

## Aerodynamic properties of lentil seeds

*Feizollah Shahbazi*<sup>1\*</sup>, *Saman Valizadeh*<sup>1</sup>, *Ali Dowlatshah*<sup>1</sup>, and *Ezatollah Hassanzadeh*<sup>2</sup>

<sup>1</sup>Department of Biosystems Engineering, Lorestan University, Khorramabad, Iran

<sup>2</sup>Technical and Vocational University, Branch of Khorram abad, Iran

Received August 4, 2014; accepted May 12, 2015

**A b s t r a c t.** Aerodynamic properties of solid materials have long been used to convey and separate seeds and grains during post-harvest operations. The objective of this study was evaluation of the aerodynamic properties of green and red lentil seeds as a function of moisture content from 10 to 25% (w.b.). The results showed that as the moisture content increased from 10 to 25%, the terminal velocity of seeds increased, following a linear relationship, from 6.90 to 9.14 and from 6.37 to 7.67 m s<sup>-1</sup> for green and red lentil seeds, respectively. Seeds of the green variety had terminal velocities with a mean value of 7.89 m s<sup>-1</sup>, while the red variety had a mean value of 7.02 m s<sup>-1</sup>, for moisture content from 10 to 25%. The Reynolds number increased linearly from 2 310.90 to 3 269.23 and from 1 215.02 to 1 535.09 for green and red lentil seeds, respectively, with the increase of seeds moisture content from 10 to 25%. While, drag coefficient decreased from 0.69 to 0.40 and from 0.84 to 0.69 for green and red lentil seeds, respectively, with the increase of moisture content. Mathematical relationships were developed to relate the change in seeds moisture content with the values of aerodynamic properties obtained. The analysis of variance showed that the effect of moisture content on all aerodynamic properties of lentil beans was significant at the 1% probability level.

**K e y w o r d s:** aerodynamic properties, separation, post-harvest operation, lentil seed

### INTRODUCTION

Lentil (*Lens culinaris* L.) is a high protein (22-34%) pulse crop used primarily for direct human consumption (Amin *et al.*, 2004). It is best adapted to the cooler temperate zones of the world, or the winter season in the Mediterranean climates. Split lentil (dhal) is an important source of dietary protein in the Mediterranean and south Asian regions. Lentil seed size is classified in two types: Chilean/large-seeded (greater than 50 g per 1 000 seeds)

and Persian/small-seeded (45 g or less per 1 000 seeds). The two main market classes are green and red. To design equipment and facilities for handling, processing and storing lentils their physical properties such as aerodynamic characteristics must be known.

The knowledge of the aerodynamic characteristics of grains (terminal velocity, drag coefficient) is significant for the design and operation of machines which treat substances with air flow and in all cases when substances are moved in the air (Shahbazi *et al.*, 2014). The behaviour of particles in an air stream during pneumatic conveying and separation greatly depends on their aerodynamic properties. The aerodynamic forces which exist during relative motion between the air and the materials act differently on different particles. Separation of a mixture of particles in a vertical air stream is only possible when the aerodynamic characteristics of the particles are so different that the light particles are entrained in the air stream and the heavy particles fall through it. When an air stream is used for separating a product such as lentil seed from its associated foreign materials, such as straw and chaff, knowledge of aerodynamic characteristics of all the particles involved is necessary. This helps to define the range of air velocities for effective separation of the grain from the foreign materials. For this reason, the terminal velocity has been used as an important aerodynamic characteristic of materials in such applications as pneumatic conveying and their separation from foreign materials (Mohsenin, 1978). Several investigators determined the aerodynamic properties of various seeds such as cheat seed by Hauhouot *et al.* (2000), different varieties of rice, corn, wheat and barley by Matouk *et al.* (2005), pine nuts by Ozguven and Vursavus

\*Corresponding author e-mail: shahbazi.f@lu.ac.ir

(2005), wheat kernel by Khoshtaghaza and Mehdizadeh (2006), makhana by Jha and Kachru (2007), *Turgenia latifolia* seeds and wheat kernels by Nalbandi *et al.* (2010), and Wild mustard by Shahbazi (2013).

