J. Agr. Sci. Tech. (2011) Vol. 13: 665-676

Resistance of Bulk Chickpea Seeds to Airflow

F. Shahbazi[1]

ABSTRACT

Knowledge of resistance to airflow through agricultural products is an important consideration in the design of drying, cooling, or aeration systems and proper fan selection for these systems. Resistance to airflow of bulk chickpea seeds was studied at moisture contents in the range of 9.21 to 21.36 % (wet basis) for airflow rate range from 0.02 to 0.50 m^3 s^{-1} m^{-2}, using an experimental test column. The effects of airflow rate, bed depth (0.25 to 1 m) fill method (loose and dense) and moisture content on airflow resistance of chickpea samples were investigated. Results indicated that the airflow resistance of chickpea seeds increased with increase in airflow rate, bed depth, and decreased moisture content. One percent increase in moisture content decreased the pressure drop about 2.94%. The dense fill method resulted in an increase in resistance to airflow by about 33.17% more than that of the loose fill. Three models (Shedd's, Hukill and Ives's, and Ergun's models) were fitted to the experimental data at each moisture level and were examined with two parameters. Shedd's model that gave a higher value for the coefficient of determination and a lower value for the mean relative percentage error of pressure drop predication was found to be the best model to describe airflow resistance of chickpea seeds.

Keywords: Airflow rate, Airflow resistance, Chickpea seeds, Fill method, Moisture content.

[DOR: 20.1001.1.16807073.2011.13.5.11.2]

INTRODUCTION

Chickpea (*Cicer arietnum* L.), an important source of protein and starch, is mainly grown in the hot climates of India, Pakistan, Iran, Ethiopia, Mexico, and the Mediterranean area (Chavan *et al*., 1986). Iran's major chickpea production areas are in the Kermanshah, Lorestan, Hamadan, Kordestan and Khorasan provinces. The average yield is 400-600 kg ha^{-1} (Tabatabaeefar *et al*., 2003).

The moisture content of the harvested seed crops, including chickpea seeds, is considerably higher than the moisture required for processing or for safe storage. This moisture can usually be reduced by forcing air with the proper temperature and relative humidity through the product by using fans. The air helps maintain the moisture, temperature, and oxygen content of the product at levels that prevent growth of harmful bacteria and fungi and excessive shrinkage. When air is forced through a bulk crop, it must travel through narrow paths between individual particles. Friction along air paths creates resistance to airflow. Fans must develop enough pressure to overcome this resistance and move air through the crop. Therefore, knowledge of the resistance to airflow through agricultural products is important in the design of drying, cooling, or aeration systems and fan selection for these systems. The resistance to airflow of grains and seeds is represented by pressure drops across unit depths of a column of the products. The pressure drop depends on a number of the product and environment factors such as airflow rate, bed depth, fill method, presence of foreign materials, moisture content and surface and shape characteristics of the products (Dairo and Ajibola, 1994; Agullo and Marenya, 2005).

---

[1] Department of Agricultural Machinery, Faculty of Agriculture, University of Lorestan, Khoram Abad, Islamic Republic of Iran. e-mail: shahbazi.f@lu.ac.ir

The study of airflow resistance through agricultural products was started by Stirniman *et al.* in 1931 and continued by others (Kashaninejad and Tabil, 2009) and has been reported for cereal grains and oil seeds (Patterson *et al*., 1971; Matthies and Petersen, 1974; Akritidis and Siatrs, 1979; Haque *et al*., 1982; Grama *et al*., 1984; Kumar and Muir, 1986; Sokhansanj *et al*., 1990; Li and Sokhansanj, 1994; Giner and Denisienia, 1996; Nalladurai *et al*., 2002; Nimkar and Chattopadhyay, 2002: Sacilik, 2004; Agullo and Marenya, 2005), nuts (Steele, 1974; Rumsey, 1981; Rajabipour *et al*., 2001; Kashaninejad and Tabil, 2009), fruits, roots, and vegetables (Staley and Watson, 1961; Neale and Messer, 1976; Abrams and Fish, 1982; Chau *et al*., 1985; Irvine *et al*., 1993; Tabil *et al*., 1999; Maw *et al*., 2002; Verboven *et al*., 2004; Shahbazi and Rajabipour, 2008), leaves (Suggs *et al*., 1985) and bladed hay (Morissette and Savoie, 2005). Some physical attributes such as size, shape, true and bulk densities and porosity as well as angle of repose and airflow resistance of various materials including chickpea var. "desi" were reported by Tabil *et al. (*1999). Up to now, no data on the resistance to airflow through chickpea seeds have been compiled in the ASABE standard D272.3 (ASABE, 2007), which gives the resistance to airflow of 33 crops.

The objectives of this study were: (1) to determine the airflow resistance of bulk chickpea seeds, (2) to study the effects of the airflow rate, moisture content, bed depth and filling method on the airflow resistance of chickpea seeds, and (3) to fit the obtained data to the selected models (Shedd's, Hukill and Ives's and Ergun's models) and determine the best model that can predict the airflow resistance of bulk chickpea seeds.

MATERIALS AND METHODS

Sample Preparation

Samples of chickpea seed (*cv. Filip93-93*) used in this study were obtained from the farms in the Lorestan Iran, during the summer season of 2006. The seeds were cleaned in an air screen cleaner to remove all foreign materials such as dust, dirt, stones, chaff, immature and broken seeds. The moisture content of the samples was determined by placing three samples, each weighing about 10 g, in a convective oven at 103±1°C for 72 hours (Tabil *et al*., 1999). The initial moisture content of the seeds was determined to be 9.21% (wet basis). The chickpea seed samples with higher moisture contents were prepared by adding calculated amounts of distilled water to wet the seeds that were later sealed in separate polyethylene bags and stored in a cold store at 5ºC for 15 days. Before starting each test, the required amounts of seeds were allowed to warm up to room temperature.

