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Effect of moisture content on terminal velocity of lentil grain

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Abstract: One of the aerodynamic characteristics of lentil is its terminal velocity. In order to determinate the terminal velocity, was designed a vertical wind tunnel. It was fabricated based on existing methods and standards. For decreasing the non-uniformity of airflow in the vertical wind column, was used a honey comb test area with 5 mesh screens. So, a wind tunnel nozzle was designed and fabricated using Morel method with the aim of increasing airflow rate and decreasing losses due to mesh screens. The height and section area of tunnel were 1.425 m and 0.1 × 0.1 m^2, respectively. The pressure loss values were calculated at different parts of tunnel and then, the required power of tunnel was determined. In this study, lentil grains of Kimia and Gachsaran varieties were separated at three groups based on their size (small, medium and large). Then, the terminal velocity was measured at 5 levels of moisture content (8, 12, 16, 20 and 24% (w.b.)) for each group. The results showed that Kimia and Gachsaran variety had the highest (7.204 $m \cdot s^{-1}$) and the lowest (6.987 $m \cdot s^{-1}$) terminal velocity, respectively. The mean value of terminal velocity increased linearly from 6.751 to 7.396 $m \cdot s^{-1}$ by increasing the moisture content from 8 to 24% (w.b.). Also, by increasing the grains dimension from small to large, the terminal velocity increased from 6.345 to 7.792 $m \cdot s^{-1}$.

Keywords: aerodynamic characteristics; dimension; grain; wind tunnel

In handling and processing of agricultural products airflow and water flow are frequently applied for the separation of the favorable product from that of unfavorable materials (Mohsenin 1978). When airflow is applied for separating a product such as lentil from its associated foreign materials, knowledge about aerodynamic properties of all the materials involved helps to define the range of air velocity for successful separation of the product from foreign materials (Rajabipour et al. 2006; Nalbandi et al. 2010). In this end, the terminal velocity is one of the most important aerodynamic characteristics of agricultural materials for separation and handling (Mohsenin 1978). Therefore, it is a very effective parameter for agricultural machine such as harvest machines, and pneumatic transfer systems design (Tabatabaeefar 2003; Gupta et al. 2007). A lot of researches have been done for determination of terminal velocity of agricultural products. Based on these researches, there are two different techniques for measuring terminal velocity. The first method is the free fall method, in which a particle falls from a height, and its free fall time and height at various elevations are recorded. Carman (1996) used this method for determination terminal velocity of lentil seeds. The slope of the linear portion of the distance versus time curve indicated the terminal velocity of the lentil grain. In second method, particles positioned on a screen in a vertical wind tunnel, by increasing airflow, the particle will gradually float in a height. The airflow velocity at the point of suspension is the particle terminal velocity. This method requires less equipment compared to the free fall technique. Also, the second method gives

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a better representation of the conditions that exist in the separators and pneumatic transfer systems. In a study, Gupta and Das (1997) used a wind tunnel for measuring the terminal velocity of sunflower seed and core. The results showed that the terminal velocity increases linearly whit increasing the moisture content. The frictional properties and terminal velocity of two garlic varieties have been determined at different moisture contents. The results showed that the friction coefficient, the angle of repose and terminal velocity of these two types of garlic were depend on the moisture content (Masoumi et al. 2003). The terminal velocity of pistachios nuts and kernels were determined as a function of moisture content and the variety. The test section was a circle of 75 mm diameter. The air velocity in the vicinity of sample's suspension place was measured by an electronic anemometer (AM4205; Lutron Company, Taiwan). The experiments were done for 5 varieties of commercial Iranian pistachio with 5 levels of moisture content (4 to 37.6% (w.b.)) in 5 replications. It was concluded that by increasing the moisture content, the terminal velocity of pistachios nuts and kernels increased linearly (Seyed et al. 2007). A wind tunnel with circular profile and a distributor were used to determine the terminal velocity and aerodynamics properties of cotton seed. It was concluded that by increasing the seed mass from 0.08 to 0.15 g the terminal velocity of cotton seeds increased linearly from 5.8 to 10 m·s^{-1} (Tabak, Wolf 1998). According to the resented studies (Bhattacharya et al. 2005; Gupta et al. 2007; Kabas et al. 2007; Gursoy, Guzel 2010; Gharibzahedi et al. 2011), no research has been done related to terminal velocity determination of two-lentil variety named "Gachsaran" and "Kimia". Thus, the aim of this study was to determine the terminal velocity of two common Iranian lentil varieties using a vertical wind tunnel. Also, this research investigated the effect of seed's moisture content and dimension on terminal velocity.