Information about the aerodynamic properties of lentil seeds is limited. The moisture content of seeds such as lentil can strongly influence their aerodynamic characteristics and movements in agricultural machines as well as in the air. Hence, the objective of this study was to investigate the aerodynamic properties of green and red lentil seeds as a function of moisture content. Tests were conducted over a range of moisture contents from 10 to 25% w.b., which spans the moisture range of harvest to the post-harvest operations.

#### MATERIALS AND METHODS

The green and red lentil seeds used for the present study were obtained from a field in the Lorestan University that were cultivated in the same conditions, in 2014 cultivation season. After attaining optimum maturity, samples of the seeds were harvested by hand and cleaned in an air screen cleaner. The initial moisture content of green and red lentil seeds was 8.5% and 8.9% (w.b.), respectively, determined with ASAE S352.2 (ASAE, 1988). Higher moisture content samples were prepared by adding calculated amounts of distilled water, then sealing in polyethylene bags, and storing at 5°C for 15 days. Samples were warmed to room temperature before each test and moisture content was verified. Sample mass was recorded with a digital electronic balance having an accuracy of 0.001 g. The major dimensions of the seeds ( $L$ ,  $W$  and  $T$ ) were measured using a digital caliper with an accuracy of  $\pm 0.01$  mm (Gupta *et al.*, 2007). The true density of the seeds was measured using the toluene displacement method (Mohsenin, 1978).

To determine the terminal velocity value of lentil seeds, a vertical wind tunnel was designed, constructed and used. A centrifugal fan powered by 0.75 kW motor was used in the inlet of the wind tunnel to supply airflow. The airflow rate of the fan was controlled at the inlet and adjusted by changing the velocity of the electric motor through an inverter set. The final section of the wind tunnel consisted of a Plexiglas region where the terminal velocity of seeds was measured. To determine the terminal velocity, each seed was placed in the centre of the cross section of the wind tunnel on the screen. The airflow was then increased until the seed flotation point. At that moment, when the rotational movement of the seed was the lowest, the air velocity was measured using a hot-wire anemometer with an accuracy of  $0.1 \text{ m s}^{-1}$ . The terminal velocity of each seed was measured two times. For each condition the terminal velocity was calculated as the average of the velocity values obtained at the centre of the test section and at four equidistantly distributed points on two orthogonal axes located at the test section. To determine the terminal

velocity at each moisture content level, ten seeds were selected and used as ten replications in the statistical analysis. The values of air density and viscosity were taken as  $1.206 \text{ kg m}^{-3}$  and  $1.816 \times 10^{-5} \text{ N s m}^{-2}$ , respectively, at room temperature of 20°C. In free fall, an object will attain constant terminal velocity ( $V_t$ ) at which the net gravitational accelerating force ( $F_g$ ) equals the resisting upward drag force ( $F_r$ ) under the condition that the terminal velocity has been achieved at an air velocity which is equal to the terminal velocity ( $V_t$ ). Substituting for  $F_g$  and  $F_r$ , the expression for terminal velocity will be as follows (Mohsenin, 1978):

$$V_t = \sqrt{\frac{2mg(\rho_p - \rho_f)}{\rho_p \rho_f A_p C_d}}, \quad (1)$$

In addition, the drag coefficient can be derived as follows:

$$C_d = \frac{2mg(\rho_p - \rho_f)}{\rho_p \rho_f A_p V_t^2}, \quad (2)$$

$$A_p = \frac{\pi}{4} LW, \quad (3)$$

where:  $A_p$  is projection area of the particle ( $\text{m}^2$ ),  $C_d$  is drag coefficient (decimal),  $g$  is acceleration due to gravity ( $9.81 \text{ m s}^{-2}$ ),  $L$  is seed length (m),  $m$  is mass of seeds (kg),  $V_t$  is terminal velocity ( $\text{m s}^{-1}$ ),  $W$  is seed width (m),  $\rho_f$  is density of air ( $1.2059 \text{ kg m}^{-3}$ ),  $\rho_p$  is density of seeds ( $\text{kg m}^{-3}$ ).