Determination of Physical Properties

Several physical properties of chickpea seeds, namely, dimensions, geometric mean diameter, sphericity, bulk density, particle density, and porosity were determined. In order to determine the dimensions, one hundred chickpea seeds were randomly selected. For each chickpea seed, the three principal dimensions, namely, length (L), width (W) and thickness (T) were measured using an electronic digital caliper (GUANGLU, China) having a resolution of 0.01 mm. The geometric mean diameter (D_e) and the degree of sphericity (S_p) of the chickpea seeds were calculated by the following equations (Mohsenin, 1986):

$$D_e = (LWT)^{1/3} \quad (1)$$

$$S_p = \frac{(LWT)^{1/3}}{L} \quad (2)$$

The weights of the chickpea seeds were recorded using a digital electronic balance having an accuracy of 0.001 g. Bulk density of the chickpea seeds was calculated from the mass and volume of the 0.5 liter circular container that was filled with chickpea seeds. After filling the circular container,

[DOR: 20.1001.1.16807073.2011.13.5.11.2]

excess seeds were removed by passing a wooden stick across the top surface using five zigzag motions. The particle density of a seed is defined as the ratio of the mass of seed to the solid volume occupied. The seed volume and its particle density was determined using liquid displacement technique. Toluene was used instead of water. The porosity (ε) of the bulk of seeds was computed from the values of bulk density (ρ_b) and particle density (ρ_t) using the following relationship (Mohsenin, 1986):

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \qquad (3)$$

Airflow Test Apparatus

Resistance to airflow through the tested chickpea seeds was determined in the form of the relationship between airflow rate and pressure drop per unit depth. A schematic diagram of the apparatus used for airflow resistance measurement is shown in the Figure 1. It consists of a variable speed fan, an airflow measurement system, a plenum chamber, a screen plate, a test column, and an inclined u-tube manometer. The test column was a cylinder with 30 cm in diameter and 120 cm height, made of 2 mm thickness iron plate. A stainless steel screen plate located under the test column containing round holes of 4 mm diameter that provided an expanded mesh floor of 40% open space. Five pressure taps were located at 25 cm intervals along the test column to measure pressure difference at different depths. The taps were made of 5 mm diameter tube and extended into the test column 5 cm from the inside wall to avoid wall effect on pressure measurements. The first tap above the screen plate was chosen as the reference and the pressure differences between that and all the other four taps, located at 25, 50, 75 and 100 cm above it, were measured and recorded. Pressure differences between the taps were measured using an inclined u-tube manometer (Dwyer Instruments Inc, Michigan City, IN), with an accuracy of 0.25 Pa. Air was supplied by a centrifugal fan driven by a three phase electric motor (3 kW, 1,900 rpm, Motogen, Iran). The motor speed was controlled by an electric inverter (4 kW, LG, Korea). An orifice plate and a manometer fitted in the connecting pipe between the fan and the plenum chamber were used to determine the airflow rates in the test column. The airflow rate was changed by regulating the inverter, which changed the fan speed. Also, a slide gate in the upstream side of the blower was

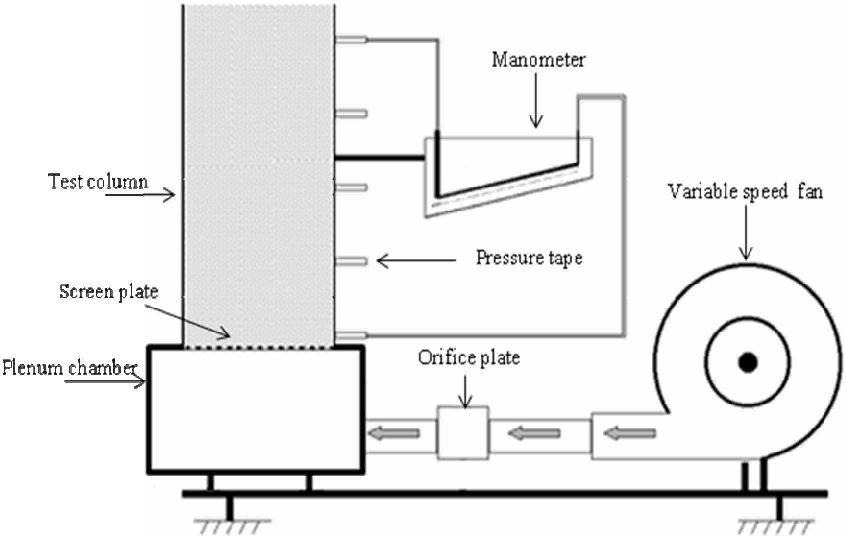

Figure. 1. Schematic diagram of the apparatus used for measurement of the airflow resistance of chickpea seeds.

[DOR: 20.1001.1.16807073.2011.13.5.11.2]

used for precision adjustment of the airflow rate.

Experimental Procedure

The resistance to airflow of bulk chickpea seeds, expressed as pressure drop per unit depth of column, was measured at 17 airflow rates, four moisture levels, two fill methods, and four bed depths. After pressure drop measurements were made, a small sample of chickpea seeds was used for moisture content determination. The test column was emptied and then refilled and the measurements were repeated to obtain three replications. The average values of the temperature and relative humidity of the laboratory where the tests were carried out were 24±2°C and 31±10 %, respectively.