MATERIAL AND METHODS

Terminal velocity measurement. The lentil varieties that selected were Kimia and Gachsaran. These are usually two common Iranian varieties. After preparing samples, those were sent to the bio-physics laboratory at the bio-systems department of Mohaghegh-Ardabili University, Ardabil, Iran. All samples were manually cleaned to remove foreign matter, dust, dirt and broken and immature grains. From each variety, 1,000 grains were selected randomly. In order to determine the main dimensions of the grains including large diameter, small diameter and thickness a digital caliper with accuracy of 0.01 mm were used. Due to major difference the large diameter of grains, this parameter was used as an indicator for grouping of grains. So, as shown in Table 1, samples were divided into three groups; small, medium and large. To determine the initial moisture content of the grains, three samples of 16 g were selected and placed inside an oven at 130°C for 24 h (Tang, Sokhansanj 1991). The initial moisture content of the grains was found to be 8% (w.b.). The experiments were done at 5 moisture content levels of 8, 12, 16, 20 and 24% (w.b.). The samples at the desired moisture levels were prepared by adding the calculated amounts of distilled water from Eq. 1 (Mohsenin 1978):

Table 1. The dimensional groups of lentil

Variety	Range of grain size (mm)		
	small	medium	large
Kimia	4–4.5	4.7–5.1	5.3–5.7
Gachsaran	5.1–5.7	5.9–6.5	6.7–7.3

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

where: Q – mass of the added water (kg); W – initial mass of the sample (kg); M_f – final moisture content of the sample (%, w.b.); M_i – initial moisture content of the sample (%, w.b.)

After adding the distilled water to the samples, the samples were poured into separate polyethylene bags, sealed tightly and kept at 4°C in refrigerator for 48 h to enable the moisture content to distribute uniformly throughout the samples. Before starting the tests, the required quantities of the samples were taken out of the refrigerator and were allowed to warm up to room temperature for approximately 2 h (Khoshtaghaza, Mehdizadeh 2006). To measure the terminal velocity of lentil grains, a vertical wind tunnel was designed and built based on recommendations by Tabak and Wolf (1998) and Pope et al. (1999). The wind tunnel had a the square test section, with the dimension of 100 mm by 100 mm and the height of 700 mm. It was fabricated using transparent poly-

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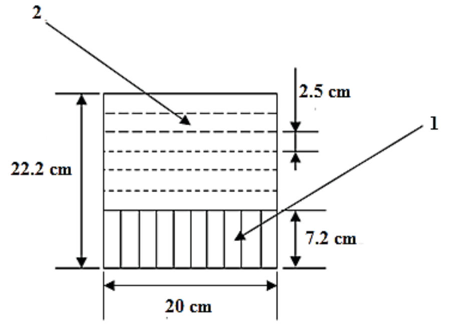

Fig. 1. Side view of diffuser region

1 – honeycomb network; 2 – mesh screens

ethylene material so that the suspended grains could be seen from the outside. A mesh layer was used in the upstream end of the test section to avoid the grains falling and put them in airflow path. In order to increase air velocity and also help to increase uniformity of the flow, a wind-tunnel nozzle was designed and built based on the method of Morel (Morel 1975). The shape of nozzle profile was shown in Fig. 1 which was plotted using the position of turning point, length and the diameter of nozzle's input. To measure the terminal velocity of the grains, a uniform velocity flow was required in the test section of the tunnel, where grains were suspended. For this purpose a honeycomb network (cells with diameter of 6 mm and length of 72 mm), 2 layers with mesh No. 36 and 3 layers with mesh No. 42 were used as a linear network as shown in Fig. 2. A uniform airflow distributer was applied between the fan and the linear network with dimensions of 300 × 300 × 300 mm^3 that it was built using wood in order to avoid the noises. The air was entered from a circle orifice with diameter 50 mm and exited from a squared orifice (with the dimensions of 200 × 200 mm^2). The selection of fan was final step of make of the vertical wind tunnel. Thus, a fan was used with the lowest static pressure of 1,100 Pa and the airflow of 0.2 $m^3 \cdot s^{-1}$.