In this study Reynolds number ( $Re$ ) was calculated using the terminal velocity of each seed sample. Reynolds number (dimensionless) equations include a velocity term using the following relationship (Mohsenin, 1978):

$$Re = \frac{\rho_f V_t D_g}{\mu}, \quad (4)$$

$$D_g = (LWT)^{1/3}, \quad (5)$$

where:  $D_g$  is geometric mean diameter of seeds (m),  $T$  is seed thickness (m),  $\mu$  is air viscosity at room temperature ( $1.816 \times 10^{-5} \text{ N s m}^{-2}$ ). In this study, the effects of lentil seed variety (green and red) and moisture content (10, 12.5, 15, 17.5, 20 and 25%, wet basis) on the terminal velocity, drag coefficient and Reynolds number of seeds were studied. The tests were conducted over a range of moisture contents from 10 to 25% which spans the moisture range of harvest to the processing operations. The factorial experiment was conducted as a randomised design with three replicates. For each test, 10 seeds were selected randomly from each sample and tested by using the airflow device. The comparison of mean values of the factors was carried out at 5% probability level. The terminal velocity, drag coefficient, Reynolds number and the moisture content data of different lentil seed varieties were fitted to linear, power, exponential and polynomial models. The models were evaluated according to the statistical criterion  $R^2$  and RMS (root mean square

error) for verifying the adequacy of fit. The best model with the highest  $R^2$  and RMS below 0.05 was selected to predict the terminal velocity, drag coefficient and Reynolds number of seeds as a function of the moisture content. Data were analyzed by SPSS 17 software.

#### RESULTS AND DISCUSSION

The average values of dimensions, projected area and true density of green and red lentil seeds at different moisture contents are presented in Table 1. The analysis of variance showed that there was a significant difference between the terminal velocity of lentil seeds of the green and red lentil varieties. Also the effect of seed moisture content on this property was significant (Table 2). The terminal velocity for the green variety was observed to be higher than those obtained for the red variety. Seeds of the green variety had terminal velocities with a mean value of  $7.89 \text{ m s}^{-1}$ , at different moisture contents of 10 to 25%, while the seeds of the red variety had a mean value of  $7.02 \text{ m s}^{-1}$ . This result can be explained by the fact that the seeds of the green variety were bigger than those of the red variety. Since the square of terminal velocity is directly related to particle size and shape, it follows that larger particles of similar shape need higher terminal velocities than smaller ones. Similar results were obtained by Kahrs

**Table 2.** Analysis of variance of the data of the aerodynamic properties of lentil seeds

| Source of variation  | df  | Mean squares      |                  |                       |
|----------------------|-----|-------------------|------------------|-----------------------|
|                      |     | Terminal velocity | Drag coefficient | Reynolds number       |
| Lentil variety (L)   | 1   | 6.899*            | 0.418*           | $1.66 \times 10^{7*}$ |
| Moisture content (M) | 5   | 2.707*            | 0.043*           | $3.49 \times 10^{5*}$ |
| L×M                  | 5   | 0.234*            | 0.006*           | $9.58 \times 10^{4*}$ |
| Error                | 108 | 0.005             | 0.001            | 274.55                |

\*Significant difference at 1% probability level, df – degree of freedom.

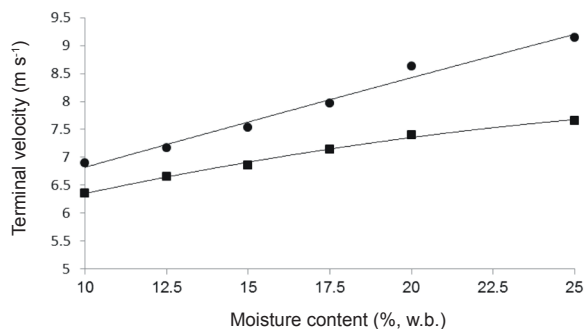
(1994) on three fractions of wheat seeds. Wheat seeds  $> 2.8 \text{ mm}$  had mean terminal velocity of  $8.8 \text{ m s}^{-1}$  while the fraction  $< 2 \text{ mm}$  had mean terminal velocity of  $6.4 \text{ m s}^{-1}$ . The terminal velocity of lentil seeds increased with increasing moisture content (Table 1).