To study the effect of airflow rate on the airflow resistance of the chickpea seeds, the test column was filled with the seeds up to 100 cm height and pressure drops were measured for 17 airflow rates of: 0.02, 0.04, 0.06, 0.08, 0.10, 0.12, 0.14, 0.16, 0.18, 0.20, 0.24, 0.28, 0.30, 0.34, 0.40, 0.45 and 0.50 $m^3 s^{-1} m^{-2}$. To determine the effect of moisture content on the pressure drop per unit depth of chickpea seeds, four moisture levels of 9.21, 12.36, 17.33, and 21.36 % (wet basis) were used. Pressure drops of each sample were measured at the same 17 airflow rates of 0.02 to 0.50 $m^3 s^{-1} m^{-2}$, at constant bed depth of 100 cm. In order to determine the effect of the fill methods on the resistance to airflow, two fill methods, namely, loose and dense, were used. For the loose fill, seeds were poured into a funnel, the outlet of which was held just above the seeds surface, by gradually raising the funnel as the filling progressed. Filling was done until the depth of the seeds in the test column was 100 cm. No compaction was done on the seeds in the column. Dense fill was obtained by a method described by Dairo and Ajibola (1994), Nimkar and Chattopadhyay (2002), and Sacilik (2004). Firstly, the test column was loosely filled up to 120 cm by adequate quantity of the test samples, then, the test column was tapped with a rubber hammer about 60 times. By tapping the test column, the height of the seeds was reduced, thus increasing the packing (bulk density). After tapping the column, additional seeds were removed from the top surface of the seeds in the column, to complete a filling height of 100 cm. To determine the effect of the bed depth of chickpea seeds on the resistance to airflow, four different bed depths of 25, 50, 75, and, 100 cm, were used.

Airflow Resistance Data Analysis

Airflow resistance data of cereal grains and oil seeds have been analyzed by using several empirical and theoretical models for relating pressure drop to airflow rate (Jayas *et al*., 1987a).The models given by Shedd (1953), Hukill and Ives (1955) and Ergun (1952) have been used by several authors. Shedd's model is represented by the following relationship:

$$\frac{\Delta P}{L} = A_1 (V)^{B_1} \qquad (4)$$

Where, ΔP is the pressure drop (Pa); L is the depth of seeds in the test column (m); V is airflow rate per unit area (m3 $s^{-1} m^{-2}$); A_1 and B_1 are the product-dependent constants for the test conditions. Hukill and Ives proposed the following empirical model, which is used in standard D272.3 of the American Society of Agricultural and Biological Engineers (ASABE) to represent the airflow pressure drop data of the selected crops:

$$\frac{\Delta P}{L} = \frac{A_2 V^2}{Ln(1 + B_2 V)} \qquad (5)$$

Where, A_2 and B_2 are the product-dependent constants for the test conditions. Ergun proposed a second-order polynomial model, which was modified by Bakker-Arkema *et al.* (1969) and Hunter (1983). The Ergun's model is written as the following relationship:

$$\frac{\Delta P}{L} = A_3 V + B_3 V^2 \qquad (6)$$

Where, A_3 and B_3 are the product-dependent constants for the test conditions.

The three models (Shedd's, Hukill and Ives's, and Ergun's), were fitted to the experimental pressure drop data for chickpea seeds using non-linear regression analysis. The nonlinear regression program of SAS (SAS, 2001), was used to fit the data to the models and determine the constants A_1, A_2, A_3 and B_1, B_2, B_3 of Equations (4), (5) and (6). The coefficients of determination (R^2) and the mean relative percentage error of the pressure drop predication (e) were used to evaluate the fitting of a model to the experimental data. The best model describing the airflow resistance of the chickpea seeds was chosen as the one with the highest R^2 value and the lowest *e*-value. The *e*-value was defined as:

$$e = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{|P_i - M_i|}{M_i}\right)\times 100 \qquad (7)$$

Where: P_i is the predicted pressure drop (Pa m^{-1}), M_i is the measured pressure drop (Pa m^{-1}), and n is the number of the data points.

RESULTS AND DISCUSSIONS

Physical Properties of Chickpea Seeds

Table 1 shows the dimensions, geometric mean diameter, sphericity, bulk density, particle density, and porosity of the studied chickpea seeds at different moisture contents in the range of 9.21-21.36% (wet basis). Length, width, thickness, geometric mean diameter, sphericity, and porosity of chickpea seeds increased with increase in the moisture content, but, particle density and bulk density decreased with increase in the moisture content. As indicated in Table 1, bulk density of the chickpea seeds decreased from 835.55 to 773.75 kg m^{-3} as the moisture content increased from 9.21 to 21.36%. The moisture content of agricultural products has been found to influence the size of the product particles (Mohsenin, 1986). For the same product, particles with higher moisture content are bigger in size compared to those that are relatively dry and, hence, an increase in the moisture content of a product results in decreased bulk density.

Effect of Bed Depth on Pressure Drop across Chickpea Seed Beds

Figure 2 shows the effect of bed depth on pressure drop of chickpea seed beds at a moisture content of 9.21% at various airflow rates. At a given airflow rate, pressure drop across loose filling of chickpea seed beds tended to increase linearly with an increase in bed depth. The same results were obtained with different moisture contents and dense filling. It can be seen from Figure 2 that doubling the bed depth for the same airflow

Table 1.Physical properties of chickpea seeds measured at different moisture contents.

Moisture content %	Dimensions (mm)			GMD[a] (mm)	Sphericity (%)	Bulk density (kg m^{-3})	Particle density (kg m^{-3})	Bed porosity (%)
	Length	Width	Thickness					
9.21	8.27	6.82	6.35	7.10	85.85	835.55	1459.73	42.75
-	(0.06)[b]	(0.04)	(0.10)	(0.12)	(3.40)	(2.76)	(7.41)	(0.25)
12.36	8.86	7.46	7.12	7.87	88.60	822.42	1454.09	43.44
-	(0.21)	(0.14)	(1.10)	(0.19)	(3.39)	(2.25)	(7.41)	(1.21)
17.33	9.03	7.34	7.20	7.81	86.54	798.08	1450.37	44.97
-	(0.06)	(0.12)	(0.13)	(0.32)	(4.42)	(2.67)	(5.61)	(0.45)
21.36	9.18	7.73	7.23	7.96	86.80	773.75	1449.93	46.63
-	(0.11)	(0.07)	(0.25)	(0.40)	(3.23)	(3.09)	(6.67)	(1.05)

[a] Geometric mean diameter.