To measure terminal velocity, each grain was placed in the center of the test section of the wind

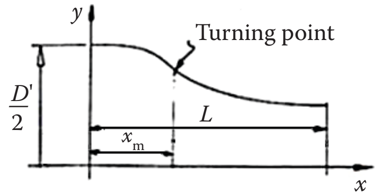

Fig. 2. Nozzle profile obtained based on its equations

D – diameter of nozzle's input; x_m – turning point distance from the nozzle's input; *L* – length of nozzle

tunnel on the screen. Then air flow increased gradually, until grain was suspended. At this moment, air velocity was measured as terminal velocity using a hot wire anemometer (405i; Testo, Germany).

For each grain, the experiments were done in 5 replications. For each replication, air velocity was measured at 4 different places of test section and their mean value was recorded as the final terminal velocity. The experimental data were analyzed by factorial randomized complete design and the mean values of mechanical parameters were compared by applying Duncan's multiple range tests in MSTAT-C statistical software (Version 1.1.0). In this research 30 treatments were considered: moisture content at 5 levels: 8, 12, 16, 20 and 24% (w.b.), grain dimension at 3 levels: small, medium and large and lentil variety at 2 levels: Kimia and Gachsaran. The experiments were conducted using factorial randomized complete design with 5 replications.

RESULTS AND DISCUSSION

The results of variance analysis of the lentil grains terminal velocity are presented in Table 2. The results showed that the main effects of variety, dimension and moisture content on terminal velocity were significant ($P < 0.01$). Interaction of variety in grain dimension, and also interactive of variety in moisture content on terminal velocity were significant ($P < 0.01$). Also, the triple interactive effect of variety, grain dimension and moisture content on terminal velocity was significant ($P < 0.05$). But, interactive of dimension and moisture content on terminal velocity was not significant.

Table 3 shows results of the mean comparison of the main effects of variety, grain dimension and moisture content on terminal velocity. Maximum mean value of terminal velocity (7.204 $m \cdot s^{-1}$) belonged to Kimia variety, while minimum mean value of terminal velocity (6.987 $m \cdot s^{-1}$) belonged to Gachsaran variety. Since mass of Gachsaran variety had a scatter distribution compared to Kimia variety, the mean value of terminal velocity of Gachsaran variety was lower than that of Kimia variety. Also, Gachsaran variety had a low sphericity coefficient as compared to Kimia variety, so it was caused Gachsaran variety grains to circulate more than Kimia variety. Based on the results of Tabak and Wolf (1998), particle circulation leads to de-

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Table 2. Result of Statistical analysis of terminal velocity for two lentil varieties

Sources of variation	*df*	Mean square error	*F*-value
Variety	1	1.767	47.544**
Dimension	2	26.280	707.123**
Moisture content	4	0.268	51.086**
Variety × dimension	2	1.899	7.205**
Variety × moisture content	4	0.009	2.253**
Dimension × moisture content	8	0.046	1.288[ns]
Variety × dimension × moisture content	8	0.094	2.531*
Total error	120	0.037	47.544

df – degree of freedom, **significant at $P < 0.01$, ns – not significant, *significant at probability level of 5%

Table 3. Results of mean comparison of the main effects variety, dimension and moisture content on the terminal velocity of lentil grains

	Terminal velocity (m·s^{-1})
Variety	
Gachsaran	6.987[b]
Kimia	7.204[a]
Dimension	
Small	6.345[c]
Medium	7.149[b]
Large	7.792[a]
Moisture content (% w.b.)	
8	6.751[e]
12	6.959[d]
16	7.125[c]
20	7.250[b]
24	7.396[a]

Different letters indicate the significant difference of effects at the probability level 5%

crease its terminal velocity. Mehdizadeh (2000) stated that the terminal velocity of lentil grains were lower than that of wheat grains due to mass distribution of lentil grains in the larger and wider area. The mean value of terminal velocity increased from 6.345 to 7.792 m·s^{-1} by increasing the grain dimension from small range to large range.

The mean values of lentil grains terminal velocity increased significantly from 6.751 to 7.396 m·s^{-1} by increasing the moisture content from 8 to 24% w.b. The reason for increasing grains terminal velocity by moisture content was due to the water uptake by grains and increasing their mass. The results this research was in agreement with the results reported by other researchers for some other agricultural material (Carman 1996; Gupta, Das 1997; Tabak, Wolf 1998; Guner 2006; Islik 2007).