The terminal velocity of lentil seeds of the green and red lentil varieties increased from  $6.90$  to  $9.14 \text{ m s}^{-1}$  and from  $6.36$  to  $7.67 \text{ m s}^{-1}$ , respectively, as the moisture

**Table 1.** Average values of dimensions, projected area, geometric mean diameter, true density and terminal velocity of lentil seeds at different moisture contents

| Moisture content (%) | Length (mm)  | Width (mm)  | Thickness (mm) | Projected area ( $\text{mm}^2$ ) | Geometric mean diameter (mm) | True density ( $\text{kg m}^{-3}$ ) | Terminal velocity ( $\text{m s}^{-1}$ ) |
|----------------------|--------------|-------------|----------------|----------------------------------|------------------------------|-------------------------------------|---|
| Green variety        |              |             |                |                                  |                              |                                     |   |
| 10                   | 6.58 (0.24)* | 6.47 (0.32) | 3.23 (0.17)    | 32.94 (1.23)                     | 5.14 (0.12)                  | 1293.61 (13.23)                     | 6.90 (0.21)                             |
| 12.5                 | 6.49 (0.31)  | 6.48 (0.31) | 3.24 (0.18)    | 33.04 (1.32)                     | 5.15 (0.11)                  | 1280.45 (12.45)                     | 7.16 (0.13)                             |
| 15                   | 6.49 (0.25)  | 6.54 (0.27) | 3.27 (0.12)    | 33.80 (1.24)                     | 5.20 (0.13)                  | 1267.31 (14.09)                     | 7.53 (0.11)                             |
| 17.5                 | 6.69 (0.26)  | 6.68 (0.20) | 3.34 (0.90)    | 35.11 (1.330)                    | 5.31 (0.09)                  | 1254.15 (13.12)                     | 7.97 (0.15)                             |
| 20                   | 6.89 (0.16)  | 6.77 (0.22) | 4.08 (0.12)    | 36.17 (0.81)                     | 5.38 (0.08)                  | 1235.12 (9.13)                      | 8.63 (0.19)                             |
| 25                   | 6.81 (0.24)  | 6.88 (0.18) | 4.14 (0.13)    | 37.22 (0.92)                     | 5.47 (0.07)                  | 1209.72 (10.43)                     | 9.14 (0.18)                             |
| Red variety          |              |             |                |                                  |                              |                                     |   |
| 10                   | 4.23 (0.11)  | 3.45 (0.12) | 1.82 (0.07)    | 11.45 (0.93)                     | 2.93 (0.06)                  | 1273.61 (10.13)                     | 6.36 (0.09)                             |
| 12.5                 | 4.24 (0.13)  | 3.45 (0.13) | 1.93 (0.09)    | 11.48 (1.02)                     | 2.94 (0.04)                  | 1260.45 (11.16)                     | 6.66 (0.11)                             |
| 15                   | 4.24 (0.09)  | 3.45 (0.12) | 1.93 (0.08)    | 11.509 (1.01)                    | 2.94 (0.05)                  | 1247.31 (10.12)                     | 6.86 (0.10)                             |
| 17.5                 | 4.27 (0.08)  | 3.46 (0.15) | 2.18 (0.09)    | 11.57 (1.04)                     | 2.944 (0.07)                 | 1234.15 (9.83)                      | 7.14 (0.13)                             |
| 20                   | 4.31 (0.08)  | 3.50 (0.14) | 2.25 (0.09)    | 11.85 (1.10)                     | 2.98 (0.08)                  | 1221.17 (13.10)                     | 7.40 (0.11)                             |
| 25                   | 4.44 (0.12)  | 3.62 (0.16) | 2.42 (0.08)    | 12.60 (1.12)                     | 3.07 (0.09)                  | 1194.72 (12.32)                     | 7.67 (0.14)                             |

\*Standard deviation.