[b] The standard deviations are given in parentheses.

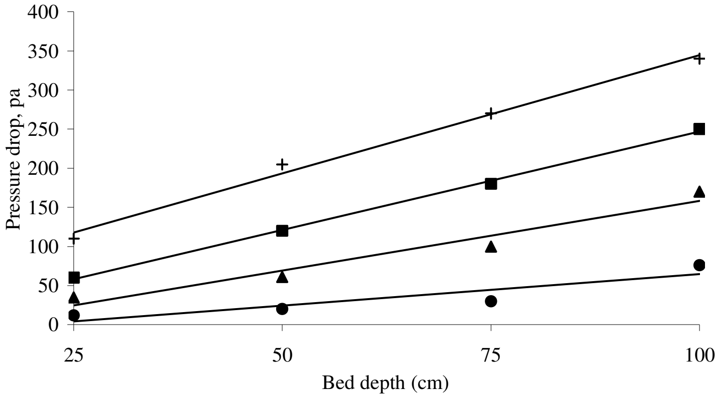

Figure 2. Effect of bed depth on pressure drop of chickpea seed beds at a moisture content of 9.21% (wb), loose fill and different airflow rates: 0.13 (●), 0.22 (▲), 0.33 (■), and 0.4 (+) m^3 s^{-1} m^{-2}.

rate has a lower effect on pressure drop than doubling the airflow rate for the same bed depth. Doubling the bed depth from 0.25 to 0.50 m at airflow rates of 0.13, 0.22, 0.33 and 0.40 m^3 s^{-1} m^{-2} increased the pressure drop by about 1.17, 1.74, 2.00 and 1.86 times, respectively. However, when airflow rate increased from 0.22 to 0.40 m^3 s^{-1} m^{-2}, the pressure drop increased by 3.14, 3.36, 4.38 and 3.62 times for bed depths of 0.25, 0.50, 0.75 and 1 m, respectively. Therefore, it can be stated that, generally, the pressure drop increased more rapidly with increasing airflow rate than with increasing bed depth. Similar observations have been reported by Jayas *et al.* (1987a) for canola, Gunasekaran and Jackson (1988) for sorghum, Dairo and Ajibola (1994) for sesame seeds, Nimkar and Chattopadhyay (2002) for green gram, Sacilik (2004) for poppy seeds, and Kashaninejad and Tabil (2009) for pistachio nuts.

Effects of Airflow Rate and Moisture Content on Pressure Drop of Bulk Chickpea Seeds

Figure 3 presents the experimental results for the variation of pressure drop per unit depth across chickpea seeds beds at various levels of moisture content and airflow rates for loose filling of the test column. It can be observed that, at each moisture level, the pressure drop per unit depth increased with

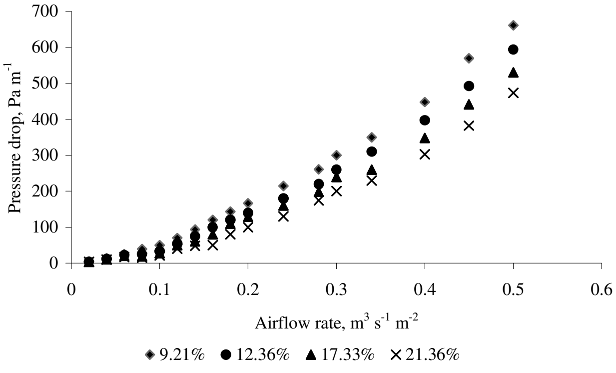

Figure 3. Effects of moisture content on pressure drop of loosely filled bulk chickpea seeds.

[DOR: 20.1001.1.16807073.2011.13.5.11.2]

increasing airflow rate in the range of 0.02 to 0.50 m^3 s^{-1} m^{-2}. The same result was also obtained with dense filling of the test column. Similar results about increase in pressure drop with increase in airflow rate have been observed and reported by Farmer *et al. (*1981), Haque *et al. (*1982), Madamba *et al. (*1993), Dairo and Ajibola (1994), and Agullo, and Marenya (2005), for blue stem grass, maize, garlic slices, sesame seeds, and parchment Arabica coffee, respectively. The increase in pressure drop with increased airflow can be attributed to the increased kinetic dissipation of the air as velocity increases.

From Figure 3, it can also be observed that, at each airflow rate, the pressure drop per unit depth decreased with increase in chickpea seeds moisture content in the range of 9.21 to 21.36%. On the average, the chickpea seeds caused pressure drops of 207.73, 178.86, 158.34 and 134.12 Pa m^{-1} at, respectively, 9.21, 12.36, 17.33 and 21.36% moisture contents at all airflow rates used. An increase in the chickpea seeds moisture content by 12.15% caused a decrease in pressure drop by about 35.43% at all airflow rates. In other words, 1% increase in the moisture content caused about 2.94% decrease in pressure drop of the bulk chickpea seeds for the airflow rates in the range of 0.02-0.50 m^3 s^{-1} m^{-2}. This reduction in pressure drop was because of a decrease in bulk density (835.55 to 773.75 kg m^{-3}) and an increase in bed porosity (42.76 to 46.63%) with the increase in moisture content (9.21 to 21.36%). The results were in conformity with the results of various workers, who have reported that the pressure drop decreased with the increase in moisture content due to a decrease in bulk density and an increase in porosity of the studied materials (Patterson *et al*., 1971; Akritidis and Siatras, 1979; Farmer *et al*., 1981; Jayas *et al*., 1987a; Siebenmorgen and Jindal, 1987; Patil and Ward, 1988; Hummeida and Ahmed, 1989; Sokhansanj *et al*., 1990; Giner and Denisienia, 1996; Al-yahya and Moghazi,1998; Nalladurai *et al*., 2002; Nimkar and Chattopadhyay, 2002; Agullo and Marenya, 2005). But, the results deviated from the findings of Madamba *et al. (*1993), Rapusas *et al. (*1995) and Kashaninejad and Tabil (2009), for garlic slices, sliced onions and pistachio nuts, respectively. These workers have reported that, with the rise in moisture content, the pressure drop increased due to the increase in bulk density and the decrease in the porosity of these materials.