Fig. 3 shows the effect of wheat moisture content on terminal velocity of two-wheat variety. By increasing the moisture content from 8 to 24% (w.b.), the terminal velocity of Kimia and Gachsaran varieties were increased linearly from 6.864 to 7.522 m·s^{-1} and 6.639 to 7.271 m·s^{-1}, respectively. Regression modelling for two varieties of wheat had shown correlation between the terminal velocity and moisture content as follows: Kimia variety (Eq. 2), Gachsaran variety (Eq. 3):

$$V_t = 6.7092 + 0.165\text{MC}\left(R^2 = 0.99\right) \quad (2)$$

where: V_t – terminal velocity (m·s^{-1}); MC – moisture content (%, w.b.)

$$V_t = 6.5315 + 0.1519\text{MC}\left(R^2 = 0.97\right) \quad (3)$$

There was a linear relationship between the moisture content and terminal velocity as shown by other researchers (Guner 2006; Islik 2007). Islik (2007) reported that by increasing moisture content from 11.36 to 25.08 % (w.b.) the terminal velocity of lentils increased from 5.9 to 7.1 m·s^{-1}. Guner (2006) also reported that in the range of moisture content from 6.7 to 19% (w.b.) the terminal velocity of lentil grains changed from 6.99 to 7.72 m·s^{-1}. The slopes of changes of terminal velocity for wheat varieties are nearly the same. Comparing Gachsaran variety with Kimia variety, for all the range of moisture content, the terminal velocity of Gachsaran variety was lower than that of Kimia variety.

Fig. 4 compares the mean of double interactive effects of grain dimension and lentil variety on terminal velocity.

By increasing the grains dimension from small range to large range for each two varieties of lentil, their terminal velocity linearly increased as shown by Rabbani 2002 for chick pea. So that in

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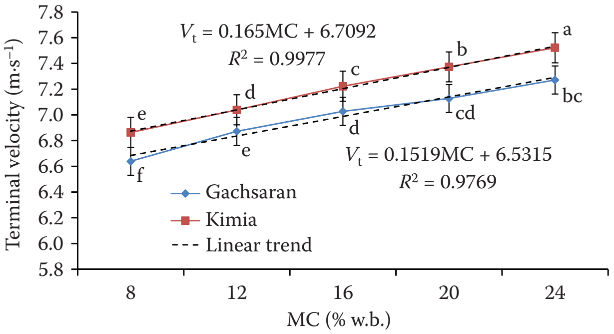

Fig. 3. Effect of moisture content (MC) on terminal velocity (V_t) of two lentil varieties: Gachsaran and Kimia

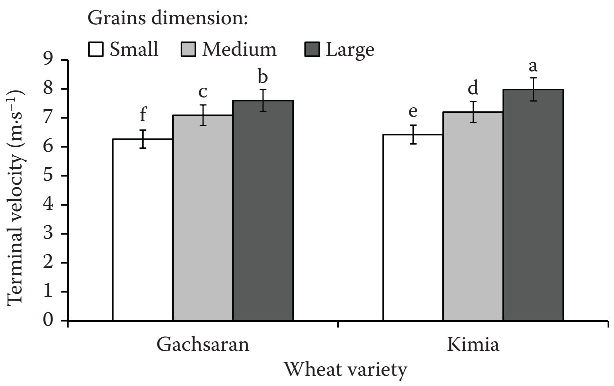

Fig. 4. Effect of grains dimension on terminal velocity of two lentil varieties

Gachsaran and Kimia varieties by increasing grains dimension from small to large, terminal velocity increased from 6.267 to 7.6 m·s^{-1} and from 6.424 to 7.984 m·s^{-1}, respectively.

CONCLUSION

By increasing the moisture content of lentil grains from 8 to 24% (w.b.) the terminal velocity increased linearly from 6.751 to 7.396 m·s^{-1}.

By increasing dimension lentil grains from small range to large range the terminal velocity increased linearly from 6.345 to 7.792 m·s^{-1}.

Terminal velocity of Gachsaran variety with mean value of 6.987 m·s^{-1} was lower than that of Kimia variety with mean value of 7.204 m·s^{-1}.

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