**Fig. 1.** Terminal velocity of lentil seed variation versus seed moisture content: ● green variety, ■ red variety.

content of seeds increased from 10 to 25% (Fig. 1). The maximum terminal velocity value ( $9.14 \text{ m s}^{-1}$ ) was obtained in the green variety at moisture content of 25% and the minimum amount ( $6.36 \text{ m s}^{-1}$ ) was obtained in the red variety at moisture content of 10%. These results are in agreement with published literature reports for some seeds. Gupta *et al.* (2007) showed that in the moisture range of 6 to 14% d.b. the terminal velocity of NSFH-36, PSF-118 and Hybrid SH-3322 variety of sunflower seed increased from 2.93 to 3.28, from 2.54 to 3.04, and from 2.98 to  $3.53 \text{ m s}^{-1}$ , respectively. Zewdu (2007) measured the terminal velocity of Tef grains. He reported that it increased linearly from 3.08 to  $3.96 \text{ m s}^{-1}$  with increasing moisture content from 6.5 to 30.1% w.b. Hauhouot *et al.* (2000) showed that the mean value of terminal velocity of wheat seeds was  $7.84 \text{ m s}^{-1}$ . The terminal velocity of millet grain varied from 2.75 to  $4.63 \text{ m s}^{-1}$  for an increase in moisture content from 5 to 22.5% d.b. (Baryeh, 2002). Matouk *et al.* (2008) reported that the terminal velocity of sunflower, soybean and canola seeds increased from 5.34 to 5.91, from 10.16 to 10.38 and from 5.10 to  $5.32 \text{ m s}^{-1}$  with the increase of seed moisture contents from 7.35 to 23.7, from 9.52 to 24.64% and from 7.11 to 25.72% w.b., respectively. Similar results were reported for coffee cherries and beans (Afonso *et al.*, 2007) and African yam bean (Irtwange and Igbeka, 2003). The increase in terminal velocity with an increase in moisture content may be attributed to the increase in mass of an individual seed per unit frontal area presented to the air stream. The other reason is probably that the drag force is affected by the moisture content of particle. The implication of the variation of the terminal velocity with moisture content (increase in terminal velocity of material with moisture content) is the need to define the range of air velocities for effective separation of the grain from foreign materials and in the material handling process at various moisture contents.

Figure 1 shows the variation of the terminal velocity with moisture content for seeds of the green and red lentil varieties. The terminal velocity data for lentil seeds in Fig. 1 were fitted to mathematical models. These models

were evaluated for verifying adequacy of fit using the  $R^2$  and RMS values. When comparing the average values of  $R^2$  and RMS it was obvious that the polynomial model had the highest  $R^2$  value and RMS below 0.05. Then it was stated that the fitting of the polynomial model to the experimental data was very good. Accordingly, the polynomial model was selected as a suitable model to predict the terminal velocity of lentil seeds as a function of moisture content. Razavi *et al.* (2007) developed a linear equation between the terminal velocity of pistachio nut and kernel as a function of moisture content. Zewdu (2007) reported that the terminal velocity of Tef grain was linearly related to moisture content. However, Afonso *et al.* (2007) reported a non-linear equation for the terminal velocity of coffee cherry and bean as a function of the combination of moisture content and true density. Nalbandi *et al.* (2010) reported a polynomial relationship for the terminal velocity of wheat kernels as a function of moisture content. Shahbazi *et al.* (2014) developed polynomial and linear equations between the terminal velocity of Makhobeli, triticale and wheat seeds as functions of moisture content. The following equations were found for the relationship between the terminal velocity ( $V_t$ ,  $\text{m s}^{-1}$ ) and moisture content ( $M$ , %) for each lentil seed variety:

Green

$$V_t = -0.0003M^2 + 0.1706M + 5.1498 \quad R^2 = 0.981, \quad (6)$$

Red

$$V_t = -0.0024M^2 + 0.1723M + 4.8683 \quad R^2 = 0.995. \quad (7)$$

All the indexes are significant at the level of 99.99%.