To determine the interaction effects of airflow rate and moisture content of the chickpea seeds on resistance to airflow, a relationship between pressure drop and moisture content was obtained by selecting points at airflow rates of 0.1, 0.2, 0.3 and 0.4 m^3 s^{-1} m^{-2}. The result is shown in Figure 4.

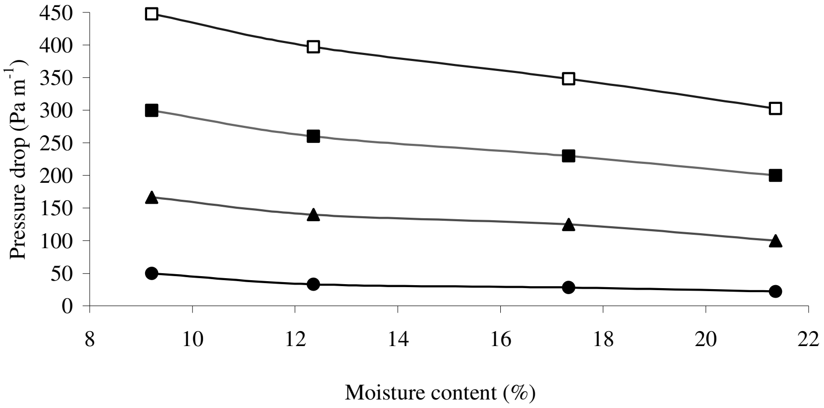

Figure 4. Pressure drop vs. moisture content for chickpea seeds in loose fill test column at airflow rates of: 0.1 (●), 0.2 (▲), 0.3 (■) and 0.4 (□) m^3 s^{-1} m^{-2}.

Third degree polynomial curves were fitted to the selected points. From Figure 4, it can be observed that, at each airflow rate, the pressure drop decreased with increase in chickpea seeds moisture content. At low airflow rates i.e. 0.1 and 0.2 m^3 s^{-1} m^{-2}, a change of the moisture content of chickpea seeds did not significantly influence the pressure drop. Nevertheless, at higher airflow rates i.e. 0.3 and 0.4 m^3 s^{-1} m^{-2}, the moisture content significantly affected pressure drop. At an airflow rate of 0.1 m^3 s^{-1} m^{-2}, pressure drops of 49.88 and 22.11 Pa m^{-1} were observed at the moisture contents of 9.21 and 21.36%, respectively, (the difference between pressure drops was 27.11 Pa m^{-1}), while at the same moisture contents, the corresponding values of pressure drops were 447.93 and 302.80 Pa m^{-1} at the airflow rate of 0.4 m^3 s^{-1} m^{-2} (the difference between pressure drops was 145.13 Pa m^{-1}). From this, it can be concluded that the airflow resistance of the chickpea seeds decreases with an increase in moisture content, but at airflow rates below 0.2 m^3 s^{-1} m^{-2}, the change of airflow resistance tends to be smaller.

Effect of Fill Method on Pressure Drop of Bulk Chickpea Seeds

Figure 5 shows the effect of the method of filling on pressure drop per unit depth across chickpea seed beds at a moisture content of 9.21%. As shown in Figure 5, at a given airflow rate, dense filling resulted in an increase in the pressure drop through chickpea seed beds. The same results were also obtained for different moisture contents. At a moisture content of 9.21% for the loose fill, pressure drops of 49.88 and 166.78 Pa m^{-1} were observed at the airflow rates of 0.1 and 0.2 m^3 s^{-1} m^{-2}, respectively, while at the same moisture content and airflow rates, the corresponding values of pressure drops were 76.47 and 245.63 Pa m^{-1} for the dense fill. At all airflow rates, in comparison with the loose fill, the dense fill caused about 33.17% increase in pressure drop. The observed higher pressure drops for dense filling is attributed to increased bulk densities due to packing of seeds, which lead to increased kinetic energy dissipation. Kumar and Muir (1986) reported that the method of filling the bin had a marked effect on airflow resistance primarily because of the effect of the filling method on bulk density. Similar results about increases in pressure drop because of dense filling have been noted by Jayas *et al.* (1987a) for canola, Dairo and Ajibola (1994), for sesame seeds and Nimkar and Chattopadhyay (2002) for green gram, Sacilik (2004) for poppy seeds, Agullo and Marenya (2005) for parchment Arabica coffee and Kashaninejad and Tabil (2009) for pistachio nuts.

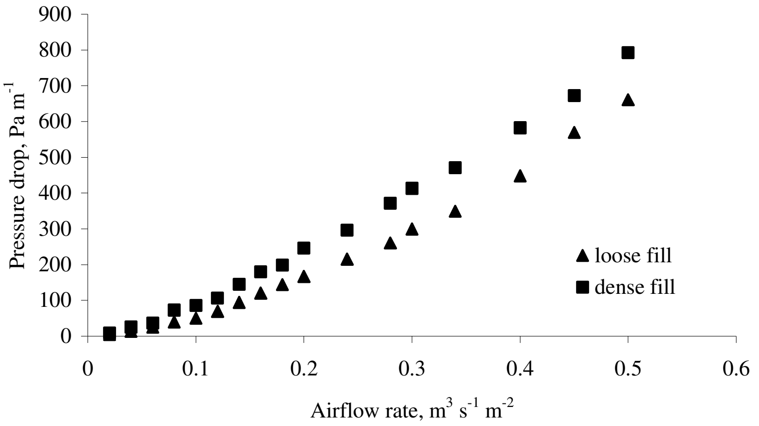

Figure 5. Effects of fill method on pressure drop of bulk chickpea seeds at a moisture content of 9.21%.

