc$	0.954
Porosity (%)	37.71	41.86	$\varepsilon = 34.36 + 0.358\ Mc$	0.993
Terminal velocity (m s^{-1})	9.54	10.05	$V_t = 9.134 + 0.041\ Mc$	0.970
Angle of repose (°)	27.12	27.91	$\alpha = 26.49 + 0.063\ Mc$	0.967
		Static coefficient of friction		
Stainless steel	0.324	0.339	$\mu = 0.311 + 0.001\ Mc$	0.984
Plywood	0.286	0.298	$\mu = 0.275 + 0.001\ Mc$	0.982
Glass	0.236	0.245	$\mu = 0.228 + 0.001\ Mc$	0.963

[a] A-B are mean value for each studied physical property in the initial and final moisture content, respectively.

(1996) and Sacilik *et al.* (2003) reported a linear increase in the angle of repose with an increase in the moisture content for cumin and hemp seeds, respectively.

The coefficient of static friction increased with an increase in moisture content on all surfaces. This is due to the increased adhesion between the seed and the surface at higher moisture values. Also, Gharibzahedi *et al.* (2009) reported that as the moisture content increased, so did the coefficient of static friction. At all moisture contents, the coefficient of static friction was the greatest against stainless steel (0.324 to 0.339), followed by plywood (0.286 to 0.298) and glass (0.236 to 0.245).

Table 3 shows some details of the chemical composition of red lentil seeds, including dry matter, ash, protein, nitrogen and other mineral contents. Dry matter content, ash and nitrogen were 93.72, 3.62, and 4.144%, respectively. Total protein (N × 6.25) and fat were found to be 25.9 and 2.7%, respectively. In general, the fat content of red lentil seeds varies due to differences in species and environmental factors. Starch, acid detergent fibre (ADF) and neutral detergent fibre (NDF) were 40.51, 5.6, and 8.2%, respectively.

Table 3 also presents the mineral content of red lentil seeds, expressed as mg 100 g^{-1} of dry matter. The mean mineral content for K, P, Ca, and Na were 1 024, 341, 170.3 and 65 mg 100 g^{-1} of dry matter, respectively. Potassium was the most abundant element, followed by phosphorus and calcium. The other elements, in descending order by quantity, were Fe, Mg, Cu, Zn and Mn (6.6 ± 0.35, 4.62 ± 0.66, 4.62 ± 0.23, 4.2 ± 0.11 and 1.62 ± 0.21 mg 100 g^{-1} of dry matter). Therefore, red lentil seeds are especially rich in protein, starch and minerals. The presence of various mineral nutrients such as K, Ca, Mg, P, Fe, Zn, Mn and Cu are of biochemical importance to the physiology of the seeds. In addition, they are an essential part of many important enzymes and play roles as catalysts and antioxidants.

Table 3 also shows the mean values and standard deviations of the red lentil seed fatty-acid composition. The major fatty acids found in lentil oil are linoleic (46.81%), oleic (23.27%), palmitic (12.04%) and linolenic (11.25%) acids. The ratios of these fatty acids are considered important for nutrition. Other fatty acids detected in the samples were stearic, gadoleic, arachidic, erucic and palmitooleic acids, at 1.14, 0.66, 0.16 and 0.04%, respectively. Fatty-acid analysis allowed the estimation of the different nutritional fractions: saturated fatty acids (SFAs) and polyunsaturated fatty acids (PUFAs). PUFAs, due to the high content of linoleic acid, were the main component of total fat extracted from the red lentils, with values higher than 58.06% of total fat. SFAs content were the minor group, with values lower than 16% (Table 3). The amounts of fatty acids in red lentils found in this study were similar to the values reported by Ryan *et al.* (2007).

Table 3. Proximate chemical, mineral and fatty acid compositions of red lentil seeds

Parameters	Value[a]
Dry matter (%)	93.72 ± 0.20
Ash[b]	3.62 ± 0.44
Fat[b]	2.70 ± 0.31
Starch[b]	40.51 ± 1.06
ADF[b,c]	5.60 ± 0.45
NDF[b,c]	8.20 ± 0.30
Crude protein[b]	25.90 ± 0.14
Minerals[d]	
P	341 ± 11.46
Ca	170 ± 8.20
K	1 024 ± 0.44
Mg	4.62 ± 0.66
Cu	4.62 ± 0.23
Zn	4.20 ± 0.11
Mn	1.62 ± 0.21
Fe	6.60 ± 0.35
Na	65.00 ± 0.44
Fatty acids	
Palmitic (C16:0)	14.41 ± 1.20
Palmitooleic (C16:1)	0.08 ± 0.01
Stearic (C18:0)	1.14 ± 0.04
Oleic (C18:1)	23.27 ± 1.05
Linoleic (C18:2)	46.81 ± 0.09
Linolenic (C18:3)	11.25 ± 0.82
Arachidic acid (C20:0)	0.39 ± 0.02
Gadoleic (C20:1)	0.66 ± 0.03
Erucic acid (C22:1)	0.16 ± 0.01
P	58.06 ± 0.34
U	80.23 ± 0.74
S	15.94 ± 1.22
P/S	3.64 ± 0.09
U/S	5.03 ± 0.17

[a]Mean value ± (standard deviation), n = 3; [b]% d.b.; [c]ADF = acid detergent fibre, and NDF = neutral detergent fibre; [d]mg 100 g^{-1} (d.b), protein = N × 6.25; N ≈ 4.144); S – saturated fatty acid (C16:0 + C8:0 + C20:0); P – polyunsaturated fatty acid (C18:2 + C18:3); U – unsaturated fatty acid (C16:1 + C18:1 + C18:2 + C18:3+ C20:1+ C22:1).

CONCLUSIONS

1. The geometric mean diameter, sphericity, porosity, angle of repose, terminal velocity and coefficient of static friction on all surfaces of red lentil seeds increased significantly in the moisture range from 9.5-21.1% w.b., while the bulk and true density decreased significantly with moisture increasing.

2. Nutritional properties showed that potassium was the predominant mineral of red lentil seed, and major fatty acid in the red lentil oil was linoleic acid.

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