The values of the drag coefficient and the projected area of lentil seeds were calculated using Eqs (2) and (3) by measuring the terminal velocity, true density and the two principal dimensions (length and width) of seeds (Table 1). The analysis of variance showed that there was a significant difference between the drag coefficients of lentil seeds at different moisture content and of different varieties (Table 2). The results showed that the drag coefficient of lentil seed decreased as moisture content increased. This was due to the fact that the parameters associated with Eq. (2) (terminal velocity, true density and the two principal dimensions (length and width)) increased along with each other as moisture content increased. Therefore, the drag coefficient of seed decreased as moisture content increased. In common separation systems, the particles are separated when one particle moves in a different direction than other particles, due to the difference between their drag forces. Therefore the implication of the variation of the drag coefficient with moisture content is the need to design separation systems that will be effective at different moisture contents. These results are in agreement with some published literature. Afonso *et al.* (2007) reported that the drag coefficient of coffee cherries (*cv.* Catual) decreased from 0.05 to 0.03 as moisture content increased from 10.7 to 53.9% w.b. Gupta (2007), Irtwange and Igbeka (2003) reported similar results



for sunflower seed and African yam bean (*cv.* TSS 138), respectively. However, some odd results have been reported for some products. Irtwange and Igbeka (2003) reported that the drag coefficient of African yam bean (*cv.* TSS 137) increased as moisture content increased from 4 to 16% w.b. Afonso *et al.* (2007) showed that the drag coefficient of coffee beans (*cv.* Catual), coffee cherries and beans (*cv.* Conilon) increased as moisture content increased.

The drag coefficient was higher for the red variety than for the green variety. This may be due to the differences in surface properties, true densities, shapes and sizes of the materials. The drag coefficient values of lentil seeds of the green variety were found to be 0.69, 0.65, 0.58, 0.51, 0.44 and 0.40 (with a mean value of 0.55 and standard deviation of 0.11) for the moisture contents of 10, 12.5, 15, 17.5, 20 and 25%, respectively. In the red variety, the drag coefficients of seeds were found to be 0.84, 0.80, 0.77, 0.74, 0.73 and 0.69 (with a mean value of 0.76 and standard deviation of 0.05) over the same moisture contents (Fig. 2). Hauhouot *et al.* (2000) reported that the drag coefficient of wheat seeds is 0.74. Matouk *et al.* (2008) reported that the drag coefficient of sunflower, soybean, and canola seeds, decreased from 0.75 to 0.62, from 0.68 to 0.68 and from 0.63 to 0.57, with the increase of seed moisture contents from 7.35 to 23.70, from 9.52 to 24.64 and from 7.11 to 25.72%, respectively.

Figure 2 shows the variation of the drag coefficient with moisture content for the two varieties of lentil seeds. The values of this interaction varied from 0.40 to 0.84, and that occurred in the green variety at the highest moisture content and in the red variety at the lowest moisture content, respectively. The models fitted to the data using the regression techniques, based on  $R^2$  and RMS values, showed that the drag coefficient decreased as a polynomial relationship with increases in the moisture content for the two varieties of lentil seeds. Therefore, the following equations were found for the relationship between drag coefficient ( $C_d$ ) and moisture content ( $M$ , %), for each variety of lentil seeds:

Green

$$C_d = 0.0006 M^2 - 0.0432 M + 0.1.076 \quad R^2=0.983, \quad (8)$$

Red

$$C_d = 0.0004 M^2 - 0.0246 M + 1.0437 \quad R^2=0.993. \quad (9)$$

All the indexes are significant at the level of 99.99%.

The values of the Reynolds number and the geometric mean diameter of lentil seeds were calculated using Eqs (4) and (5) by measuring the terminal velocity and the three principal dimensions (length, width and thickness) of seeds (Table 1). The analysis of variance showed that there was a significant difference between the Reynolds number of lentil seeds of the green and red varieties. In addition, the effect of seed moisture content on this property was significant (Table 2). The results showed that the Reynolds number of lentil seeds increased with moisture content.