Fitting of Pressure Drop Data to Airflow Resistance Models

The Shedd's, Hukill and Ives's, and Ergun's models that are commonly used in predicting the pressure drop across beds of agricultural granular materials were fitted to the experimental pressure drop data for the bulk of chickpea seeds. Tables 2 show the estimated parameter (A_1, A_2, A_3 and B_1, B_2, B_3) and the comparison criteria used to evaluate goodness of fit, namely, the coefficients of determination (R^2), and the mean relative percentage error of pressure drop predication values with respect to the measured values (e), of Equations (4), (5) and (6) for the full airflow range of 0.02 to 0.50 $m^3 s^{-1} m^{-2}$, at various moisture contents for the loose fill method, respectively. The loose fill method was used because this method has been used extensively (ASABE, 2007) in many studies for determining the constants of Equation (5) for a number of agricultural grains, seeds and other agricultural products. This choice is probably based on the assumption that the loose fill method results in product densities that are close to those that would be realized under field conditions. In Tables 2, the pressure drop per unit depth was also calculated using the three models, at the airflow rate of 0.1 $m^3 s^{-1} m^{-2}$, which, in practice, is used for drying and aeration systems of grains, seeds and other agricultural granular materials,. At this airflow rate and for moisture content of 9.21%, Shedd's, Hukill and Ives's, and Ergun's models predicted pressures drop values of, respectively, 54.91, 63.15, and 59.41 Pa m^{-1}, compared with the average actual experimental value of 49.88 Pa m^{-1}. Thus, it can be stated that Shedd's model predicted pressure drop value was closer to the experimental value than the other models.

The values of R^2 and e obtained from Shedd's model were in the range of, respectively, 0.990 -0.999 and 2.96 - 14.43%, for different experimental conditions. These values for Hukill and Ives's model ranged from 0.984 to 0.993, and 15.99 to 29.57%, while the corresponding values for Ergun's model ranged between 0.996 and 0.998, and 10.08 and 16.81%, respectively. The average values of e (mean of the values at four moisture levels) obtained for Shedd's, Hukill and Ives's and Ergun's models at complete airflow ranges were 9.43, 23.33 and 14.61.%, respectively. It can be stated in general that the R^2 values were greater than 0.98 for all the models, indicating that the three models were

Table 2. Estimated parameters and comparison criteria of Shedd's (equation 4), Hukill and Ives's (equation 5) and Ergun's models (equation 6) at various moisture contents for loose fill method.

Moisture content (%)	Shedd's model (Equation 4)			e (%)	$\Delta P/L$ (Pa m^{-1}) @V=0.1 $m^3 s^{-1} m^{-2}$
	A_1	B_1	R^2		
9.21	1896.32	1.537	0.999	2.96	54.91
12.36	1648.12	1.564	0.993	8.51	44.97
17.33	1440.14	1.558	0.997	11.85	40.58
21.36	1173.65	1.543	0.990	14.43	33.59
	Hukill and Ives's model (Equation 5)				
	A_2	B_2	R^2		
9.21	5336.80	13.28	0.993	15.99	63.15
12.36	4166.21	12.48	0.989	20.63	51.69
17.33	3966.21	11.51	0.984	29.57	51.43
21.36	2814.49	10.02	0.988	27.15	40.54
	Ergun's model (Equation 6)				
	A_3	B_3	R^2		
9.21	1648.50	429.25	0.998	16.81	59.41
12.36	1632.21	304.21	0.998	15.23	46.74
17.33	1459.11	267.22	0.996	16.30	41.31
21.36	1490.02	164.00	0.998	10.08	31.30

acceptable for predicting pressure drop across chickpea seed beds. However, the Shedd's model gave a higher R^2 value and a, lower *e*-value and predicted the pressures drop (at 0.1 m^3 s^{-1} m^{-2}) closer to the experimental value than the other models. Therefore, Shedd's model was considered the best model for predicting pressure drop through chickpea seed beds in all the cases. As shown in Table 2, the value for the constant A_1 of the Shedd's model had a specific trend as its value decreased with the increase in moisture content, substantiating the negative effect of moisture content on pressure drop. Thus, it could be ascertained that, for the design of drying or aeration system for chickpea, the pressure drop case of only the dry material (about 9.21%) needs to be considered, as it would result in a safe design.

CONCLUSION

From the results of this study, the following conclusions can be drawn:

The resistance to airflow through a bulk of chickpea seeds increased with increase in airflow rate and bed depth, but the resistance increased more rapidly with airflow rate compared to the bed depth, since doubling the depth of the seeds nearly doubled the resistance, while doubling the airflow rate offered more than twice as much resistance.

An increase in moisture content of chickpea seeds from 9.21 to 21.36% resulted in a decrease of about 35.43% in the resistance to airflow of loose fill chickpea seeds for the airflow rates in the range of 0.02 to 0.50 m^3 s^{-1} m^{-2}.

The dense fill resulted in an increase in the resistance of bulk chickpea seed to airflow by 33.17% more than that of the loose fill.

Shedd's, Hukill and Ives's, and Ergun's models were well fitted to the experimental data for the airflow rates in the range of 0.02 to 0.50 m^3 s^{-1} m^{-2}. All the three models were accurate enough for predicting pressure drop through chickpea seed beds within the experimental range of study. However, Shedd's model gave a higher value for the coefficient of determination and lower value for the mean relative percentage error of pressure drop predication; thus, it was considered the best model for predicting pressure drop across chickpea seed beds.

AKNOWLEDGEMENTS

The financial support provided by the University of Lorestan of Islamic Republic of IRAN under research award number: 719/1/354 is gratefully acknowledged.