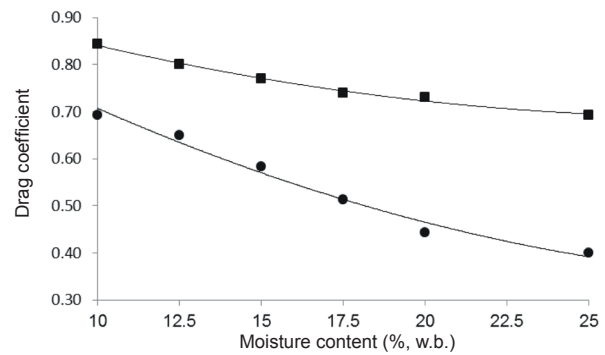


Fig. 2. Drag coefficient variation versus seed moisture content: Explanations as in Fig. 1.

This was due to the fact that the parameters associated with Eq. (4) (terminal velocity and the three principal dimensions (length, width and thickness)) increased as moisture content increased. Therefore, the Reynolds number of seeds decreased as moisture content increased. Similar results were reported by Matouk *et al.* (2005) for rice, corn, wheat and barley. The Reynolds number values of lentil seeds of the green variety were found to be 2310.90, 2404.14, 1555.41, 2755.40, 3028.10 and 3253.49 (with a mean value of 2717.49 and standard deviation of 345) for the moisture contents of 10, 12.5, 15, 17.5, 20 and 25%, respectively. In the red variety, the Reynolds numbers of seeds were found to be 1215.02, 1274.30, 1313.39, 1369.23, 1436.00 and 1535.09 (with a mean value of 1357.17 and standard deviation of 109) over the same moisture contents (Fig. 3). Matouk *et al.* (2008) reported that the Reynolds number of sunflower and soybean seeds were in the ranges of 2226 to 2571 and 4379 to 4652, with the increase of seeds moisture contents from 7.35 to 23.7% and from 9.52 to 24.64%, respectively.

Figure 3 shows the variation of the Reynolds number with moisture content for the two varieties of lentil seeds. The models fitted to the data using the regression technique, based on  $R^2$  and RMS values, showed that the Reynolds number increased linearly with increases in the moisture

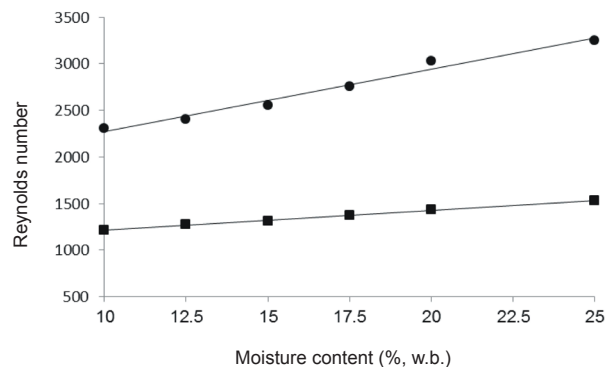


Fig. 3. Reynolds number variation versus seed moisture content. Explanations as in Fig. 1.

content. Similar results were also reported by Matouk *et al.* (2005) for rice, corn, wheat and barley. Therefore, the following equations were found for the relationship between the Reynolds number ( $R_n$ ) and moisture content ( $M$ , %), for each variety of lentil seeds:

Green

$$R_n = 67.337M + 1595.6 \quad R^2=0.980, \quad (10)$$

Red

$$R_n = 21.404M + 1000.4 \quad R^2=0.997. \quad (11)$$

All the indexes are significant at the level of 99.99%.

### CONCLUSIONS

1. The analysis of variance showed that there was a significant difference between the terminal velocity, drag coefficient and Reynolds number of lentil seeds of both the green and the red varieties and at different moisture contents.