REFERENCES

1. Abrams, C. F. and Fish, Jr. J. D. 1982. Airflow Resistance Characteristics of Bulk Piled Sweet Potatoes. *Trans. ASAE*, **25(4)**: 1103–1106.
2. Agullo, J. O. and Marenya, M. O. 2005. Airflow Resistance of Parchment Arabica coffee. *Biosys. Eng*., **91 (2)**: 149–156.
3. Akritidis, C. B. and Siatras, A. J. 1979. Resistance of Pumpkin Seeds to Airflow. *Trans. ASAE*, **22(6)**: 1414–1416.
4. Al-yahya, S. A. and Moghazi, H. M. M. 1998. Static Pressure Drop through Barley Grain. *Can. Agric. Eng.,* **40 (2)**: 213–217.
5. ASABE Standards. 2007. ASAE D272.3 MAR1996 (R2007): "Resistance to Airflow of Grains, Seeds, other Agricultural Products, and Perforated Metal Sheets. American Society of Agricultural and Biological Engineers, St. Joseph, MI, **54,** pp., 627-633.
6. Bakker-Arkema, F. W., Patterson, R. J. and Bickert, W. G. 1969. Static Pressure-airflow Relationships in Packed Beds of Granular Biological Materials such as Cherry. *Trans. ASAE*, **12(1)**: 134-136.
7. Chau, K. V., Gaffney, J. J., Baird, C. D. and Church, A. G. 1985. Resistance to Airflow of Oranges in Bulk and in Cartons. *Trans. ASAE*, **28(6)**: 2083–2088.
8. Chavan, J. K., Kadam, S. S. and Salunkhe, D. K. 1986. Biochemistry and Technology of Chickpea (*Cicer arietinum* L.) seeds. *Crit. Rev. Food. Sci. Nutr.*, **25**: 107–132.
9. Dairo, O. U. and Ajibola, O, O. 1994. Resistance to Airflow of Bulk Sesame Seed. . *J. Agric. Eng. Res.,* **58(2)**: 99–105.
10. Ergun, S. 1952. Fluid Flow through Packed Columns. *Chem. Eng. Prog.* **48**: 89–94.

[DOR: 20.1001.1.16807073.2011.13.5.11.2]

11. Farmer, G. S., Busewitz, G. S. and Whitney, R. W. 1981. Resistance to Airflow of Bluestem Grass. *Trans. ASAE*, **24(2)**: 480–483.
12. Giner, S. A. and Denisienia, E. 1996. Pressure Drop through Wheat as Affected by Air Velocity, Moisture Content and Fines. *J. Agric. Eng. Res.,* **63**: 73–86.
13. Grama, S. N., Bern, C. J. and Hurburgh, Jr. C. R. 1984. Airflow Resistance of Mixtures of Shelled Corn and Fines. *Trans. ASAE*, **27**: 268–272.
14. Gunasekaran, S. and Jackson, C. Y. 1988. Resistance to Airflow of Grain Sorghum. *Trans. ASAE,* **31(4)**: 1237–1240.
15. Haque, E. G., Ahmed, Y. N. and Deyoe, C. W. 1982. Static Pressure Drop in a Fixed Bed of Grain as Affected by Grain Moisture Content. *Trans. ASAE*, **25**:1095–1098.
16. Hukill, W. V. and Ives, N. C. 1955. Radial Airflow Resistance of Grain. *Agric. Eng.*, **36(5)**: 332–335.
17. Hummeida, M. A. and Ahmed, A. E. T. 1989. Resistance of Sorghum, Peanut and Sesame to Airflow. *Agric. Mech. Asia. Afr. Lat. Am.*, **20(2)**: 53-56.
18. Hunter, A. J. 1983. Pressure Difference across an Aerated Seed Bulk for Some Common Duct and Store Cross-sections. *J. Agric. Eng. Res.,* **28**: 437-450.
19. Irvine, D. A., Jayas, D. S. and Mazza, G. 1993. Resistance to Airflow through Clean and Soiled Potatoes. *Trans. ASAE*, **36(5)**: 1405–1410.
20. Jayas, D. S., Sokhansanj, S., Moysey, E. B. and Barber, E. M. 1987a. Airflow Resistance of Canola (Rapeseed). *Trans. ASAE*, **30(5)**:1484-1488.
21. Kashaninejad, M. and Tabil, L. G. 2009. Resistance of Bulk Pistachio Nuts (Ohadi Variety) to Airflow, *J. Food Eng.*, **90**: 104–109.
22. Kumar, A. and Muir, W. E. 1986. Airflow Resistance of Wheat and Barley Affected by Airflow Direction, Filling Method and Dockage. *Trans. ASAE*, **29(5)**: 1423–1426.
23. Li, W. and Sokhansanj, S. 1994. Generalized Equation for Airflow Resistance of Bulk Grains with Variable Density, Moisture Content and Fines. *Dry. Technol.,* **12(3)**: 649–668.
24. Madamba, P, S., Driscoll, R. H. and Buckle, K. A. 1993. Bulk Density, Porosity and Resistance to Airflow of Garlic Slices. *Dry. Technol.,* **11(7)**: 1837–1854.
25. Matthies, H. J. and Petersen, H. 1974. New Data for Calculating the Resistance to Airflow of Stored Granular Material. *Trans. ASAE*, **17(6)**:1144–1149.
26. Maw, B. W., Williams, E. J. and Mullinix, B. G. 2002. Resistance of Sweet Onions to Airflow. *Trans. ASAE*, **45(1)**: 39-45.
27. Mohsenin, N. N. 1986. *Physical Properties of Plants and Animal Materials*. Gordon and Breach Science Publishers, N.W., New York.
28. Morissette, R. and Savoie, P. S. 2005. Resistance to Airflow of Baled Hay as a Function of Air Velocity, Hay Density and Stack Height. ASAE Paper No. 051050. ASAE, St. Joseph, MI.
29. Nalladurai, K., Alagusundaram, K. and Gayathri, P. 2002. Airflow Resistance of Paddy and Its Byproducts. *Biosys. Eng*., **83(1)**: 67-75.
30. Neale, M. A. and Messer, H. J. M. 1976. Resistance of Root and Bulb Vegetables to Airflow. *J. Agric. Eng. Res.,* **2**: 221–231.
31. Nimkar, P. M. and Chattopadhyay, P. K. 2002. Airflow Resistance of Green Gram. *Biosys. Eng*., **82(4)**: 407- 414.
32. Patil, B. G. and Ward, G. T. 1988. Resistance to Airflow of Oilseed Rape. *J. Agric. Eng. Res.,* **41:** 25–31.
33. Patterson, R. J., Bakker-Arkema, F. W. and Bickert, W. G. 1971. Static Pressure–airflow Relationship in Packed Beds of Granular Biological Materials such as Grain II. *Trans. ASAE*, **14(1):** 172–174.
34. Rapusas, R. S., Driscoll, R. H. and Srzednicki, G. S. 1995. Bulk Density and Resistance to Airflow of Sliced Onions. *J. Food Eng*., **26:** 67–80.
35. Rajabipour, A., Shahbazi, F., Tabatabaeefar, A. and Mohtasebi, S. 2001. Airflow Resistance in Walnuts. . *J. Agric. Sci. Technol*., **3**: 257-264.
36. Rumsey, T. 1981. Pressure Drop Equations for Fixed Bed Walnut Dryer. ASAE Paper No-81.3556.
37. Sacilik, K. 2004. Resistance of Bulk Poppy Seeds to Airflow. *Biosys. Eng*., **89(4)**: 435–443.
38. SAS. 2001. SAS Users' Guide: Statistics, Statistical Analysis System. SAS Institute Inc., Cary, NC.
39. Shahbazi, F. and Rajabipour, A. 2008. Resistance of Potatoes to Airflow. *J. Agric. Sci. Technol.,* **10**: 1-9.
40. Shedd, C. K. 1953. Resistance of Grains and Seeds to Airflow. *Agric. Eng.*, **34(9):** 616–619.

[DOR: 20.1001.1.16807073.2011.13.5.11.2]

41. Siebenmorgen, T. J. and Jindal, V. K. 1987. Airflow Resistance of Rough Rice as Affected by Moisture Content, Fines Concentration and Bulk Density. *Trans. ASAE*, **30(4)**: 1138–1143.
42. Sokhansanj, S., Falacinski, A. A., Sosulski, F. W. and Jayas, D. S. and Tang, J. 1990. Resistance of Bulk Lentils to Airflow. *Trans. ASAE*, **33(4)**: 1281–1285.
43. Staley, L. M. and Watson, E. L. 1961. Some Design Aspects of Refrigerated Potato Storage. *Can. Agric. Eng.*, **3(1)**: 20–22.
44. Steele, J. L. 1974. Resistance of Peanuts to Air flow. *Trans. ASAE*, **17(3):** 573-577.
45. Stirniman, E. J., Bodnar, G. P. and Bates, E. N. 1931. Tests on Resistance to the Passage of Air through Rough Rice in a Deep Bin. *Agric. Eng.*, **12**:145–148.
46. Suggs, C.W., Zimmer, A. L. and Gore, J. W. 1985. Pressure *vs.* Air Flow through Fresh Tobacco Leaves. *Trans. ASAE*, **25(5)**: 1664-1667.
47. Tabatabaeefar, A., Aghagoolzadeh, H. and Mobli, H. 2003. Design and Development of an Auxiliary Chickpea Second Sieving and Grading Machine. Manuscript FP 03 005. *Agr. Eng. Inter.: The CIGR. Ejournal*, Vol. V.
48. Tabil, L. G., Hong, Qi., Chawla, K. K., Kienholz, j., Crossman, V. and White, R. 1999. *Physical Properties of Selected Special Crops Grown in Alberta*. ASAE Paper No. 996049.
49. Tabil, L. G., White, R., Kienholz, J., Hong, Q. and Marshall, V. 1999. *Airflow Resistance of Sugar Beets*. ASAE Paper No.99-6059.
50. Verboven, P., Hoang1, M. L., Baelmans, M. and Nicola, B. M. 2004. Airflow through Beds of Apples and Chicory Roots. *Biosys. Eng.*, **88(1)**:117–125.

مقاومت توده دانه نخود به عبور جریان هوا

ف. شهبازی

چکیده

پایه و اساس طراحی خشک کن‌ها و دیگر سیستم‌های هوادهی محصولات کشاورزی و انتخاب دمنده مناسب برای آن‌ها، مقاومت به عبور جریان هوا از میان توده محصول است. در این مطالعه مقاومت به عبور جریان هوای توده نخود در چهار سطح رطوبت از ۹/۲۱ تا ۲۱/۳۶٪ در دامنه سرعت‌های جریان هوا از ۰/۰۲ تا ۰/۵۰ متر در ثانیه اندازه‌گیری شد و اثرات سرعت جریان هوا، عمق توده محصول (۰/۲۵ تا ۱ متر)، نحوه پر کردن مخزن از محصول (به صورت معمول و به صورت فشرده) و رطوبت نخود بر میزان مقاومت به عبور جریان هوا بررسی شد. نتایج آزمایش‌ها نشان داد که مقاومت به عبور جریان هوای توده نخود با افزایش سرعت جریان هوا، عمق توده و کاهش رطوبت محصول، افزایش یافته است. با افزایش رطوبت توده نخود به اندازه ۱٪، مقاومت به عبور جریان هوای توده به اندازه ۲/۸۴٪ کاهش یافته است. پر کردن مخزن به صورت فشرده باعث افزایش مقاومت به عبور جریان هوا به اندازه ۳۳/۱۷٪ در مقایسه با پر کردن به صورت معمولی شده است. معادلات مربوط به شید، هوکیل و ایویس و آرگون با داده‌های مقاومت برازش داده شدند که نتایج نشان داد که معادله شید می‌تواند با دقت بیشتری نسبت به دیگر معادلات برای تخمین مقاومت به عبور جریان هوای توده نخود مورد استقاده قرارگیرد.