2. The terminal velocity of lentil seed increased following a polynomial relationship with increase in moisture content and was higher for the green variety than for the red variety.

3. The drag coefficient of lentil seeds decreased as a polynomial relationship with increases in the moisture content and was higher for the red variety than for the green variety.

4. The Reynolds number of lentil seeds increased linearly with the increase of seeds moisture content and was higher for the green variety than for the red variety.

5. Mathematical relationships were developed to predict the terminal velocity, drag coefficient and Reynolds number of lentil seeds as a function of moisture content.

### REFERENCES

- Afonso Jr. P.C., Correa P.C., Pinto F.A.C., and Queiroz D.M., 2007.** Aerodynamic properties of coffee cherries and beans. *Biosystems Eng.*, 98, 39-46.
- Amin M.N., Hossain M.A., and Roy K.C., 2004.** Effects of moisture content on some physical properties of lentil seeds. *J. Food Eng.*, 65, 83-87.
- ASAE, 1998.** ASAE Standards. St. Joseph, MI, USA.
- Baryeh E.A., 2002.** Physical properties of millet. *J. Food Eng.*, 51, 39-46.
- Gupta R.K., Arora G., and Sharma R., 2007.** Aerodynamic properties of sunflower seed (*Helianthus annuus* L.). *J. Food Eng.*, 79, 899-904.
- Hauhouot O.M., Criner B.R., Brusewitz G.H., and Solie J.B., 2000.** Selected physical characteristics and aerodynamic properties of cheat seed for the separation from wheat. *Agric. Eng. Int.*, 2, 1-14.
- Irtwange S.V. and Igbeka J.C., 2003.** Effect of accession and moisture content on aerodynamic properties of African yam bean (*Sphenostylis Stenocarpa*). *Appl. Eng. Agric.*, 19(3), 321-328.
- Jha S.N. and Kachru R.P., 2007.** Physical and aerodynamic properties of makhana. *J. Food Proces. Eng.*, 21, 301-316.
- Kahrs J., 1994.** Aerodynamics properties of weeds seeds. *Int. Agrophysics*, 8, 259-262.
- Khoshtaghaza M.H. and Mehdizadeh R., 2006.** Aerodynamic properties of wheat kernel and straw materials. *Agric. Eng. Int.*, CIGR Ejournal, 8, 1-10.
- Matouk A.M., Abd El-latif S.M., and Tharwat A., 2008.** Aerodynamic and mechanical properties of some oil crops. *J. Agric. Sci. Mansoura Univ.*, 33(6), 4195-4211.
- Matouk A.M., El-Kholy M.M., Hamam A.S., and Ewis T.R., 2005.** Aerodynamic characteristics for different varieties of some cereal crops. *Misr J. Agric. Eng.*, 22(3), 1086-1102.
- Mohsenin N.N., 1978.** Physical Properties of Plant and Animal Materials. Gordon Breach Sci. Press, New York, USA.
- Nalbandi H., Seiedlou S., and Ghassemzadeh H.R., 2010.** Aerodynamic properties of *Turgenia latifolia* seeds and wheat kernels. *Int. Agrophys.*, 24, 57-61.
- Ozguven F., and Vursavus K., 2005.** Some physical, mechanical and aerodynamic properties of pine (*Pinus pinea*) nuts. *J. Food Eng.*, 68, 191-196.
- Razavi S.M.A., Rafe A., and Akbari R., 2007.** Terminal velocity of pistachio nut and its kernel as affected by moisture content and variety. *African J. Agric. Res.*, 2(12), 663-666.
- Shahbazi F., 2013.** Aerodynamic properties of wild mustard (*Sinapis arvensis* L.) seed for separation from canola. *J. Sci. Food Agric.*, 93, 1466-1470.
- Shahbazi F., Valizadeh S., and Dolatshaie A., 2014.** Aerodynamic properties of Makhobeli, triticale and wheat seeds. *Int. Agrophys.*, 28, 389-394.
- Zewdu A.D., 2007.** Aerodynamic properties of tef grain and straw material. *Biosystems Eng.*, 98, 304-309.